Saeid Eslamian
Faezeh Eslamian *Editors*

Disaster Risk Reduction for Resilience

Disaster Socio-Hydrological Resilience and Sustainability

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Prof. Richard H. McCuen (University of Maryland), the best Flood Hydrologist that I have met in my 28 years of academic life. Identifying the start time of nonstationarity is important because the time that climate change is assumed to have become influential will influence the model used to represent the hydrologic change. If incorrectly selected, the model type can greatly affect projected changes in hydrologic data.

Preface

This book entitled *Disaster Socio-Hydrological Resilience and Sustainability* is part of a six-volume series on Disaster Risk Reduction and Resilience. The series aims to fill in gaps in theory and practice in the Sendai Framework, and provides additional resources, methodologies, and communication strategies to enhance the plan for action and targets proposed by the Sendai Framework. The series will appeal to a broad range of researchers, academics, students, policymakers, and practitioners in engineering, environmental science, geography, geoscience, emergency management, finance, community adaptation, atmospheric science, and information technology.

This volume discusses the implementation of socio-hydrological resilience measures to curb the impacts on vulnerable communities of hydrologic disasters such as coastal floods, drought, water scarcity, and thunderstorms. The book provides a framework for sustainable hydrology-community interactions to inform local communities about the best practices to achieve hydrological resilience, and to implement resilient water infrastructure. Hydrological influences on the resilience of a region are comprehensively surveyed, and a "green economy strategy" is described and recommended for achieving climatic and hydrological sustainability.

The series are open for new books under "Disaster Risk Reduction and Resilience" topic. The book proposals are welcome to submit to Book Series Editor (pr.eslamian@gmail.com).

Isfahan, Iran — Saeid Eslamian
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About the Editors

Saeid Eslamian is a full professor of environmental hydrology and water resources engineering in the Department of Water Science and Engineering at Isfahan University of Technology, where he has been since 1995. His research focuses mainly on statistical and environmental hydrology in a changing climate. In recent years, he has worked on modeling natural hazards, including floods, severe storms, wind, drought, pollution, water reuses, sustainable development and resiliency, etc. Formerly, he was a visiting professor at Princeton University, New Jersey, and the University of ETH Zurich, Switzerland. On the research side, he started a research partnership in 2014 with McGill University, Canada. He has contributed to more than 600 publications in journals, books, and technical reports. He is the founder and chief editor of both the *International Journal of Hydrology Science and Technology* (IJHST) and the *Journal of Flood Engineering* (JFE). Eslamian is now associate editor of three important publications: *Eco-Hydrology and Hydrobiology* (Elsevier), *Journal of Water Reuse* (IWA) and *Journal of the Saudi Society of Agricultural Sciences* (Elsevier). Professor Eslamian is the author of approximately 40 books and 400 book chapters.

Dr. Eslamian's professional experience includes membership on editorial boards, and he is a reviewer of approximately 150 Web of Science (ISI) journals, including the *ASCE Journal of Hydrologic Engineering*, *ASCE Journal of Water Resources Planning and Management*, *ASCE Journal of Irrigation and Drainage Engineering*, *Advances in Water Resources*, *Groundwater*, *Hydrological Processes*, *Hydrological Sciences Journal*, *Global Planetary Changes*, *Water Resources Management*, *Water Science and Technology*, *Eco-Hydrology*, *Journal of American Water Resources Association*, *American Water Works Association Journal*, etc. UNESCO has also nominated him for a special issue of the *Eco-Hydrology and Hydrobiology Journal* in 2015.

Professor Eslamian was selected as an outstanding reviewer for the *Journal of Hydrologic Engineering* in 2009 and received the EWRI/ASCE Visiting International Fellowship in Rhode Island (2010). He was also awarded outstanding prizes from the Iranian Hydraulics Association in 2005 and Iranian Petroleum and Oil Industry in 2011. Professor Eslamian has been chosen as a distinguished researcher of Isfahan University of Technology (IUT) and Isfahan Province in 2012 and 2014, respectively. In 2023, he has been awarded total career 2-percent top researcher title by Stanford University and Scopus (Elsevier).

He has also been the referee of many international organizations and universities. Some examples include the US Civilian Research and Development Foundation (USCRDF), the Swiss Network for International Studies, the Majesty Research Trust Fund of Sultan Qaboos University of Oman, the Royal Jordanian Geography Center College, and the Research Department of Swinburne University of Technology of Australia. He is also a member of the following associations: American Society of Civil Engineers (ASCE), International Association of Hydrologic Science (IAHS), World Conservation Union (IUCN), GC Network for Drylands Research and Development (NDRD), International Association for Urban Climate (IAUC), International Society for Agricultural Meteorology (ISAM), Association of Water and Environment Modeling (AWEM), International Hydrological Association (STAHS), and UK Drought National Center (UKDNC).

Professor Eslamian finished Hakimsanaei High School in Isfahan in 1979. After the Islamic Revolution, he was admitted to IUT for a BS in water engineering and graduated in 1986. After graduation, he was offered a scholarship for a master's degree program at Tarbiat Modares University, Tehran. He finished his studies in hydrology and water resources engineering in 1989. In 1991, he was awarded a scholarship for a PhD in civil engineering at the University of New South Wales, Australia. His supervisor was Professor David H. Pilgrim, who encouraged him to work on "Regional Flood Frequency Analysis Using a New Region of Influence Approach." He earned a PhD in 1995 and returned to his home country and IUT. In 2001, he was promoted to associate professor and in 2014 to full professor. For the past 28 years, he has been nominated for different positions at IUT, including university president consultant, faculty deputy of education, and head of department. Eslamian is now director for center of excellence in Risk Management and Natural Hazards (RiMaNaH).

Professor Eslamian has made three scientific visits to the United States, Switzerland, and Canada in 2006, 2008, and 2015, respectively. In the first, he was offered the position of visiting professor by Princeton University and worked jointly with Late Professor Eric F. Wood at the School of Engineering and Applied Sciences for one year. The outcome was a contribution in hydrological and agricultural drought interaction knowledge by developing multivariate L-moments between soil moisture and low flows for northeastern US streams.

Recently, Professor Eslamian has published 14 handbooks by Taylor & Francis (CRC Press): the three-volume *Handbook of Engineering Hydrology* (2014), *Urban Water Reuse Handbook* (2016), *Underground Aqueducts Handbook* (2017), the three-volume *Handbook of Drought and Water Scarcity* (2017), *Constructed Wetlands: Hydraulic Design* (2019), *Handbook of Irrigation System Selection for Semi-Arid Regions* (2020), *Urban and Industrial Water Conservation Methods* (2020), the three-volume *Flood Handbook* (2022), and the three-volume *Handbook of Irrigation Hydrology and Management* (2023).

An Evaluation of Groundwater Storage Potentials in a Semiarid Climate, *Advances in Hydrogeochemistry Research*, *Handbook of Eurasian Forecasting*, *Water Scarcity: Global Perspectives, Issues and Challenges* by Nova Science Publishers are also his book publications in 2019, 2020, and 2022, respectively. The two-volume *Handbook of Water Harvesting and Conservation* (Wiley) and *Handbook of Disaster Risk*

Reduction and Resilience (Vol. 1: *New Frameworks for Building Resilience to Disasters*) are early 2021 book publications of Professor Eslamian. *Handbook of Disaster Risk Reduction and Resilience* (Vol. 2: *Disaster Risk Management Strategies*, Vol. 3: *Disaster and Social Aspects*, Vol. 4: *Disaster Economic Vulnerability and Recovery Programs*) and two-volume *Earth Systems Protection and Sustainability* are early 2022 Professor Handbook. The three-volume *Handbook of Hydroinformatics* (Elsevier) and *Handbook of Disaster Risk Reduction and Resilience* (Vol. 5: *Climate Change and Disaster Risk Adaptation*) are early 2023 book publications of him.

Professor Eslamian has been appointed as World Top 2-Percent Researcher by Stanford University, USA, in 2019, 2020, 2022 and 2023. He has also been a Grant Assessor/Report Referee/Award Jury/Invited Researcher for international organizations such as United States Civilian Research and Development Foundation (2006), Intergovernmental Panel on Climate Change (2012), World Bank Policy and Human Resources Development Fund (2021), and Stockholm International Peace Research Institute (2022), respectively.

Faezeh Eslamian is a PhD Holder of Bioresource Engineering in McGill University. Her research focuses on the development of a novel lime-based product to mitigate phosphorus loss from agricultural fields. Faezeh completed her bachelor and master's degrees in Civil and Environmental Engineering from Isfahan University of Technology, Iran, where she evaluated natural and low-cost absorbents for the removal of pollutants such as textile dyes and heavy metals. Furthermore, she has conducted research on the worldwide water quality standards and wastewater reuse guidelines. Faezeh is an experienced multidisciplinary researcher with interest in soil and water quality, environmental remediation, water reuse, and drought management.

Part I
Socio-Hydrological and Socio-Economic Resilience

Chapter 1
Modeling Human Dimensions to Reduce the Disaster Risk: A Socio-Hydrological Approach

Mohammad Mahdi Dorafshan and Saeid Eslamian

Abstract Human activities affect the environment and the hydrological cycle. Changing the rainfall regime and increasing extreme phenomena (such as floods) is the response of nature to these changes. For this purpose, it is necessary to study the mutual effects of human and hydrological system carefully. Therefore, a framework should be developed to take into account the mutual influence of the social system and the hydrological system and provide an appropriate response to the existing conditions. In order to understand the interactions between humans and water, a new science of hydrology-social has been proposed, which conducts research in two aspects of the social system (human) and the hydrological system (water). Also, this concept is introduced to understand the complex approach in the management of hydrological resources with the aim of creating resilience.

Keywords Coupled human-water systems · Socio-hydrological · Resilience · Flood

1 Introduction

Nowadays, water is at the center of the most difficult sustainability challenges for humans (Abedi-Koupai et al., 2022a). Water scarcity, especially in arid and semi-arid regions, has led to crises and conflicts among consumers (Eslamian et al., 2019;

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Abedi-Koupai et al., 2020) even threats to the environment and water resource-dependent (Sivapalan & Blöschl, 2015; Abedi-Koupai et al., 2022b; Srinivasan et al., 2017). On the other hand, the development of human societies and consequently, changes in land use and the application of various management practices in the use of water resources have led to drastic changes in the hydrological regime throughout the history of each region. In other words, the increase in world population from two hundred million to seven billion people over 2000 years has intensified the involvement of human societies in the hydrological regime to meet water needs, so that water flow paths on earth have been changed by humans in many parts of the world compared to their pure nature (Postel, 2011). Thus, the hydrological regime, which was often controlled by factors such as climate, vegetation, geology, and topography of the catchment area in the past, is now increasingly influenced by social and economic stimuli such as population growth and urban development, agricultural development, industrialization, technology, and engineering (Carpenter et al., 2011; Vitousek et al., 1997). Certainly, it is not possible to predict the dynamics of the water cycle in the future on a long time scale, regardless of the "interactions" and "feedback" between human and hydrological systems. Despite knowing the connection between human activities and water in the "system of interactions" for many years (Falkenmark, 1977), natural scientists have long ignored the role of human factors in natural systems. To study the dynamics of the water cycle in traditional hydrology, hydrologists have considered water-human-centered management activities as an external stimulus to the system and evaluated their effects on the hydrological system based on the assumptions of durability and the establishment of stable conditions (Peel & Blöschl, 2011).

In order to understand the interactions between humans and water, a new science of hydrology-social has been proposed, which conducts research in two aspects of the social system (human) and the hydrological system (water). Socio-hydrological seeks to identify the way in which the coupled human-water system evolves. What distinguishes socio-hydrological from the integrated management of water resources is the explicit study of the concept of human and water co-evolution and its dynamics in very long time scales and the quantification of interactions and feedbacks between the two. In socio-hydrological, human as a dynamic element of the anthropocene era is included in the calculations of the water cycle, and the effects he makes and receives on the water cycle are considered in the calculations. Studies on the concept of socio-hydrological began in 2012 and after the famous article of Sivapalan et al. (2012) under the title "Sociohydrology: A new science of people and water".

Hydrological extreme phenomena cannot be evaluated without human considerations, and fortunately, this matter has received more attention in recent years. Socio-hydrological claims to be an explicit study of the relationship between humans and nature, and above all, the co-evolutionary relationship between human societies and natural disasters. In this regard, many studies have been conducted in the last few decades regarding human influence on extreme phenomena, but our understanding of the dynamics of human factors and the changes caused by their reactions, whether in the form of response or effect, is still limited (Di Baldassarre et al., 2017). Finally, the objectives of this chapter are: (i) Introduction to socio-hydrological systems (its objectives, applications, challenges, and resilience), (ii) Difference between hydrological-social systems and integrated water resources system, and (iii) Investigating the risk reduction of hazards using socio-hydrological.

2 Socio-Hydrological Systems (SHS)

Socio-hydrology, which was first introduced by Sivapalan et al. (2012), aims to understand the "dynamics and coevolution of human-water systems". This field of science has been formed in the framework of economics and politics (Lane, 2014) and emerged from the realization of the fact that human societies are the most important stimulus in changing life cycles such as water, food, and energy (Vitousek et al., 1997; Vörösmarty et al., 2010).

Concerning the traditional hydrology, human activities were generally assigned in the water system as boundary conditions or external forces (scenario-based approach). Such a traditional approach usually resulted in unrealistic long-term predictions, as it fails to consider dynamic interactions and two-way feedback between humans and water systems (Di Baldassarre et al., 2013a, b). This issue pushes the boundaries of hydrology toward the acceptance of humans as an integral part of the hydrological cycle and indicates a breakthrough in hydrological studies that necessitates the rethinking of traditional hydrology (Blair & Buytaert, 2016).

The field of socio-hydrology seeks to specify the dynamics of the harmonious evolution of human-water systems. Contrary to traditional hydrology, socio-hydrology considers humans and their practices as a part of the dynamics of the water cycle and generally, depends on integrated water resources management. In particular, while Integrated Water Resources Management (IWRM) focuses on controlling and managing water systems to achieve optimal outputs for society and the environment, socio-hydrology attempts to observe, understand, and predict the dynamics of human-water systems. Therefore, socio-hydrology can be considered a fundamental science for the IWRM (Viglione et al., 2014).

In this regard, International Association of Hydrological Sciences (IAHS) designated the title of the recent "Scientific Decade" (2013–2022) as the Panta Rhei (anything that flows), which highlighted the importance of socio-hydrology. The main goal of this decade is to improve the understanding and interpretation of water cycle control processes by focusing on changing their dynamics concerning rapid changes in human systems. The association believes that current hydrological models are mainly suitable for natural and pristine catchments and social interactions are generally considered in separate models, leading to insufficient understanding of interactions between the two fields of hydrology and society. Therefore, the studies of social hydrology will be a new step toward a deeper integration of these two issues. In other words, the series of research published in recent years in the field of "debate", such as Di Baldassarre et al. (2015), Sivapalan (2015), and Troy et al. (2015), indicates a real and continuous commitment and effort in the development

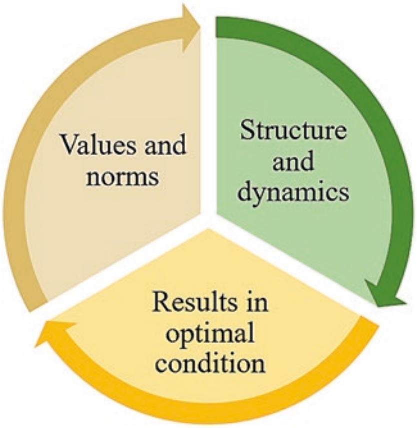

Fig. 1.1 General framework of socio-hydrological approach

of socio-hydrology as an independent subject. Generally, most research emphasizes the necessity of considering the interactions between human communities and water in the development of models, despite differences in the views of authors on how to address interactions, the scope of socio-hydrological performance, and the value of socio-hydrological models. These studies were conducted before 2012 on topics such as the study of socio-environmental systems, environmental hydrology, water economics, and IWRM, which also have common features with socio-hydrology.

Socio-hydrology encompasses a broad theoretical framework based on three fundamental aspects, which are shown in Fig. 1.1.

Considering this theoretical structure, it is possible to explain the feedback between humans and aquatic systems in the past and predict their paths of sustainable evolution for the future, which include emerging dynamics resulting from the two-way feedback of human-aquatic systems. Socio-hydrology has been built on previous research and the placement of decentralized effects of human factors and water-related institutions, as well as their feedback, to address the great and new challenges of water resource sustainability.

Socio-hydrological studies are pursued in three historical, comparative, and process directions. Historical studies aim to find historical patterns to support theories and models of human-water interconnected systems. These studies also look for locations with appropriate databases on a decade-to-century scale that can be used to discover phenomena and to produce and test hypotheses (Kandasamy et al., 2014; Liu et al., 2015). On the other hand, comparative studies compare the stimuli of continuous systems to understand the resiliency and sustainability of water consumption. Note that there are challenges in identifying data affecting hydro-climatic and socio-economic stimuli in this group of studies (Scott et al., 2014; Srinivasan et al., 2012). Finally, process studies, which are based on the results of historical and comparative studies, seek to explain a range of interdisciplinary theories and design models regarding positive and negative feedback between human societies and water (Chen et al., 2016; Srinivasan, 2015).

Kelly et al. (2013) believed that the three main areas of application of socio-hydrology studies include (a) system understanding, (b) forecasting, and (c) policy-making and decision-making, and all three types of socio-hydrology studies, including historical, comparative, and the process can be used in these three areas.

In a more specialized classification, some groups of socio-hydrological studies have modeled and others have developed conceptual frameworks. Generally, both groups pursue operational goals such as understanding behavioral processes, determining the source of resiliency, predicting areas of vulnerability, defining the dynamics of water supply and demand, specifying interactions between human activities and the quality of water resources, elaborating human-flood interactions, and analyzing political approaches and decision support (Chang et al., 2014; Fabre et al., 2015; Fraser et al., 2013; Medellín-Azuara et al., 2012).

2.1 Objectives of Socio-Hydrological Systems

The main objectives of socio-hydrology studies are as follows (Sivapalan et al., 2014):

1. Analysis of different patterns at different temporal and spatial scales to understand the basic features of human and biophysical systems and their interactions.
2. Explain and interpret the reactions of the socio-hydrological system, to predict its future reactions, as conventional management approaches often lead to unsustainable management operations due to the inability to predict.
3. Promotion of knowledge on water from cultural, economic, and political aspects along with recognizing its biophysical properties and its necessity for life.

2.2 Application of Socio-Hydrological Systems

According to the Anthropocene theory, the future path of ecosystems on Earth is equally divided into two categories of internal processes (Crutzen, 2016; Steffen et al., 2007; Waters et al., 2016): (1) processes that operate in the physical, chemical, and biological systems of Earth, and (2) processes that exist in human societies, cultures, and economies. The Earth's history of changes is derived from the increasing complexity and interaction of these two processes on a planetary scale (Gaffney & Steffen, 2017). As mentioned, socio-hydrology is a sub-branch of Anthropocene theory that focuses on the dynamic interactions and coevolution of human and aquatic systems. Considering the important role of water in all aspects of human life, including land use and agriculture, environmental, economic, and social policies and planning, water-related natural phenomena such as floods, droughts, and climate change, socio-hydrology science provides the basis for using it to gain a complete understanding of the future direction of human-aquatic systems.

2.3 Challenges of Socio-Hydrological Systems

Despite being a new science, socio-hydrology does not differ from other hydrological discussions for study and research and requires prior data. Given the complexity of the system under study, addressing human systems requires providing sufficient system-related data, which is a major challenge (Levy et al., 2016). Generally, collecting data on human systems, such as socio-economic assessments of agricultural production, job, and labor opportunities, and the use of water resources for high-yield purposes is often either too costly or not available at all. Then, variables should be identified to define and interpret the data. After determining the relationship between variables, it is necessary to develop a quantitative framework for interpreting the phenomenon and measuring variables, such as population, agricultural production, wetland capacity, and the like. The measurement scale should also be specified for each case (Pande & Ertsen, 2013).

Despite various opportunities and ways to present socio-hydrological theories, many social processes, including the evolution of human-legal values, norms, and institutions, which play a key role in determining feedback in the socio-hydrological context, require hypotheses that may be difficult to measure (Dietz et al., 2005). For example, the unit for measuring the sensitivity of society to water resources, with the assumption of finding a unit for it, may not be acceptable to sociologists. In other cases, it is very difficult to determine whether humans want to preserve the environment for future generations and measure to what level humans want to preserve the future.

In this regard, one of the proposed ways to develop socio-hydrological theory is to identify a pattern between related data to observe the cause-and-effect relationships and how they affect other aspects of the hypothesis (data → pattern → information flow → hypothesis generation → testing the hypothesis). This action can eliminate the socio-hydrological dependence on the limited phenomena that have been studied so far (Pande & Ertsen, 2013). Socio-hydrology considers human behavior as an intrinsic part of the system, which distinguishes this field from others. This feature represents a challenge that will greatly increase the complexity of the model and this complexity should be considered in the model in such a way that it is a proper expression of the dominant pattern of coordinated human-water systems and is efficient and valuable for management and policy-making in a world of interconnected systems.

2.4 Resilience of Socio-Hydrological Systems

Holling (1973) introduced the concept of resilience, which has gained enormous popularity over the past several decades. A system's resilience refers to its ability to maintain its structure and patterns of behavior when disturbed (Holling, 1986). Having the ability to adapt to ever-changing environments is a sign that humans, ecosystems, and communities are resilient (Folke, 2016). Simply, it means how well a system can recover after being affected by a disturbance (Walker & Salt, 2012). Several consider resilience an integral part of sustainability science (Anderies et al., 2013; Walker et al., 2004). It is not possible to define resilience in terms of a single measurement or number; instead, it is defined as the combination of several factors (Walker & Salt, 2012). As a first step toward assessing the resilience of a system, it would be very helpful to identify the identity (a measure of the system's response/function) of the system (Eslamian et al., 2019). Resilience analysis is concerned with how that identity may change and what might threaten it (Walker & Salt, 2012).

In the last two decades, there has been an increasing interest in resilience research across a variety of scientific disciplines, including biology, engineering, sustainability, and natural disasters. It has been found that the concept of resilience is used in many contexts in the last few years, such as hydrological resilience, ecological resilience (especially that of aquatic systems), community resilience, and resilience to disasters in urban areas. Although there has been a great deal of research applied to the resilience concept, it has not been able to capture the essence of socio-hydrological dynamics in the coupled human-water context (Mao et al., 2017). According to Keck and Sakdapolrak (2013), social resilience can be viewed as a combination of three things: the capability of social actors to handle and overcome a wide variety of immediate adversities (coping capacities), their ability to learn from past experiences and adapt to changing circumstances (adaptive capacities), and their capability to create conditions that foster individual welfare and sustainable societal resilience to future crises (transformative capacities). Socio-hydrological resilience can be defined as the capacity of a society to adjust in the face of a changing environment to cope with biophysical and hydrological changes. Sivapalan et al. (2012, 2014) have introduced the concept of "socio-hydrology"as a framework to understand the complex approach in managing hydrological resources aiming to create resilience. The social sciences have played an important role in interdisciplinary research programs in natural hazards and disasters as well as sustainability, resilience, adaptation, and knowledge mobilization (Adger et al., 2005; Brown & Westaway, 2011; Edelenbos et al., 2011; Ostrom, 2009). Socio-hydrological field could be enhanced by using these themes as links between the socio- and hydrology portions of the field in order to foster multidisciplinary collaborations and to enable socio-hydrological research to grow and become significantly more significant to society. Sustainability (Ostrom, 2009), vulnerability and resilience (Eakin & Luers, 2006), adaptation and governance (Folke et al., 2005), and hazards (Cutter et al., 2008) are among these topics and fields. The following is a review of research on social hydrology resilience:

Wurl et al. (2018) have provided valuable insights into how to analyze the hydrological resilience of an arid ecosystem subject to future extraction scenarios and changes in climate conditions. The results of this study provide an appropriate basis for realizing how social systems and hydrological systems are interconnected. Moreover, different indicators have been derived from coupled human-water systems as accurate means of predicting water trajectories influenced by various human effects. Xu et al. (2018) investigated the socio-hydrological trends using mixed-methods and outlined a comprehensive explanation of the findings. Applying bibliographic metrics and network analysis, they detected the main trends and illustrated the relationship between socio-hydrology and other fields of study. In addition, their results suggested that wider definitions of socio-hydrology could lead to a greater interdisciplinary approach and introduce novel approaches and points of view, which ensure the inclusion of location-related values in the investigations on water systems dynamics. Considering the association between rainfall and groundwater recharge, Hund et al. (2018) illustrated a "groundwater recharge indicator". This facilitated the estimation of the overall groundwater recharge during a wet season using data of the most recent rainfall totals. The indicator was introduced with the purpose of facilitating the assessment of annual recharge before the end of wet seasons by the water management departments. The mentioned approach could be implemented for sectors with seasonal rainfall; moreover, it could help administrators increase the socio-hydrological resilience to seasonal droughts. Jaramillo et al. (2018) proposed a socio-hydrological model, which possessed novel criteria, to assess the impacts of developing hydropower in Nepal through constructing and implementing indicators. Their eight-vulnerability parameter-based conceptual framework considered resilience and adaptation capability as a relative complement of vulnerability and a prerequisite, respectively. Using indicators in this study, we can gain a deeper understanding of the approaches of evaluating the socio-hydrological structures, especially during the assessment of developing hydropower-based structures. This could affect a multitude of economic and socio-hydrologic systems. Horn and Elagib (2018) provided a systematic explanation and a socio-hydrological framework to better understand the flash flood-related risks and possible accommodative actions applied to urban arid areas. This could be accomplished by an extensive explanation on the flash flood-related problems faced by managers. Their research highlighted the major managerial problems, including low organizational potential, weak management, constraint sources, as well as inappropriate projects planned for cities. Moreover, this study proposes approaches to improve the mentioned risks-related databases, their usage details based on a mixed method, as well as plans of developing the community and civil society capacities through better knowledge and commitment. Using a machine learning approach, Veettil et al. (2018) presented a methodology for predicting hydrologic ratios for watersheds in the contiguous United States (CONUS). This method is based on a set of climate, soil, vegetation, and topographic variables. In this study, the concept of nonparametric elasticity was used to analyze the effect of hydrologic ratios on drought characteristics (resilience, vulnerability, and exposure) that are commonly experienced by river basins in the CONUS. They found that a machine learning approach based on a random forest algorithm can be used effectively to estimate the spatial distribution of hydrologic ratios, as long as sufficient data is available. Further, the use of the nonparametric-based elasticity approach may be able to identify the potential influence of hydrologic ratios on the spatial pattern of droughts. Sharma and Goyal (2018) used district (i.e., administrative division) scales to assess the resilience of terrestrial ecosystems to hydroclimatic disturbances in India (Sharma and Goyal, 2018). The results of this research showed that there was a large spatial variation in the Ecosystem Water Use Efficiency (WUEe) in India at the district scale, which was significantly higher in the lower Himalayan regions than anywhere else in the country. Moreover, resilience has also been assessed in terms of the ratio of the WUEe under the dry condition and the mean WUEe, which indicates the ability to absorb hydroclimatic disturbances, if any. Considering the results of this study, it has become clear that better ecosystem management policies are needed in India, and an analysis is provided on how to achieve this process.

Hough et al. (2018) proposed a social-ecohydrological thresholds (SEHT) framework that integrates social-hydrological concepts, trait-based ecological concepts, and ecosystem service concepts. Using the San Pedro riparian corridor as a case study, the SEHT framework was utilized to identify key drivers and thresholds that play a role in the socio-hydrological system of Arizona. In this study, the SEHT framework has been applied to identify several critical drivers of potential thresholds that could result from either natural or social components of ecosystem services. Al-Amin et al. (2018) provided an insight into how to capture the dynamics of household-level consumer and policymaker interactions in order to simulate water demand in the Verde River Basin, Arizona. Using an agent-based modeling approach, they were able to improve the interaction between stakeholders involved in collective water management by facilitating the heterogeneity, complexity, and adaptive behavior of actors. They provided a framework for the evaluation of water reduction strategies for long-term water resilience as part of a holistic approach that incorporates the objectives of water users, municipalities, and basins. Zhang et al. (2019) gave a novel method to quantify wetland hydrological resilience at a regional scale, thereby facilitating the understanding of the ecological and hydrological resilience of wetlands while facing intensified climate disturbances. In the current investigation, we developed the quantitative metrics of evaluating the North Carolina state's shoreline with forested and herbaceous wetlands. We found that multiscale variations in the groundwater table influenced by dry climate were strong indexes of wetlands hydrological resilience to droughts by examining the thresholds of groundwater table, overland flow, as well as saltwater table during 1995–2014. Gutierrez-Lopez et al. (2019) estimated the capacities of Haiti's health services through evaluating their position in the aftermath of natural phenomena, including hurricanes, and identifying ways that the community could increase its resilience. There were two resilience indexes proposed with the purpose of comparing and analyzing the subsequent capacities of resilience-related actions, including a theoretical index (TRF) and an index of resilience measured in situ (RF). Using a previously applied approach, they claimed that it could restore the pre-disaster living conditions; moreover, it decreased related vulnerability. Hynds et al. (2019) provided valuable insights into the efficiency of hydrometric network while considering the user's requirements. Using a numerical method, the following purposes were achieved: (1) identification of the implementation methods, network-related strong points, prerequisites, and constraints; (2) quantification of network effectiveness; as well as, (3) preparation of an adaptive basis for subsequent investigations on a hydrometric networks, plans, and data. Over 60% of respondents believed that the best way to achieve future resilience would be through the amendment of network density, with more than half favoring increases in network density that were geographically and/or categorically focused rather than greater national network density. Furthermore, they indicated the considerable transformation of a "managerial-driven" approach into a scientifically oriented compliance-driven one for data usage.

3 Interaction of Human and Natural Systems from Two Perspectives of IWRM and SHS

In the past, the study of the hydrological cycle was carried out for specific political purposes (Linton & Budds, 2014) and considered relatively separate from human interactions. Decades later, in the 1970s, the focus shifted to water sources improvement and a clear consumption approach. Water Resources Management (WRM) was focused in 1980; therefore, the meanings and concepts were significantly changed and topics such as IWRM and Adaptive Water Management (AWM) were pursued (Savenije et al., 2014). Thus, the shift from "development" to "management" led to significant changes in the framing of water issues, as the two concepts of integrated analysis and adaptability showed the emergence of a more comprehensive mindset. In the meantime, IWRM has received a lot of attention as a comprehensive solution. Global Water Partnership (GWP) defines IWRM as "a process that promotes the integrated development and management of water, land, and related resources without compromising the sustainability of vital ecosystems, to maximize economic and social welfare outcomes equitably" (TAC, 2000).

Similar to socio-hydrology, the IWRM has been able to powerfully examine the relationship between people and water. However, the question is how IWRM differs from sociological hydrology. Compared to socio-hydrology with the IWRM, socio-hydrology efficiently considers a comprehensive integration of the environmental and socio-economic aspects of hydrology from a different angle than that of the IWRM, while the IWRM focuses on the policy-oriented water management strategies imposed on the hydrology cycle and address interactions between people and water using "scenario-based" approaches. In other words, the difference between socio-hydrology and IWRM is the study and quantification of the concept of co-evolution between humans and hydrological systems (Sivapalan et al., 2012).

Although IWRM has historically been a framework to explore interactions between human development and water resources, it cannot understand and receive meaningful co-evolution and continuous system interactions in the long term (Liu et al., 2008; Sivapalan et al., 2012), as it fails to address the dynamics of interactions between humans and water. In contrast, the focus of socio-hydrological studies is on observations, system understanding, and prediction of future co-evolution paths of human-water systems. It can be said that socio-hydrology is the basic science and foundation of IWRM operation (Sivapalan et al., 2012). Figure 1.2 shows the relationship between human and natural systems from the perspective of IWRM and socio-hydrology (Elshafei, 2016).

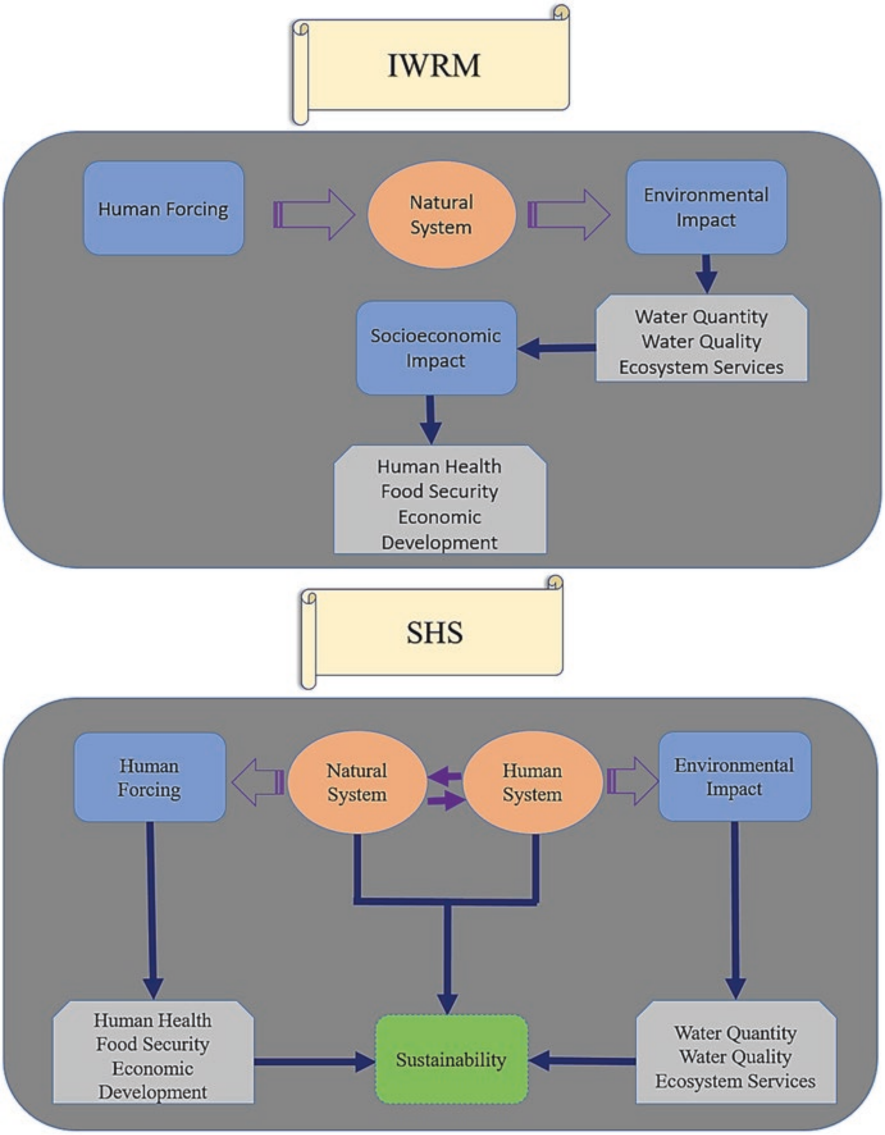

Fig. 1.2 Human-hydrology system interaction under Integrated Water Resources Management (IWRM) and Socio-Hydrological System (SHS)

4 The Role of Socio-Hydrology in Explaining the Relationship Between Humans and Natural Hazards (Reducing Flood Risk Using Socio-Hydrological)

In recent decades, a large body of research has been conducted on human feedback (social, political, economic, etc.) and the fundamental changes followed by the occurrence of phenomena such as floods for humans. Meanwhile, other hydrological studies have examined the human effects of the flood phenomenon. These studies include changes in the incidence, magnitude, and extent of floods caused by urban development or environmental measures. The socio-hydrological approach provides an insight into the complex dynamics between humans and floods (feedback and effects), enabling us to examine the reciprocal relationships and emerging co-evolution feedback occurring in hydrological and social processes. Previous research has shown that conventional flood risk assessment methods have failed to provide a good solution, or strategies to reduce flood risk only work for a short time, or may lead to unforeseen long-term consequences. At the same time, the results of socio-hydrological models show that a better understanding of the dynamics and interactions between communities and floods greatly enhances our ability to investigate and analyze changes in the possibility of floods and improve decisions and actions to reduce flood risk over time (Di Baldassarre et al., 2017).

As shown in Fig. 1.3, the above section is a symbol of conventional approaches to flood risk analysis based on scenarios. For each period, risk analysis is based on a combination of flood damage and hazards, as well as community vulnerability. The dynamics resulting from feedback between hydrological and social processes cannot be examined in these analyses. The lower part symbolizes the

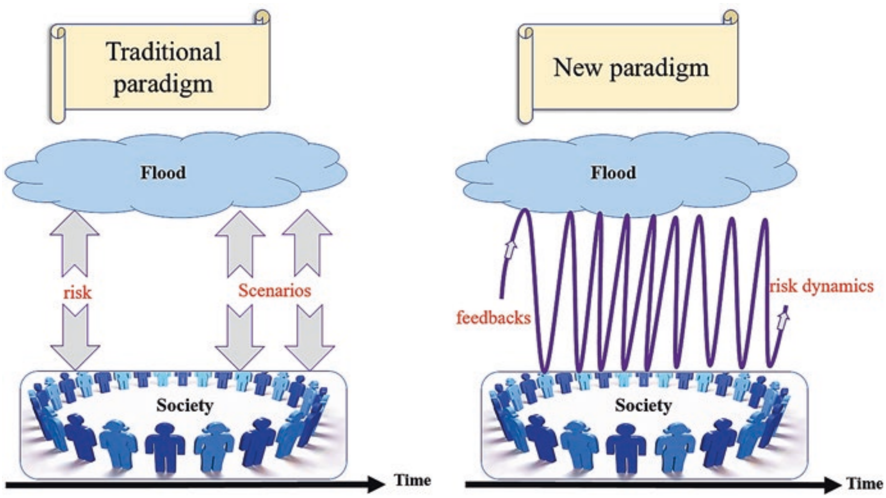

Fig. 1.3 Conventional approach (left) and socio-hydrology approach (right) for flood risk analysis

socio-hydrological approach, which examines the integrated dynamics of communities, floods, and behaviors that emerge from their long-term feedback.

Considering the capabilities of the socio-hydrological approach in the field of flooding, important research has been carried out, some of which will be reviewed in the following.

In traditional hydrology, humans are often considered as boundary conditions or external pressure forces for these ecosystems, and their mutual and interactive relationship has not been taken into account, while the way societies influence the frequency of floods and, in parallel with it, the way societies are formed and developed Exposure to floods is well explained by socio-hydrology (Di Baldassarre et al., 2013a, b). For example, the well-known concept of "Levee Effect" (White, 1945) which creates a sense of security for people in the presence of safer structures and higher embankments, and as a result of the density of economic structures and more expensive industrial infrastructures on the banks of rivers and finally erasing human memory from the occurrence of extreme phenomena) was unfortunately the cause of the 2011 flood in Brisbane, Australia (Bohensky & Leitch, 2014).

The influence of the community on the effects of such events is so great that according to the researchers, the amount of damage that may be caused by these events depends on whether the community thought about their occurrence or not. Barendrecht et al. (2018) used socio-hydrology to model the level of community awareness and preparedness against Elbe river flood damage in Dresden, Germany. They concluded that the amount of damage in the 2013 flood was reduced compared to 2002 because awareness was created in the second flood.

In this regard, previously Di Baldassarre et al. (2013a, b) also presented a conceptual model for considering socio-economic factors and the height of embankments at the same time with regard to a hypothetical river with hypothetical population data. Focusing on flood risk and developing risk management plans is imperative, but in the meantime, community understanding of risk is often neglected. An important aspect is that this risk is understood in different ways by scientists, decision-makers, and the general public, which has caused some flood management plans to fail in the past (Fuchs et al., 2017).

Di Baldassarre et al. (2009) investigated the effects of human activities on the spread of floods from 1878 to 2005. By evaluating the relationship between increasing the height of embankments to protect against floods and its effect on the intensity and rate of floods, they found that this action had two opposite results as follows: (1) A positive effect on reducing the rate of drowning in flood-prone areas and (2) A negative effect on the natural expansion of the river capacity and increased excess flow rate at the downstream level. By quantifying the historical data of river flow and flood events, the most important conclusion was that the absence of floods in 1951 (mainly due to the increase in embankment height between 1878 and 1951) caused catastrophic damage to the downstream because of the high intensity of the flood current (the output of the current was about 2×10^9 m^3 and the affected area was about 1000 km^2). If the geometrical characteristics of the area were the same as in 1878, the same flood would impose less damages (the estimated flow output was about 450×10^6 m^3 and the affected area was about 200 km^2). Therefore, increasing

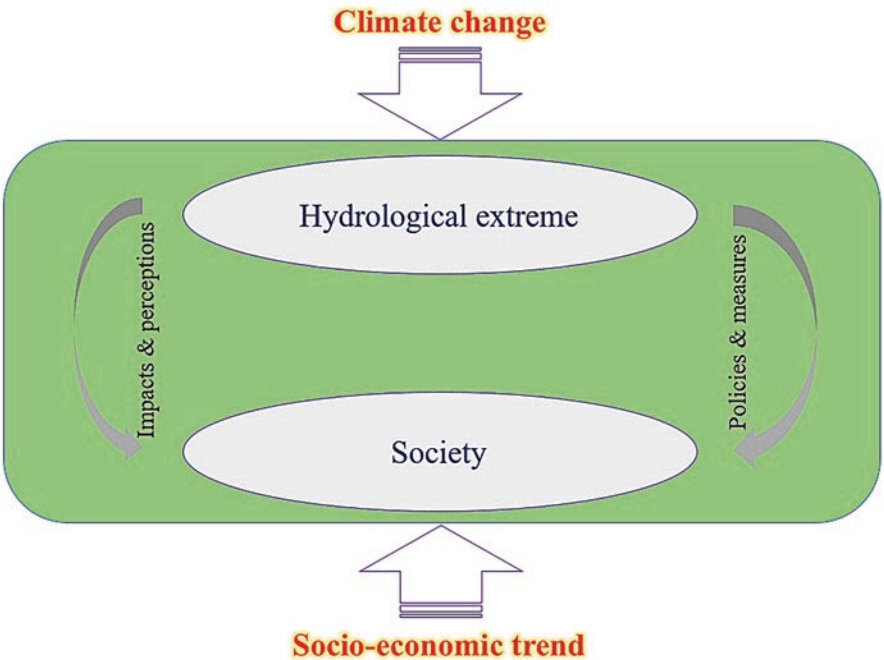

Fig. 1.4 Feedback process between floods and societies

the height of embankments is not a good way to reduce flood risks and causes catastrophic and unpredictable events. Despite conducting this research before the emergence of Socio-hydrology, Di Baldassarre categorized it into basic research for socio-hydrology and complemented and developed this view (Di Baldassarre et al., 2017). Figure 1.4 depicts internal interactions between flood zones as human-water systems and external factors (climate change and socio-economic trends). By analyzing the interactions between community attitudes, flood damages, and economic growth trends, Viglione et al. (2014) studied the relationship between the culture and how society should respond to flood risks and urban development in flood-prone areas. The research was focused on three indicators of (1) collective memory, i.e., the capacity of the community to maintain a high level of awareness and consciousness of flood hazards, (2) attitude of risk-taking, i.e., the amount of risk that the community is ready to be exposed, and (3) public confidence in the equipment and measures taken to reduce the risks of floods. For this purpose, a dynamic model was used to show the relationship between community feedback and hydrological systems. The results showed that understanding the risks of floods (due to short collective memory and overconfidence in flood protection measures), along with a high risk-taking attitude, have significantly limited community development because of the various damages caused by floods. On the other hand, over-risking (long collective memory and lack of trust in flood protection measures) has led to the loss of opportunities for economic prosperity and the decline of society.

In summary, the development of society in flood-prone areas highly depends on the history of flood events in those areas.

The interactive effect between flood events and humans and the establishment of laws can be seen in many cases. The 2013 flood in Calgary in Canada caused financial damage of 1 billion Canadian dollars, which was named the costliest natural disaster in Canada. The event of this flood also had effects on politics. The control of changes in land use in high-risk areas was intensified and new insurance laws were established for landowners in floodplains. The combination of human factors (urbanization, economic growth, and misgovernance) along with natural forces (climate changes, droughts, and floods) affected the Saskatchewan River basin in Canada, and Gober and Wheater (2014) reviewed the type and extent of their impact.

In a study, Kuil et al. (2016) evaluated the feedbacks between an agricultural community and the surrounding environment. This study was conducted according to the historical data of the ancient Maya people and how successive droughts affected the destruction of these people in the nineteenth century. One of the important results obtained by considering the hydrological-social framework was facts that could not be observed in common hydrological studies before. For example, in the case of this tribe, the results of the studies showed that the decrease in the frequency of rainfall caused the population to disperse. It seemed that the construction of dams could improve this destruction to some extent, but it was observed that after the construction of dams and when the dams were empty of water, the effect of droughts on human societies was more severe and as a result, the population of this tribe decreased more than before.

Ciullo et al. (2017) studied and dynamically assessed the risks of floods and the resiliency of society to floods. They considered two different socio-hydrological systems: (1) green systems, in which communities deal with floods using non-structural and natural arrangements, as well as a settlement outside flood zones, and (2) technological systems, in which humans deal with flood hazards by using fabricated methods and structures such as embankments, dams, and artificial canals. By adapting the model of human-flood interactions to data collected from two scenario studies in Bangladesh and Rome in Italy, they predicted potential flood risks in the future. Studies have shown that flood risk in technology systems is significantly lower than that of green systems, although technology systems can suffer catastrophic events that lead to greater losses and damages. In addition, green systems have shown higher resiliency compared to technological systems, which increases their resiliency to social and environmental changes.

Fuchs et al. (2017), in two different watersheds in Greece (one in the suburbs and the other in the village outskirts) that have been involved with the highest number of flood events in the last 10 years, investigated the adaptation capacity and understand the flood risk by applying the socio-hydrological framework. By presenting 155 and 157 questionnaires, they examined and compared two different types of flood occurrences, including periodic floods (in rural areas) and flash floods (in urban areas). The most important question that was raised in both basins was about people's opinion about the main causes of past flood events. Based on the comparisons obtained from the answers, the percentage of answers to questions such as the main cause of past floods, the level of people's understanding of flood risk (based on whether or not a person has been exposed in past events), and the use of protective structures have been investigated. Finally, the correlation matrix was drawn for different variables measured in both regions.

Floodplains throughout history have always been the focus of human settlement due to the fact that rivers are considered as a kind of communication channel. To eliminate the risk of flooding, humans have built flood control structures and protected themselves with the help of embankments and so on. Therefore, feedbacks between humans and floodplains have not been out of two general types: war or adaptation. Based on this, Ferdous et al. (2018) presented a socio-hydrological study with a new definition of hydrological-social spaces in the investigation of Jamuna river floodplain (by dividing the left and right banks of this river from the point of view of the type of protection against floods and by referring to these two different types of feedback).

One of the functions of multi-purpose dams is to control floods and use them as flood control structures, and to analyze the effectiveness of these dams, socio-hydrological methods should be used (the works that seem to have not been well studied so far, especially in relation to the impact of these structures on the economic and social conditions downstream of the rivers). In order to cover this gap in their recent study, Lee and Kang (2020) performed hydrological-social modeling by considering social factors (such as population, land use, gross domestic product, and damages caused by floods and droughts) and hydrological factors (such as the inflow and outflow of the dam, the amount of precipitation, and the amount of water demand), which examined the future effects and effectiveness of the dam by defining various combined scenarios. They divided the hydrological and social systems governing the Hoengseong dam in the south of Korea through equations into the above-mentioned factors and put them in a ring, and then applied three different scenarios (maintaining current conditions, extreme climatic conditions, and rapid urbanization) and in this way presented a model to estimate the dynamics of the system. According to him, the built social hydrology model can be used well in the process of decision-making and optimal planning of water resources.

Despite the attention of most or almost all case studies on floods, the relationship between man and water has recently been considered in the understanding of rivers and their social relationships. Due to the fact that in recent years environmental flows have become very important, researchers have also used socio-hydrological to navigate an important stage in the advancement of environmental water flow management. Anderson et al. (2019) combined the relationship between man and the river in the form of a new definition of environmental flows and conducted studies on different rivers (from Honduras, India, Canada, New Zealand, and Australia) in which comprehensive efforts were made to determine the environmental conditions and human needs at the same time. Finally, it was found that without considering socio-economic factors and local participation, it will not be possible to properly plan and manage the ecological status of rivers. In another study, Chen et al. (2016) examined two different types of Kissimmee River management in Florida, USA, which were applied in different time frames due to differences in priorities. This river was prepared for flood control around the 1960s, and then after about 10 years, it was restored to its original state. They studied these changes based on human factors and concluded that the level of sensitivity of communities to floods has been different in different decades. According to the review of available sources, it was found that socio-hydrologic investigations on floods have recently developed. Nowadays, the natural disasters-caused adverse effects, including the floods and drought, cannot be evaluated without human considerations. A number of researchers conducted new studies on floods, rivers, and their social relations. Therefore, this method provides a more comprehensive view on the interactive behavior of rivers and humans, as well as its effects on extreme events.

5 Conclusions

The interaction between human activity and hydrologic cycle is currently taking place in a manner that has never been seen before. The anthropogenical actions have strengthened the association between human and hydrological systems. Moreover, the benefits and adverse effects resulting from social-related improvements could influence the hydrologic-based systems through management policies. The association of humans and water has been completely identified; however, there is not an appropriate numerical recognition of outcomes, joint communications, and co-evolution of coupling systems. Therefore, "socio-hydrology"has emerged, which studies the dynamics of coupled human-water systems through co-evaluating the social and hydrological systems, as well as analysis of their mutual outcomes and interactions. This science has also formed limitations for human acceptance as a main component of the hydrological cycle and proposes novel developments that demand further reviews. However, socio-hydrology is still at an exploratory stage, which requires considerable interdisciplinary collaborations to develop a depth- and scope-based recognition of interactions between the mentioned systems. Although the importance of improving the social and natural scientists cooperation with the purpose of achieving a better understanding of complicated dynamic systems is highly demanded, current empirical analysis indicated the dominance of social scientist's minimal participation. The resilience of socio-hydrologic systems is of utmost importance to their long-term sustainability, particularly when those systems are confronted with dramatic stressors such as natural hazards and rapid economic growth. A resilience assessment of socio-hydrological systems should also include the investigation of the connections between thresholds, recovery and response capacities, and adaptive capacity. These assessments aim to enhance resilience, which requires an awareness of uncertainty, as well as monitoring, adjustment, and engagement for long-term planning. Further research is necessary to develop realistic simulations of human-water systems for decision-making in order to better integrate socio-hydrology concepts. Also, most studies show in different ways how better understanding of the resilience of socio-hydrological systems is important for ensuring the sustainability of social-ecological systems in times of global change.

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Chapter 2
Improvement of Urban Socio-Hydrologic Resilience in Extreme Hydro-Climatic Conditions

Saeid Eslamian, Niloofar Nasehi, and Mousa Maleki

Abstract Considering the increase of human activities in nature and its effects on the environment and water resources, the necessity to change the approach in hydrology modeling is inevitable. Until the last few years, scientists studied the science of hydrology without considering the role and integrated effect of human intervention on the environment and vice versa. But later it became clear that without it, the study of a hydrological cycle is fraught with error. The feedbacks and interactions between humans and water show that human activities have led to a strong connection between human and hydrological systems and the positive and negative effects of the development of social systems are reflected on hydrological systems through management decisions. Although the link between human activities and water in a "system of mutual interaction" has been known for many years, until now, a quantitative understanding of feedbacks, two-way interactions, and the concept of co-evolution in continuous systems has not been possible. The purpose of socio-hydrology is the understanding of the dynamics and evolution of integrated water and human systems. As a research-oriented science, one of its other goals is to observe, understand, and predict phenomena, and it generally focuses on long-term periods. Social hydrology analyzes how feedbacks and mutual interactions occur, and in the frameworks of economy and politics, it pushes the boundaries of hydrology science toward the acceptance of humans as an integral part of the hydrological cycle. In this study, urban communities' resilience versus extreme hydroclimatic

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conditions is evaluated from the viewpoint of socio-hydrology, and some tips to improve the urban socio-hydrology resilience are given.

Keywords Socio-hydrologic · Extreme event · Climate changes · Resilience · Urban

1 Introduction

Today, interactions between the human societies and hydrological cycle are occurring that have never been observed in the past. The feedbacks and interactions between human and hydrological systems show that human activities lead to a strong connection between the humans and hydrological systems and the positive and negative effects of the development of social systems that are reflected on hydrological systems through management decisions. Although the link between human activities and water in a "system of mutual interaction" has been known for many years, until now little understanding of feedbacks, two-way interactions, and the concept of evolution and co-evolution in continuous systems has been possible. These conditions led to the emergence of the new science of "social hydrology" with the aim of understanding the "dynamics and co-evolution of human-water continuous systems". In fact, social hydrology is the study of human-water continuous systems based on the co-evolution of social and hydrological systems, in which feedback and mutual interactions are analyzed. Social hydrology, formed in the frameworks of economics and politics, has pushed the boundaries of hydrology toward the acceptance of humans as an integral part of the hydrological cycle, and it is considered as a new development in hydrology that calls for a rethinking of this knowledge.

The exponential growth of scientific knowledge and the challenges faced by researchers in keeping up with this information necessitate the need for comprehensive review studies. Additionally, effective water resources management holds strategic importance due to its critical role in sustaining societies. In response to these demands, a new scientific discipline called "social hydrology" has emerged, which focuses on integrating social and natural factors to address the limitations of current hydrological methods. Consequently, there is a pressing need for students and the wider scientific community to gain awareness and understanding of the evolving concepts within this discipline. To fulfill this need, a comprehensive review of scientific activities conducted since the inception of each project is essential. (Eslamian et al., 2019). So far, the title of social hydrology has been formed. To conduct the study and secure the scientific credit of the information, reliable databases are used and almost most of the sources, including articles, books, or scientific documents, have been examined, and by using the narrative review method, the information is produced in four groups; (1) Conceptualization, (2) Application in agriculture, (3) Flood and drought studies, and (4) Modeling and watershed studies. According to the studies, despite the rapid growth of this discipline in scientific circles, there are still important challenges in the way of its development, which necessitates further studies of basic, methodological, and ontological concepts in social hydrology.

All over the world, the development of human societies followed by changes in land use and the application of various management methods in the use of water resources have led to the drastic changes in the hydrological regime throughout the history of each region. In fact, with the increase in the world's population of two hundred million to seven billion people in 2000 years, the intervention of human societies in order to meet the water requirements has intensified in the hydrological regime so much that in majority parts of the world, the water flow paths on the earth have been dictated by humans compared to their pristine nature (Postel, 2011).

Thus, the hydrological regime, which in the past was often controlled by factors such as climate, vegetation, geological condition, and topography of the catchment area, today is increasingly influenced by social and economic factors such as population growth and development of cities, agricultural development in irrigation, industrialization, technology, and engineering (Carpenter et al., 2011; Vitousek et al., 1997).

Hydrological extreme events cannot be evaluated without human considerations, and fortunately, this matter has received more attention in recent years. Social hydrology claims to be an explicit study of the relationship between man and nature, and at the top of them is the co-evolutionary relationship of human societies and disasters that are natural. In this regard, many studies have been conducted in the last few decades regarding the human impact on the flood and drought phenomena, but our understanding of the dynamism of human factors and the changes caused by their reactions, whether in the form of response or effect, is still limited (Di Baldassarre et al., 2017).

Fuchs et al. (2017), in two different watersheds in Greece (one in the suburbs and the other in the countryside) that have been affected by the highest number of flood events in the last 20 years, assessed the adaptive capacity and understanding of flood risk by applying the social hydrology framework. They have reviewed with completing 155 and 157 questionnaires and they examined and compared two different types of floods, including periodic floods (in rural areas) and rapid flows (in urban areas). The most important questions that were raised in both basins were about people's opinion about the main causes of past flood events. Based on the comparisons obtained from the answers, the percentage of answers to the questions such as the main cause of past floods, the level of people's understanding of flood risk (based on whether or not a person has been exposed in past events), and the use of protective structures have been investigated. And finally, the correlation matrix was drawn for different variables measured in both regions (Fuchs et al., 2017).

In a study, Kuil et al. (2016) evaluated the feedbacks between an agricultural community and the surrounding environments. This study was conducted according to the historical data of the ancient Maya people and how successive droughts affected the destruction of these people in the nineteenth century. One of the important results obtained by considering the framework of social hydrology was the facts that could not be observed before in the common hydrology studies. For example, in the case of this tribe, the results of the studies showed that the decrease in the frequency of rainfall caused the population to disperse. It seemed that the construction of dams could improve this destruction to some extent, but it was observed that after the construction of dams and when the dams were empty of water, the effect of droughts on human societies was more severe and as a result, the population of this tribe decreased more than before (Kuil et al., 2016).

It is estimated that about 1 billion people live in floodplains across the world. Throughout history, these areas have always been considered a kind of communication channel by humans for settlement, which, of course, also entails risks, and for this purpose, humans have to build the flood control structures and protect themselves with the help of embankments and so on. Therefore, feedbacks between the humans and floodplains have not been out of two general types: fight or adapt. Based on this, Ferdous et al. (2018) investigated the floodplain of the Jamuna River in Bangladesh and the division of the left and right banks of this river from the point of view of the type of protection available against floods and based on these two different types of feedback, the study of social hydrology has been defined with a new definition as they presented the social hydrology spaces.

In common hydrology, humans are often considered as the boundary conditions or external pressure forces for these ecosystems, and their mutual and interactive relationship have not been taken into consideration, while the way societies influence the periodicity of floods and along with it, the way communities are formed and developed floods are well explained by social hydrology (Di Baldassarre et al., 2013a, b). For example, the famous concept of "embankment effect" (White, 1945) which creates a sense of security for people in the presence of safer structures and higher embankments, and as a result of the density of economic structures and more expensive industrial infrastructures on the banks of rivers and finally erasing the human memory of the occurrence of extreme events. Unfortunately, it was the factor that caused the 2011 flood in Brisbane, Australia (Bohensky & Leitch, 2014). The influence of the community on the effects of such events is so great that according to the researchers, the amount of damage that may be caused by these events depends on whether the community thought about their occurrence or not. In their study, Barendrecht et al. used the social hydrology to model the level of awareness and preparedness of society against the Elbe river flood damages in the city of Dresden, Germany, and concluded that the amount of damages in the flood of 2013 compared to 2002 because in the second flood the awareness that had been created has decreased (Barendrecht et al., 2018; Di Baldassarre et al., 2017). In this regard, according to a hypothetical river with hypothetical population information, Di Baldassarre et al. (2013b) have presented a conceptual model for considering the socio-economic factors and the height of embankments at the same time.

Urbanization, by increasing impervious surfaces and changing flow paths, has caused an increase in floods in recent decades (Chen et al., 2015). A flood itself is a natural phenomenon that is usually associated with positive consequences. However, when the flood happens in an urban environment, it has devastating consequences for the residents in terms of property destruction and is also a threat to human health (Becker, 2014). To reduce and prevent flood damage, urban water management and flood risk management are key factors. Their work is to identify and inform the concerns related to floods by considering economic, socio-economic, and environmental variables that are affected by floods. Today, new literature on flood management often discusses the concept of resilience (Sayers et al., 2013; Matyas & Pelling, 2015; Ran Nedovic-Budic, 2016; Edelenbos et al., 2017). Resilience or flexibility is the ability of a system or community at risk to resist, absorb, and adapt in a timely and efficient manner to the effects of a hazard, including through the maintenance and restoration of its essential basic structures and functions (Morrison et al., 2018). In contrast to vulnerability to natural disasters, resilience refers to the positive aspects and strengths of societies. Vulnerability refers to how people and properties and other elements are damaged by floods (Boudou et al., 2016). The level of sensitivity of the elements depends on preparation against the flood and the ability to deal with this event. The vulnerability of urban elements depends on the characteristics of building structures, services, equipment and connections, equipment mobility, and available materials (Cho & Chang, 2017). In this study, urban communities' resilience versus extreme hydroclimatic conditions is evaluated from the viewpoint of socio-hydrology, and some tips to improve the urban socio-hydrology resilience are given.

2 Socio-Hydrology: A New Method to Understand Hydrology

For thousands of years, the hydrological cycle at the scale of the basins and at the global scale has been intertwined with human activity. Humans have a direct effect on 84% of the earth's surface and 14% of the world's fresh water. About 80% of the world's population lives under the severe water stress conditions and 91% of the world's rivers are experiencing moderate to the high biodiversity stress (McMillan et al., 2016). Many of the challenges that the world is facing today can be better explained by understanding the development process that societies have gone through since the past (Kuil et al. 2016).

There are many terms and expressions to express the mutual relationship between man and nature in the texts and writings of researchers, such as Hydrosociology (Falkenmark, 1979; Sivakumar, 2012), Hydro-social (Swyngedouw, 2009), and Hydro-cosmological (Boelens, 2014), which is between some of the above concepts and also, the two concepts of Socio-Hydrology and Hydrosocial from a perspective of ontology, methodology, and epistemology (concepts of philosophy of science), the comparisons have been made (Wesselink et al., 2017).

In social hydrology, human as a dynamic element of the era is included in the calculations of the water cycle, and the effects that have on the anthropocene water cycle are considered in the calculations. The studies about the concept of social hydrology started from 2012 onwards and after the famous article of Sivapalan and his colleagues (2012) under the title "Social hydrology: a new science of man and water". In this article, Sivapalan attempted to create an understanding of the dynamics and interactive cooperation (mutual) of the interconnected water and human systems, which includes the effects and dynamics of changes in the social standards and values, as well as system behaviors such as the peak points and feedback mechanisms, some of which can be predicted or be caused by non-linear reactions between the processes occurring in different spatial and temporal scales. Therefore, social hydrology is the knowledge of human impacts on hydrology and also the impact of the water cycle on human social systems. Because freshwater systems are closely related to the ecological, social, and geomorphological systems, and in any time scale that is a little more than a few decades, the methods of these sciences should be integrated in hydrology to make the deeper hydrological investigations possible (Thompson et al., 2013). Humans have changed the systems of rivers, lakes, and floodplains since many centuries ago and these changes are still ongoing. The goal in today's management of water systems is to define new solutions, because the operation of water engineering, which is only based on profitability, has led to the creation of many problems. Having a good prediction of future limit events is necessary for river engineering, and historical hydrological records of such events can be used to estimate their re-occurrence in the future (Crăciunescu et al., 2010). The need to combine and consolidate these points of view is repeatedly mentioned as an effective solution by the various sciences and also by many water-related organizations such as HELP (Hydrology for Environment, Life and Policy), UNESCO, and the EU Water Directive is also under review (Makarigakis & Jimenez-Cisneros, 2019).

In social hydrology, the constant increase of human influence on the water cycle, along with the important role of water as a source of shaping human societies, leads to a pattern in which the feedbacks between human-water and water-natural habitats become the bilateral relations that in the principle forms the framework of socio-ecological studies (Widlok et al., 2012). Therefore, social hydrology not only depicts the feedbacks of human societies with the hydrological cycle, but also researches in the field of the involvement of the gender factor in social hydrology modeling. It comes to the fore, because the way women and men deal with the water resources is different, and due to the challenge in the common models in the inability to involve the human factor, gender differences were not included in the models (Baker et al., 2015).

In a world that is under the global changes and population growth, understanding the natural processes that govern the water cycle is not enough, and cultural reasons and human impacts on water systems should also be identified. Today, water engineering projects have suffered billions of dollars in damage, and part or all of the project has been lost only because of not seeing the important social factor in technical and engineering issues (Lund, 2015). From this point of view, social hydrology is a concept for decision-making in order to ensure access to the safe and sufficient water resources and provide the protection against the hydrological limit events. Management based on hydrological systems increasingly requires a scientific background that not only knows about hydrological processes in the natural systems, but also includes the past and present effects of human intervention.

The broad theoretical framework presented by Sivapalan et al. (2012) for social hydrology includes three important aspects of social hydrology systems: (1) multiple structures and dynamics of water systems, (2) system outcomes in the form of human well-being that physical scales and levels of governance appear, and (3) personal and social normative goals regarding water protection, sustainability, and use. This theoretical framework explicitly shapes the feedbacks between the humans and water systems and helps us to describe the past, present, and future and clarify the future sustainable paths considering their simultaneous evolution.

On this basis, 2016 was named the International Year of Global Understanding (IYGU) and the main idea of this naming was that regional and global works that are related in many ways. Today, there are few regional phenomena in the world that are not associated with the global effects, even in a mild way. The great drought of the Sahel region in North Africa, which in the 1680s caused severe famine and large-scale unwanted human migrations, the drying of the Aral Lake, and many other climatic events, in addition to the effects of regions with large dimensions on a global scale. Today, many researches with the main focus of "regional activities: global works" are being done (Robinson et al. 2016).

There are the land uses that vary from 10% to 84% (Zhou et al., 2016), changes in the land surface change the response to runoff, causing changes in evaporation and transpiration and as a result the atmosphere of the region, runoff at a faster rate. They occur and become stronger in the downstream areas of the rivers. The socio-economic effects of these floods are often extensive and sometimes lead to the forced migrations. In the world, the total water capacity stored in dams is about 1000 cubic kilometers or 1.1 times the average annual runoff of rivers. Therefore, global changes often begin when humans initiate the local actions (Singh, 2018). Due to the clear effect that local actions and changes have on the global scales, modeling events at local scales are also vital to understand their impact at global scales.

It is also clear that the challenges related to water engineering often cannot be answered in one discipline alone and a combination of the physical, biological, and social sciences that is required for the successful implementation and continuation of the water engineering projects. Because these projects often involve thousands of people from implementation to maintenance and to use and exploitation (Lund, 2015). Today, in addition to the severe climate changes and the associated effect on the hydrological cycles and paying attention to the fact that there are few watersheds on the planet that have been spared from positive or negative human impacts (mostly negative), it should be noted that social systems are also changing at a much faster rate. In such a situation, providing drinking water for the 6 billion population of this earth until the end of 2010 AD (Vogel et al., 2015) is an art mixed from different sciences and a combination of interdisciplines from hydrology and society. Therefore, as predicted 40 years ago by Matalas and his colleagues, a comprehensive view of water should be reached, and that is nothing but a change from the conventional paradigm to the active paradigm of social hydrology (Matalas et al., 1982).

Social hydrology studies, which were conducted by researchers in different classifications from 2012 onwards, continued in the three directions predicted by Sivapalan himself, and in the present study, in addition to the subject classification in three main axes, it was divided into each case study that is also discussed in these three perspectives (Sivapalan et al., 2012):

1. Historical social hydrology: This type of study generally investigates the distant and near history of water-man, the role of water in the rise and fall of civilizations, management and governance of water in the history of societies and human technologies in the direction of water management. The level of analysis in this category of studies is considered large.
2. Comparative social hydrology: It entails comparing the similarities and differences in water management and consumption in the different places, comparative study of human-water interactions according to the different social layers. Economic, climatic, and geographical and drawing spatial and regional differences are considered as the main goals of this axis, and the level of analysis is also considered "average".
3. Processive social hydrology: It conducts the time-spatial analyses at the level of small-scale/basin systems, conducting causal investigations and generating information about hydrological-sociological processes in order to understand the functioning of the human-water system at the present time and predict the path of possible changes in the future. One of the most important goals of this axis is that the level of analysis is small (Sivapalan et al., 2012).

3 Urban Socio-Hydrologic Flood and Drought Resilience

The expansion of urban areas, especially on the edges of rivers, on large alluvial cones or floodplains and alluvial plains and other geomorphological types, regardless of its effect on hydrological behaviors caused by land use change, changing the morphology of the landscape and especially, the significant reduction in water infiltration. Rainfall and the associated surface runoff into the soil has caused the potential of flood generation to increase in such areas.

In many cities, the uncontrolled and irregular growth of the urban area has taken place against the principles and rules of urban planning, and this has led to the emergence and of many urban problems. This population growth, urban development, and industrialization of communities leave the adverse effects on the hydrology of the watershed and lead to the intensification of floods. In other words, the main hydrological changes caused by urbanization and the type of land use in urban areas that can be summarized in the change in the total volume of runoff and nutrition caused by rainfall, as well as the change in the both amount of flooding and water quality. The most important effective factors in hydrological developments include the amount of impervious surfaces or lands in the basin as well as the characteristics of water flow paths, both of which have been changed significantly in areas that have undergone or are undergoing urban development, and also the source of these changes that are hydrological areas. Increasing the impervious levels of the area as a result of the expansion of urbanization, various constructions are made on the impermeability of the soils of the basin, which are able to absorb part of the rainfall and increase the volume and intensity of runoff, as well as the time of concentration. Paving surfaces act against rainwater infiltration into the soil and feeding the ground water table, as a result of which a greater part of each rainfall turns into the surface runoff and causes floods.

With the development of urban life and cities, the issue of managing urban areas has received more attention. The development of urban life has caused the irreparable damage to nature and has put many natural resources under threat, as well as the widespread floods in urban areas cause a lot of loss of life and money and destructive effects in natural form, water quality, and ecological values in urban areas. Therefore, examining technical considerations, challenges and limitations in urban flood management is one of the important issues in urban planning. Achieving sustainable urban development requires designing development models compatible with the environment. Watershed management is considered an applied knowledge for the sustainable use of biological resources in metropolises. Paying attention to urban watershed management as a sub-branch of watershed management is a necessity for urban management. In this regard, remote sensing technology can play the important and valuable role as an important tool in providing the spatial and descriptive information related to the place (Reyhani et al., 2017).

Due to the fact that the spatial development of cities is important in the process of decision-making and planning, therefore, determining the amount of spatial development over many years along with the expansion of the population and the type of land use and the allocation of land to the space of a city, it is necessary to investigate and determine the spatial development of cities. In fact, the Geographic Information System (GIS) is a computing system that has the ability to compile, prepare an information bank, analyze and display information spatially (Kuil et al., 2016). It could help the decision-makers and planners in this regard.

Focusing on the flood risk and developing risk management plans is imperative, but in the meantime, community understanding of risk is often neglected. An important aspect is this fact that the risk is perceived in different ways by scientists, decision-makers, and the general public. This same problem has also caused some flood management planning to fail in the past (Fuchs et al., 2017). The interactive effect between flood events and humans and the establishment of laws can be seen in many cases.

The flood of 2013 in Calgary, Canada generated $5 billion in damages, making it Canada's costliest natural disaster. The occurrence of this flood also had the significant effects on politics. The control of changes in land use for high-risk areas was intensified and new insurance laws were established for the landowners in the floodplains. The combination of human factors (urbanization, economic growth, and misgovernance) along with the natural forces (climate changes, droughts, and floods) has affected the Saskatchewan River Basin, Canada.

It is highly impressed that Gober and Wheater (2014) conducted a review of the nature and extent of their influence. The drought of 2001–2002 in the Saskatchewan River basin had also caused a severe economic impact in rural regions of Canada, but at the same time it led to a political opening in Alberta and through the "Water for Life" strategy, the preparations were made to modify the water allocation methods (Gober & Wheater, 2014). One of the tasks of multipurpose dams is the flood control and their use as the flood control structures, which is used to analyze their effectiveness. These multi-purpose dams should use the methods based on social hydrology. In order to address the existing research gap pertaining to the impact of structures on the economic and social conditions of downstream rivers, a recent study by Lee and Kang (2020) has undertaken a comprehensive investigation. This study takes into consideration various social factors, including population, land use, gross domestic product, as well as the damages caused by floods and droughts. Additionally, hydrological factors such as dam inflow and outflow, precipitation levels, and water demand are also considered in their modeling approach. By integrating these diverse factors, the study aims to provide a holistic understanding of the complex interactions between structures and downstream rivers, thereby shedding light on previously unexplored aspects within this field.

In the south of the Korea country, it was divided into the aforementioned Hoeng Seung factors through equations and placed in a ring, and then three different scenarios (maintaining the current conditions, extreme climatic conditions, and rapid urbanization) were applied, and in this way, a model for estimating System Dynamics has been presented. According to this, the built social hydrology model can be used well in the process of decision-making and optimal planning of water resources. To model the feedbacks between the humans and floodplains in a hypothetical case study, Viglione et al. (2014) used a relationship with four differential equations. They used these four simplified equations to describe economic, political, technical, and social factors and analyzed the most important feedbacks between the economic, political, technical, and hydrological processes in the evolution of a society with this model.

4 Conclusions

It should be confirmed that man is both the agent of development and the goal of development, and therefore, it will not be possible to create the sustainable development in any field except through serious attention to the human factor and the active and responsible participation in development programs. In this regard, one of the important obstacles to achieve the goals of sustainable development in the water sector is the vast technological progress in the water sector and to the same extent, the deficiency in sociological studies of this sector, that social hydrology can be a suitable solution in this field. This new approach, due to the special attention, pays to the human factor, under the condition of defining and implementing the extensive and detailed interdisciplinary joint projects consisting the experts in the fields of water and social sciences, is certainly far more than the theoretical and practical requirements for creating the sustainable development that will have in the field of water resources. Therefore, it is very necessary for interdisciplinary experts to carry out the fundamental joint research and use the advanced mathematical expressions to produce the models that are more compatible with the complex realities of the outside world and have the more accurate analytical and predictive power for human-water behavior, a suitable response to the challenges ahead. Applying basic scientific principles and conducting research in the field of hydrology is vital to develop a knowledge base that can facilitate progress and leverage the immense potential of this approach. This is particularly important in addressing the imminent challenges faced by the water sector, which is crucial for meeting the most fundamental human needs. It is predicted that competition between humans and natural ecosystems will escalate in numerous regions worldwide in the coming decades. In light of this, it becomes imperative to resolve conflicts and develop balanced strategies that accurately model the interaction between humans and natural ecosystems. In this context, social hydrology assumes a significant role in advanced modeling and should be duly considered, especially within the context of a changing climate. By incorporating social factors into hydrological models, a more comprehensive understanding can be achieved, leading to effective and sustainable water management strategies.

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Chapter 3
Fluvio-Geomorphic Hazard and Its Impact on Socio-economy: A Study on Resilience and Sustainability in Assam

Niranjan Bhattacharjee and Saeid Eslamian

Abstract Environment and development are essential from the beginning of human civilization on the surface of the earth. Among the other means of natural matter, water bodies play a unique role in the modification and development of socio-environmental scenarios especially in the third-world countries. The river has a close relationship with man since its inception on the surface of the earth. But, nowadays, the impacts of the increasing trend of urbanization on the physical environment are reflective, complicated, and are manifested at the local regional and global scale. The Brahmaputra valley suffers from flood every year and out of 22 districts, as many as 10 districts are severely, and the other 12 are moderately affected by the floods of the Brahmaputra and its tributaries. The floods in the entire Brahmaputra valley have rendered more and more multifarious problems in the socio-economic arena. The mighty Brahmaputra flows east to west from the southern part of the area. The location of the river basin area is conspicuously significant due to its favorable geo-climatic situation. The hazardous nature of Brahmaputra valley, especially the flood and bank erosion problems, is influenced by its geographical location, the scale of human activities along with morphometric characteristics. Floods in the Brahmaputra valley create various problems to the valley dwellers. It has been observed that while the Brahmaputra river has been an agent of devastating floods, high bank erosion and channel shifting, low to high sedimentation along the river channel, and depressed areas in its downstream on the south-western part of the district have also been of great concern. It is observed that during the last few decades or so there have arisen various kinds of problems related to the hydrological, geomorphological, and human regimes in the area caused hurdles for the economic development in the valley. Resilience and Sustainability are important

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tasks for the development of a country considering all physical hinder like flood and other fluvially associated problems in the state like Assam. Hence, there is a need for drastic action, despite the uncertainties of predicted changes; but action requires concrete context to facilitate anticipatory measures by the decision-makers.

Keywords Fluvio-Geomorphic Hazard · Socio-economy · Resilience · Sustainability · Assam

1 Introduction

Since the initiation of drainage above the surface of the earth, rivers have been forceful entities causing morphological changes in land and hydrological domains. Hydrological problems, especially the flood in some low-lying areas, mostly in moist climatic areas, have been fast growing to have their impacts on a number of morphological forms and patterns. Social aspects like ritual and belief are the problem-enhancing factors in few areas, mostly in underdeveloped countries. The alarming situation with rivers and floods as geomorphological agents in the state has caused serious social, geomorphic, hydrologic, and environmental problems. Floods are potentially damaging physical events, human activity, that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. All the natural and man-made hazards are not single, it is sequential or combined in their origin and effects. Each hazards are characterized by its location, magnitude, frequency, duration, speed of onset, and uncertainty.

Uncertainty or susceptibility is an issue of weakness in different elements when uncovered to a given hazard and is defined as a percentage or fractions of all the elements in a particular set of elements that will be exaggerated by a specific event. Based on elements at risk, vulnerability can be classified as physical, communal, attitudinal, environmental, and so on. Elements at risk may include human life, livelihood, livestock, living places, environment, etc. (Eslamian & Eslamian, 2022).

A grouping of all the forces and possessions is available within a community, society, or organization, which can reduce the level of uncertainty or the effect of any disaster. Capacity may include physical, institutional, social, or economic means as well as skilled personnel or collective attributes such as leadership and management.

A severe disturbance of the functioning of a community causing widespread human, material, economic, or environmental losses surpasses the ability of affected community to cope with its own resources. A disaster is a task of the risk process. The orderly process of using managerial decisions, organization and operational skills, capacities to implement the policies, guidelines, and coping capacities of the communities is to lessen the impacts of hazards. It comprises all activities including structural and non-structural measures to avoid, prevent, mitigate, and prepare against adverse effects of hazards.

Developed, developing, or underdeveloped countries have, of late, been one of the most attractive and heart-rending features of news items because of their hazardous nature. This hazard has variously affected the natural landscape and the habitat, society, culture, and economy of man in the flood-affected areas. In the developing countries like India and Bangladesh, floods, because of their chronic hazard effect, have invited the special attention of geomorphologists, hydrologists, engineers, environmentalists, and land managers as well for proper evaluation and estimation of floods and associated problems. Floods in the midst of geomorphic, geographic, hydrologic, environmental, ecological, economic, and communal significances have become by far the most important aspect of the investigation of their primary influences on land and soil, river bed, and banks, which ultimately influence the human habits, occupation, production, etc. in the region concerned. In the present world of high population and use of most modern technological devices on resources, floods are increasing day by day only to accelerate erosion, sedimentation, and other kinds of hazards (Fig. 3.1).

A drainage basin is the best unit for hydro-physical studies among many (Horton, 1945; Chorley, 1969), and bears significance in today's fluvio-geomorphological inquiry of channel network and drainage morphology along with flood events and their relationship with land, water, and man (Chorley, 1969). Bank erosion and channel shifting are the foremost problems in Assam due to the severe hydrological problem of a river system as it carries a huge amount of sediment from its catchment area on the one hand and river channel shifting on the other. Being in an unvarying process of changes, river basins are always an issue to the forces carried out in ecological, economic, social, and cultural aspects, i.e., the so-called "driving forces" of land use and land cover (LULC) change. The role of river basins as repositories of natural, environmental, and cultural resources along with capturing, channeling, regulating, and storing the freshwater for anthropogenic uses, makes them

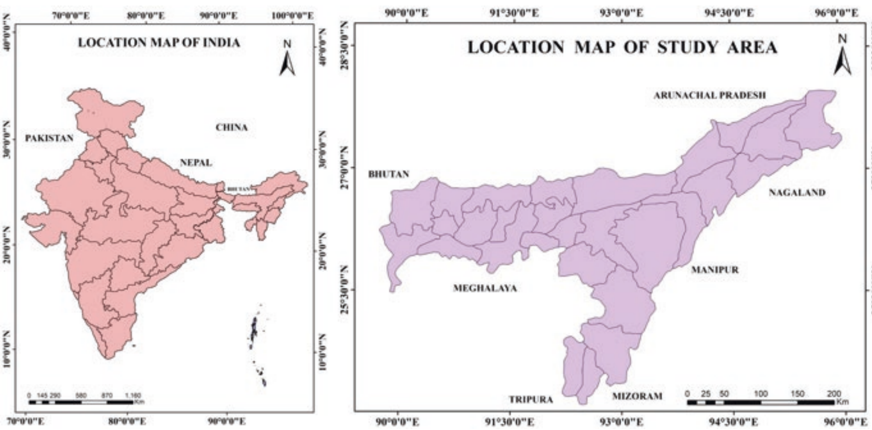

Fig. 3.1 Location of the study area

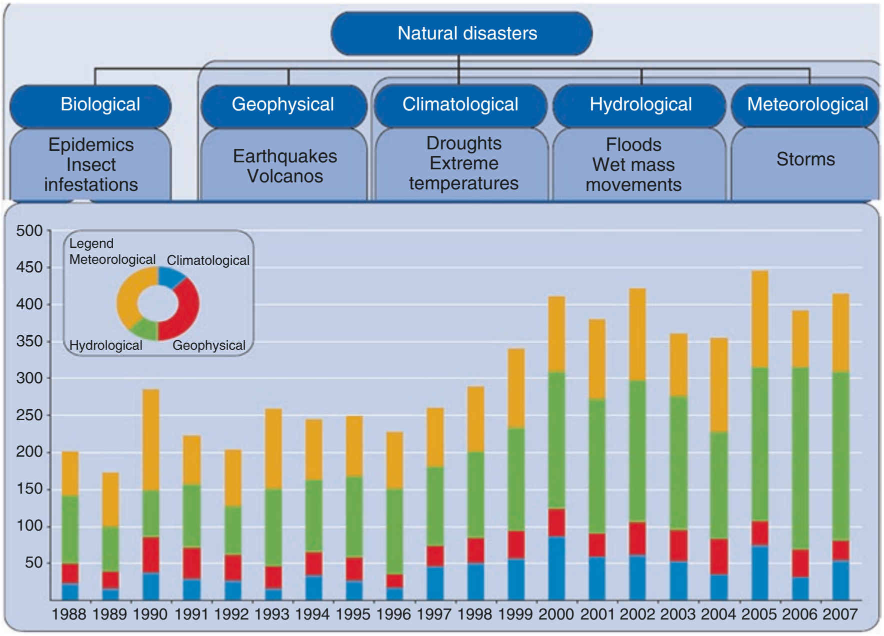

Fig. 3.2 Factors of natural disaster

multifunctional units in all perspectives, i.e., hydrological, biophysical, socio-economic, etc. Bank erosion and its effects on channel evolution are vital geomorphic research problems with relevance to many scientific and engineering fields (Sarkar et al., 2011).

The river Brahmaputra of Assam has a total of 41 major tributaries in the north bank and 26 in the south bank. Brahmaputra valley in Assam has occupied 56,000 sq. kilometer area which is rich with alluvial soil. The Brahmaputra river valley suffers from very high to medium flood almost in every year long durations. The economy of Assam basically depends on agriculture; almost 80% of peoples are engaged with primary economic activity in rural areas. Therefore, flood problem, i.e., socio-hydrological aspect is one of the major hindrances and challenges for the socio-economic development of Assam (Figs. 3.2, 3.3, and 3.4).

2 Geo-hydrological Scenario of Assam

Assam occupies 2.39% of India's landmass. Assam shares its internal boundaries with West Bengal, Nagaland, Tripura, Mizoram, and Arunachal Pradesh, while Bangladesh and China surround the international contours of the state. The state is extending from 22°19′ to 28°16′ North *latitude* and 89°42′ to 96°30′ East *longitude*.

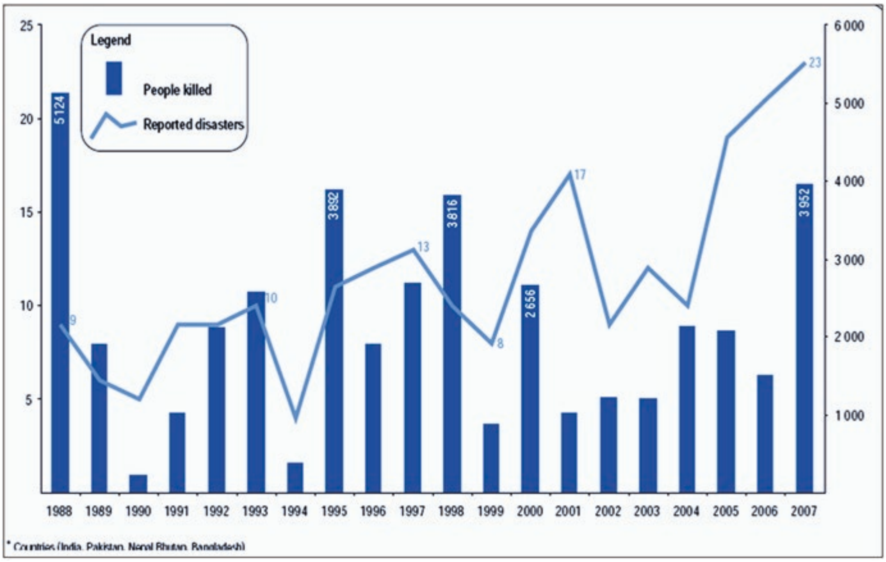

Fig. 3.3 Indian monsoon-related hydrological disaster (2 years trends in occurrence and mortality)

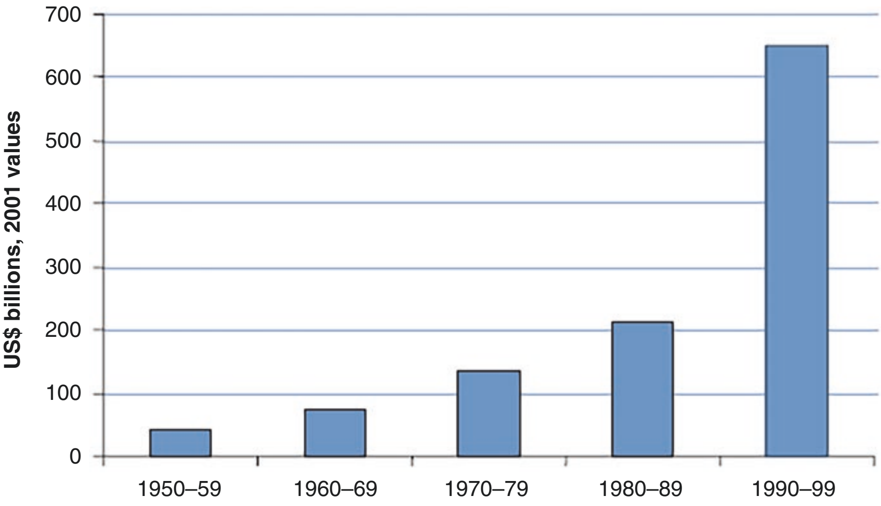

Fig. 3.4 Cost of disaster damage is rising. (Source: IMF-2003)

Its location in northeast India and its openness from the rest of India makes it the gateway to northeast India.

The Brahmaputra Valley of Assam is an alluvial plain (Goswami, 1985). It is about 724 km in length and 81 km in breadth. The loftiest Himalaya stands to its north and the Garo, Khasi, Jaintia, and Naga hills are to its south. The river Brahmaputra floods the nearby land with fertile silt every year, ensuring a rich harvest. To the south of the Brahmaputra Valley are the Karbi Anglong Hills and further south are the North Cachar Hills. The southern part of Assam is the Barak Valley. The rivers Brahmaputra, Barak, and their 120 tributaries ensure a fertile land dotted with more than 3500 wetlands, 800 expansive tea estates, and 25 major wildlife preserves housing to rare species of flora and fauna. The landform is gently sloping toward south of the Brahmaputra valley. Again, the middle part of the Brahmaputra valley is comparatively lower than the eastern and western part of the valley. Therefore, the Brahmaputra valley has been characterized unique material base, processes, and problems of the seven major tributaries. The geo-hydrology of the Brahmaputra valley have been modified by the collective effect of these rivers on geologic and surficial materials, geomorphic process along with human interference.

The endogenetic earth movement and their impact on the landforms of the Assam, especially in the Brahmaputra valley have been acting to a large extent as the basis of geo-hydrology of the area. Earthquakes of high magnitudes and intensities have always their roles to make land surface up and down or damage river beds, thereby modifying the land surface and river planform of the districts are alike other parts of the Brahmaputra valley it was very shoddily affected by the great 1897 and 1950 earthquakes. Goswami (1985) described that a large amount of the sediment generated by landslides due to the earthquake of 1950. These sediments were to redeposit in a different way to the rivers, thereby raising the beds of the rivers considerably. It is found that in many places along the courses of the rivers, for example, many areas of the Pagladiya and Pahumara basins got down by 3–4 m below the ground surface. Some portions, it is observed in the field that along the intfluves of the tributary rivers in the north and south bank of the mighty Brahmaputra river got depressed by about 5 m.

Along with surface water, groundwater level also plays a significant role in the study of geo-hydrological behavior of an area like Assam. The Assam Remote Sensing Application Centre (ARSAC), the Central Ground Water Board, and the Department of Geology and Mining, Assam have conducted some works on the groundwater condition of parts of North-East India.

The groundwater condition in the study area reveals that there are many factors influencing the groundwater stipulation in the valley. The impact of climate and terrain characteristics is found to a more prominent role in this case. The groundwater conditions in the area vary from region to region. Here in this work a study on the seasonal ranges of groundwater levels in the four physiographic units or zones, viz. foothill zone, tarai zone, built-up zone, and the active floodplain zone is discussed. The active floodplain in the extreme south of the region is recharged with shallow groundwater levels ranging from 1 m to more than 4 m. In the district, the depth of water table is gradually declining as the slopes of the surface rise south to north.

The built-up plain in the north of the active flood plain has been recognized as a partially recharged zone having water table at a relatively high depth ranging within 1.98–8.05 m below the surface of the ground.

In the piedmont plain, which is composed of unconsolidated materials of varying sizes, there exist groundwater levels at additional depth ranging from 2.08 m to

11.16 m below the ground surface. This fraction of the geomorphic land of the study area has very good recharge during the period of heavy downpour in the monsoon months. Groundwater reveals that the slope of the water tables in the old alluvium and piedmont zones is steeper than that of the alluvial plains near the river channels. Again in the foothill area there exist ground water levels at depth ranging from 2.08 m to more than 16 m below the ground surface. The fluctuation of the water table in the Tarai and built-up plains lies within 2 m. The depth of water table gradually decreases from the foothills to the active flood plains mainly because of decrease of both the absolute and relative reliefs as well as of the decrease of land slope. The whole of the Brahmaputra valley, especially the flood plain and chronically flood-affected areas near the river banks, have been spotted by wetlands (locally known as *beels*), swamps and marshes of different shapes, sizes, and depths. All the wetlands, areas, though now under stressed condition, favor passing of flood water during the rainy season. Of all the wetland areas with stagnant water in Assam, *beels* are by far the most prominent ones. These beels are characterized by comparatively less deep water (depth ranging from about 1 m to more than 3 m) within the coverage of about 1755 hectares to more than 70,695 hectares of land. The *beels* in the study area like other parts of the river valley stand as great valuable part of the surface toward ecological, environmental, geomorphic, and economic significances (Fig. 3.5).

According to the origin of the *beels,* they may be classified into three main types, viz. that (i) formed out of abandoned courses of the streams, (ii) dug by strong floods, and (iii) formed due to tectonic influence. It is worth mentioning that in the area there are lots of man-made tanks recognized wetlands or water bodies. Most of these tanks are now in the process of heavy silting caused by floods as found near the Brahmaputra valley.

Soil plays a vital role as a basic element of natural and cultural environment and also as the basic factor of riverbank and valley erosion. The flood plains of the Brahmaputra valley are formed by alluvial soils of recent river deposits (Goswami, 1985). Though on the basis of micro characteristics, the soils of the Darrang district may be classified into a number of types, they can be considered of being of more or less similar ingredients at the macro level. Among the various types of soil, the new alluvial, i.e., flood deposited soils are available in the entire Brahmaputra valley causing high rates of bank erosion and channel shifting (Figs. 3.6, 3.7 and 3.8).

The Brahmaputra River, counted among world's top ten large and branching mega-rivers (Lahiri & Sinha, 2014; Latrubesse, 2008), occupies the position of the seventh-largest tropical river in terms of mean annual discharge (20,000 m^3/s in Bangladesh) (Lahiri & Sinha, 2014; Latrubesse, 2008). As a trans-Himalayan river, the Brahmaputra glides through the narrow valley of Assam also known as the Brahmaputra valley with an east-west extension of ~720 km and an average width of ~80 km (Goswami, 1985; Bora, 2004) (Fig. 3.9).

The total drainage area of the Brahmaputra River from source to the confluence point with the Ganga River in Bangladesh is ~580,000 km^2 (293,000 km^2 in China, 195,000 km^2 in India, 45,000 km^2 in Bhutan and 47,000 km^2 in Bangladesh) (Sarma, 2005). Enrich with the Brahmaputra river system and its numerous tributaries, Assam has been witnessing frequent and regular flood along with riverbank erosion.

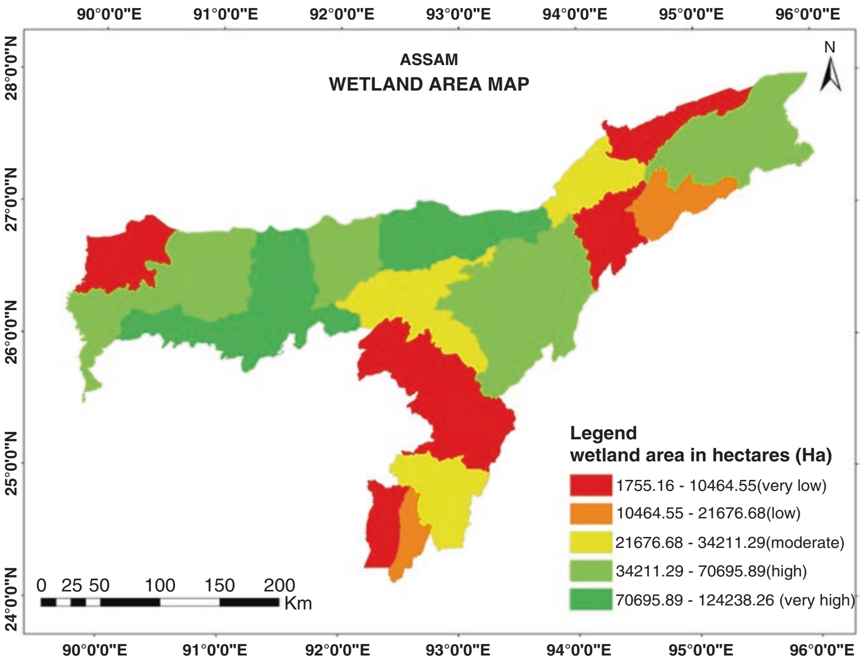

Fig. 3.5 Wetland area of Assam

Being situated amidst the riparian environment of the Brahmaputra valley. Every year, during the monsoon season the Subansiri River in the north and the southern branch of Brahmaputra River in the south are inundated by high to medium fluvially associated problems like flood and river bank erosion (Fig. 3.10).

Assam has undergone a number of geologic and geo-environmental disturbances because of its structural framework. Brahmaputra valley has notable tributaries like Kapili, Subansiri, Pagladia, Manas, Jia Bharali, etc. are pass as anticedent river, and the basins are greatly faced by number of problems in the form of earthquake, landslide, channel shifting flood, etc. The valley receives heavy rainfall in the monsoon period amounting annually from 2300 mm up to 5000 mm. Because of heavy incessant downpour in the valley there have been acute problems of flood, siltation, and river bank erosion. The material yield on the beds and basins of the rivers and their behavior constitute integral part of the dynamics of river mechanics. Knighton (1984) pointed out that bank erosion is one of the principal means of supply of sediment supply to streams. The riverbed in the Brahmaputra valley has been experiencing high sedimentation and floods mainly because of high debris-yielding weathering and denudation in many parts of the basins in the Eastern Himalaya. Schumm (1956), Fairbridge (1968), and Goswami (1985) have also estimated the denudation rates of the Eastern Himalaya.

Flood in the Brahmaputra river is a regular event. The flood waves generally are recurring four to five times annually. The basin in India, particularly its valley in

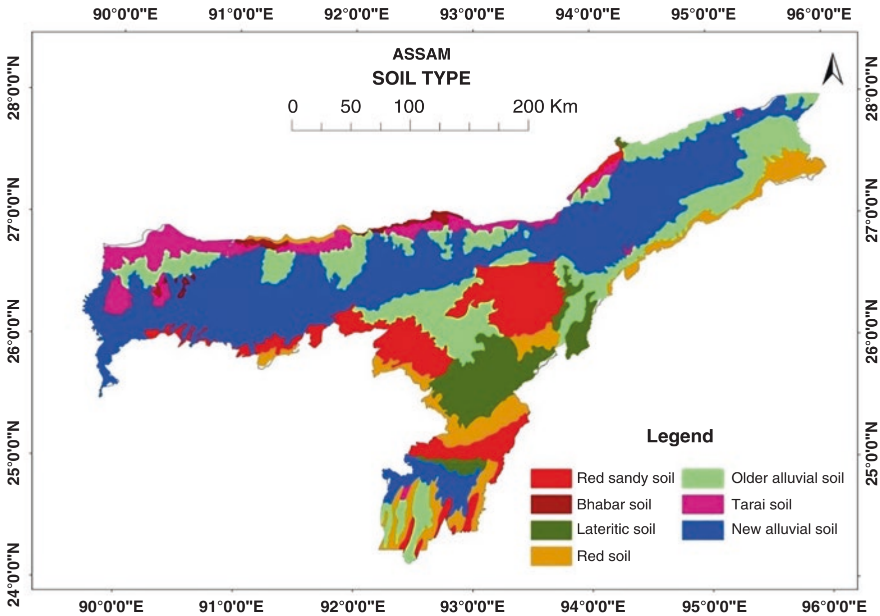

Fig. 3.6 Soil type of Assam

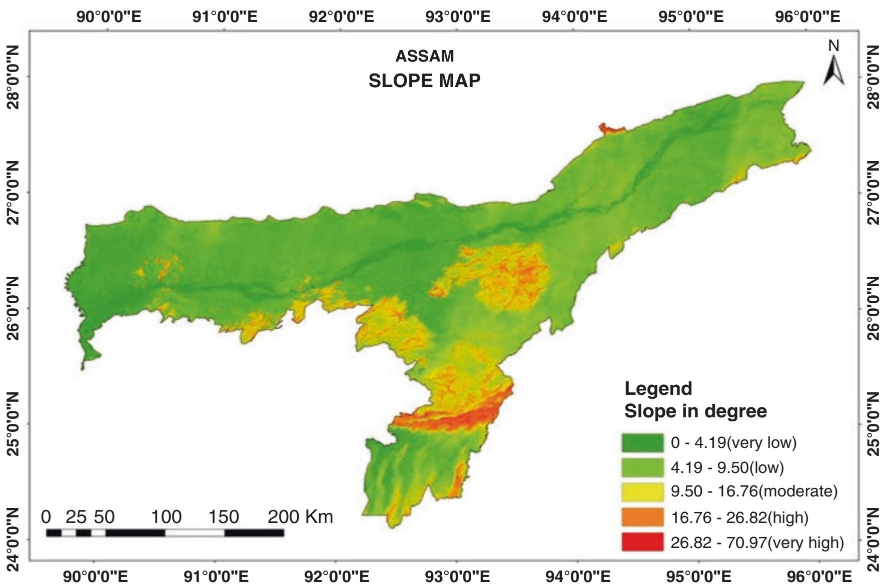

Fig. 3.7 Slope map

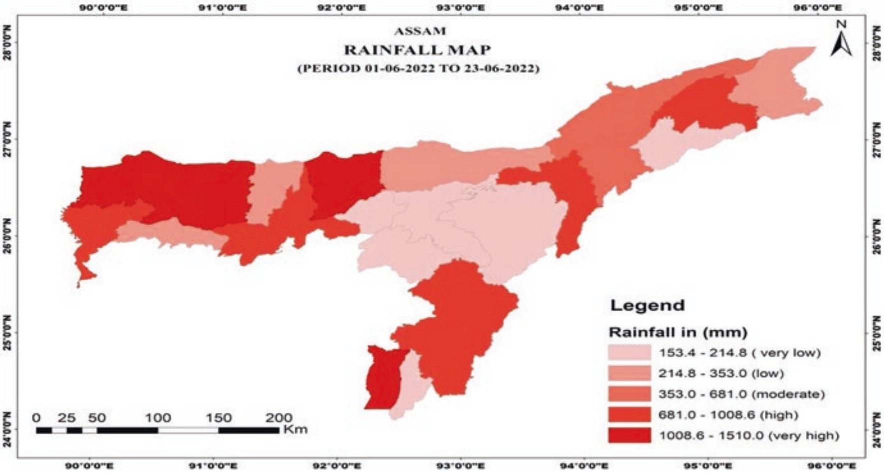

Fig. 3.8 Rainfall map

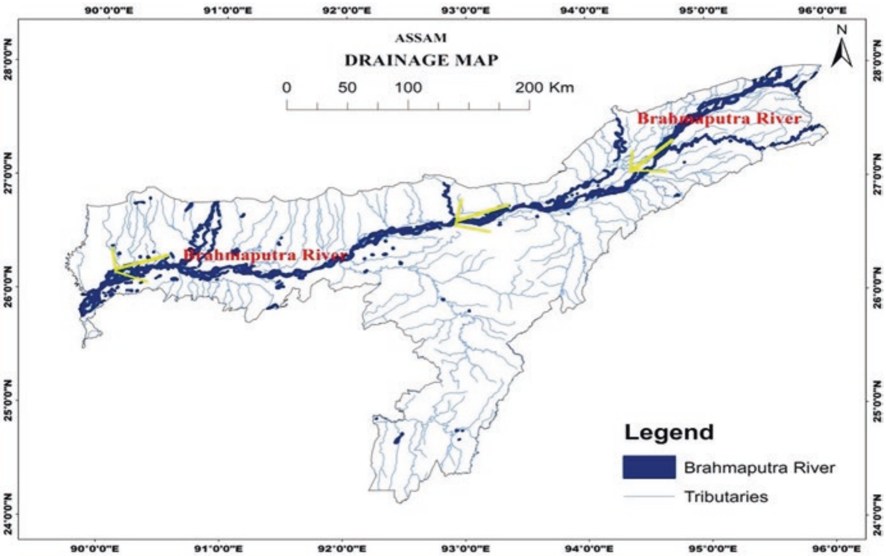

Fig. 3.9 Drainage map of Assam

Assam, represents an acutely flood-prone region characterized by flood-associated problems causing loss and damage of life and property. The valley is surrounded by hills and plateaus and therefore environmentally sensitive to floods. Assam has a total flood-prone area of more than 3.40 million hectares of land. The dimension of river strength and erosion of land due to floods in the district can be judged from the governments record that during 1954–2003, more than 4 lakh hectares of plain land

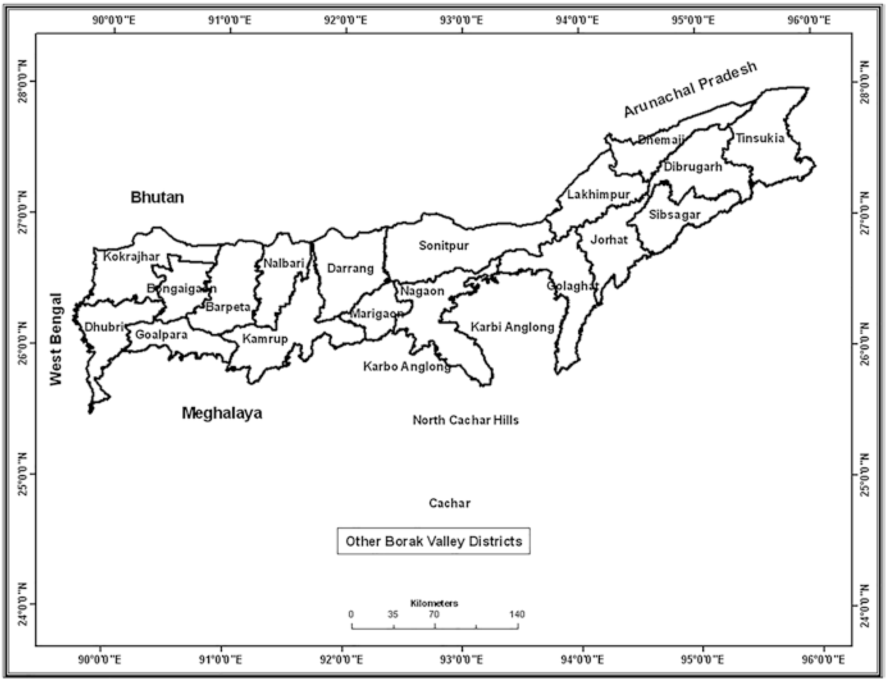

Fig. 3.10 Brahmaputra valley

(equivalent to 4000 sq.km or 6.70% of the plain areas in Assam) in Assam were eaten away by the monsoon floods (Water Resource Dept, Government of Assam, 2003). Due to rains and floods during 2003 (Provisional, as of 10-07-2003) in the entire valley, 2614 villages were affected and a total of 18.18 lakh people were severely affected. Here, it is again mentioned that floods and their impact on land and people have been historically. Historical record (Gait, 1905, reprint of second edition, 1926) reveals that the severe earthquake of 1897 caused heavy siltation along the river beds in lower Assam and very high flood was observed.

3 Hydrological Mayhem in Brahmaputra Valley and Its Impact

The Brahmaputra river system covers as much as an area of 184.2 thousand sq.km flowing along with 120 major tributaries on both banks. The entire Brahmaputra valley falls under the monsoon regime of South East Asia (Goswami, 1985). The syntaxial bend of the Eastern Himalaya in the east of the basin and processes of evolution of the Purbanchal have their far-reaching impact of the geologic events and landform make up in the basin. Geologically, the river basin is formed mostly of recent alluvial deposits that rested along and across the foredeep (Krishnan, 1982) of the Tethys sea, giving rise to the Siwalik river and its basin according to Pilgrim or the Indo-Brahm according to Pasco.

The river originates from the Himalaya (Kailash ranges) which transverses east through the southern part of China and enters into eastern India; the upper part of the Brahmaputra river discharge mostly comes from the snowmelt before it enters Arunachal Pradesh. The river experiences with heavy rainfall in Arunachal Pradesh and Meghalaya, which contributes substantially to the river flow. As a result the river carries a huge amount of discharge along with to the plain region, i.e., Brahmaputra valley. That type of character experiences high to medium flood in the lower part of the basin, which disturbed the entire hydraulic regime. In Brahmaputra river system the flood and bank erosion is a very common factor which is always provoking by the monsoon climate (heavy rain). Due to the severe flood, almost every year the lower part of the basin faced heavy lost in terms of life and property than any other river of the country. The Barak river basin is the second largest river system in the Northeastern region, which is extending up to Bangladesh. The river Barak slopes down from 2995 m in its origin, 1355 at Jiribum (Manipur) to 68 m at Silchar in Assam. During the entire course the river system mainly fed by the rainwater. So, during monsoon period (April–September) the region experienced high to medium flood along with bank erosion problems. Apart from these some other hydrological systems in the region like Tuivai in the Manipur and Mizoram, Dhaleswari-Katakhalin Mizoram, Surma, and Chindwin-Irrawaddy also received high spates of rainfall during the monsoon season causing huge damage of life and property through the means of flood and bank erosion.

The flood events' different magnitudes and durations clearly indicate their differential impacts on the landform developments (taking flood as geomorphic agent) along and across the valley. The change of landforms of the basin is related to the energy of the rivers. The energy of the river, on the other hand, is controlled by a number of factors as mentioned above (Fig. 3.11).

3.1 Changes of River Valley

Erodility of banks and basins is the function of numbers of factors such as the intensity of rainfall, supply of surface waters, infiltration and saturation levels of soil, physical and chemical properties that control the disintegration and decomposition of rock materials and vegetation cover (Leopold et al., 1964). Sheet erosion in the basin is associated with laminar flow of water on the surface which is smooth or slightly rough. It has been observed that a large volume of fine particles are being concentrated along and across the channels of the Brahmaputra river basin during flood times. Setting of more and more sediments along the channels contributes to more and more overland flows during flood storms. Most of the riverbeds in the

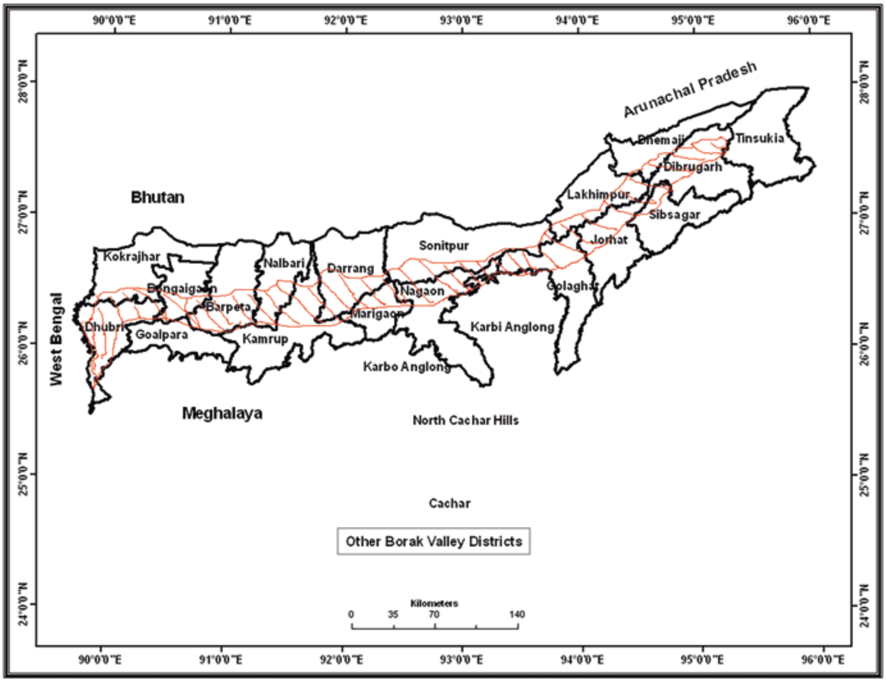

Fig. 3.11 Brahmaputra Valley, Flood-affected Areas

Brahmaputra valley including all districts have been experiencing increasing sedimentation and floods mainly because of high debris-yielding weathering and denudation in many parts of the basins in the Eastern Himalaya. Denudation rates on the Eastern Himalaya are estimated by Lyell (1873), Menard (1961), Schumm (1956), Fairbridge (1968) (Fig. 3.12).

The shifting of channels has caused a change of landform characteristics. The channel shifting has changed the fluvio-geomorphic situation and environment of the basin.

Bank erosion not only along the Brahmaputra river, but also along the major tributaries of the river basin has added an important aspect in the fluvio-geomorphic characteristics of the basin landform. The mighty Brahmaputra has been flowing with meanderings almost in its entire course where sedimentation acts as one of the major factors for change of fluvially developed landform. Moreover, human beings are always recognized as an important agent in the change or modification of landform.

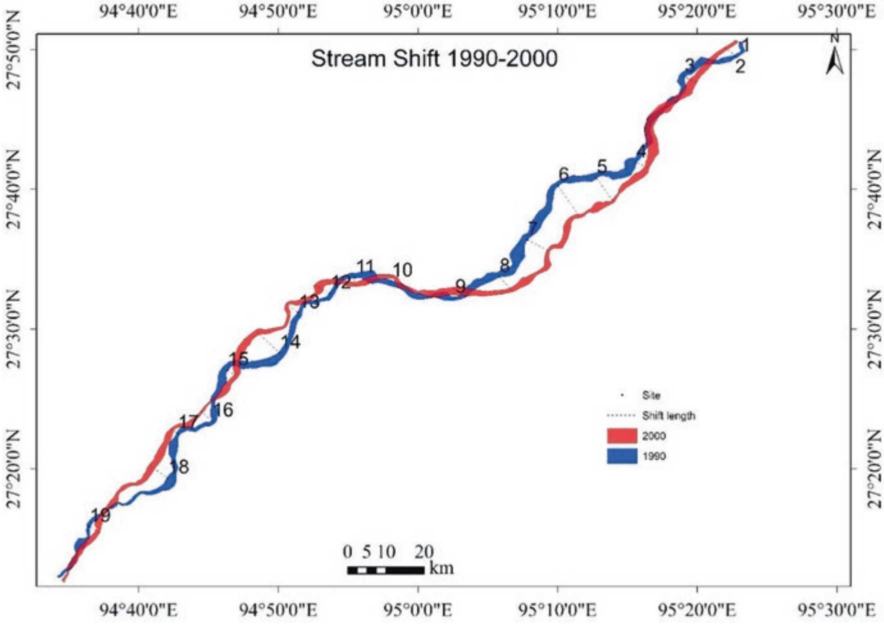

Fig. 3.12 Channel shifting of the upstream of the Brahmaputra River

4 Hydro-geomorphic Impact on Socio-economic Development

The word rural development is the process of enhancing the standard of living and economic well-being of people living in relatively isolated and sparsely populated areas. Nowadays, rural areas are highly influenced by the globalization concept and economic networking with urban centers. Education, entrepreneurship, physical infrastructure, and social infrastructure all play an important role in developing rural regions. Rural development is also characterized by its emphasis on locally produced economic development. As the Assam is a motherland of the river so its economy is also highly related to water. One of the most important areas in rural development is agriculture. Entire valley is formed by very fertile soil, i.e., old and newly formed alluvium soil. Many steps have been taken to improve the agriculture, especially in the interior parts of the villages.

The economic growth of any area is based essentially on its agriculture. The locational factors, characteristics of the transport network, and the structure of the past and present economy are the major attributes of the socio-cultural situation of the area. The growth and distribution of settlements maintained a close relation with the availability and productivity of land. The economy of Assam is predominantly based on agriculture. More than 80% of the population are engaged directly or indirectly in agriculture. It is interesting to note that unlike the most parts of the world, the multiple cropping is also practiced in Assam valley. It reflects far far-reaching impact of the frequent occurrence of flood on agricultural land, especially on the southwestern part of the Brahmaputra Valley. The tribal prefers to settle mostly in the forest and riverine environment which may help them in maintaining their occupational pursuits of a traditional nature, such as duck rearing, pig rearing, firewood collection, and fishing. Likewise the indigenous non-tribal and the schedule castes people do not exhibit any specific land use character. On the other hand, the Muslim peasants of erstwhile East Pakistani immigrant origin are concentrated in the low-lying and the sedimented (Locally known as *char*) areas of the district. This is the only group of people who could settle on the active flood plains. They know how to adopt with the riverine topography of low-lying nature. The multiple cropping is a common practice in this part of the landscape of the study area.

5 Fluvio-Geomorphic Resilience and Sustainability

The various facts about floods in the district area are simple in appearance, but very complex and serious in nature. Floods in the districts could modify patterns of development and aspirations of the people. The problem of flood has adverse effect on landform development even as flood behaves as a boon in some cases among the peasants.

An in-depth study on the line of flood and bank erosion problem is of outmost necessity to draw out the genesis and nature of flood hazard and its impact on the modification of landform in the Brahmaputra valley. The facts and phenomena of flood hazard and its impact, intensity, and magnitude if analyzed properly may help planners to work efficiently for flood and floodplain management in the way of good production from land and water leading ultimately high-grade sustainability of the flood plain and alluvial plain dwellers in particular.

Even as much a problem and mitigation of floods in the valley is addressed through well-adequate interpretation, exploration, and analysis, many more things as regards their complexity are to be seriously considered. These new lines may fulfill some of the goals and objectives of academic interests and practical solutions. As such the following points may take effective berths.

Well-organized and planned efforts are necessary to investigate the various facts of flood problems in the valley and their good effects may be conducted to minimize the problems. To begin the sustainability of the land and people of the region there lies the urgent need of flood hazard study and conducive management of flood, floodplain, and people's perception.

Healthy designed networks most up-to-date efficiency, each of rainfall, water discharge and levels along with sediment discharge at optimum numbers of sites and stations be prepared and assessment of order, functioning the records done without delay. Well-organized efforts are required to quantitatively identify and evaluate in detail the behavior of the channels for the cause of effective planning and functioning of the river regimes through river training, anti-erosion and channel diversion works, etc. Also a holistic approach should be made to check the bank erosion and channel shifting in the future. The pattern of water flow in terms of qualities and quantity along with sediments discharge affecting the channels and basins of the rivers are to be studied so as to understand and manage the disturbing rivers and their basins.

The flood warning system, including constant monitoring of dangerous levels of floods, is required very urgently. For this purpose, a study on the modern line is to be conducted. An integrated study of landforms, discharges of water and sediments, and climatic influences should be made in order to meet the needful demands of alleviating or eradicating flood problems. Appropriate practical steps as regards river training by shortening or streamlining meanders and draining away waters from the water logging areas are to be taken urgently.

6 Conclusions

The Brahmaputra being the most troublesome river, causing routine devastating flood floods, river bank erosion and channel shifting of high significance needs detailed studies.

Dredging along the channel of some rivers is to be regularly done to clear out and make the channel efficient where and when required. This can be done through a project.

Degradation of forests, both on the banks and basins of the rivers, is to be checked, and works on a forestation are to be encouraged in the upstream parts of the river.

The government should remain vigilant for emergency rescue and relief of the people from floods during the rainy seasons. Furthermore, the victims must be financially helped and the loss should be compensated by means like insurance of crops, properties, etc.

For this an action group should be ready for assessment and monitoring of the flood situation. At the same time a cell for flood damage monitoring and estimating the value should be established in the line adopted by the NCAER (National Council of Applied Economic Research).

Obligatory steps and follow-up action shall have to be made to train up the flood plain dwellers with the indulgent of eco adjustment on the one hand, and to save the land from flood and erosion disaster caused at the time of heavy downpour on the other. All these need glowing strategies in consideration of the topographic, hydrologic, geomorphic, and socio-economic factors in the district area.

Evidently this migration is a push factor occurring due to the declining opportunity in agriculture. It has been noted that displaced women have higher levels of perceived stress than the non-displaced counterpart. Bank erosion also affects property and belongings. Basically, there are two types of measures for bank protection:

(a) structural measures like long spur and dredging, channelization of flow and (b) non-structural measures like installation and dissemination of advance warning system, rehabilitation, and resettlement of the people away from river bank, prevention of agriculture and cattle grazing near the bank erosion site, afforestation work along the river bank.

Preventive and protective measures to arrest bank erosion in the vicinity of the barrage, adopted by the State Irrigation Department (SID) and FBA are (i) long-spurs, (ii) bull-headed submersible spurs, and (iii) revetment of the river.

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Part II
Climate Change Impacts, Adaptation Strategy and Education

Chapter 4
Effect of Climate Change on the Agricultural System of Hirakud Command Area

Ashutosh Rath, Ayan Mishra, Saroj Kumar Nikhindia, and Subhashree Panda

Abstract Drastic alteration in the climatic conditions is increasingly affecting people's livelihood. The research here examines the influence of climatic variation on the agriculture system of the Hirakud command area and inspects proposals to combat this situation. Data has been collected for the last 40 years that is 1981–2021 from National Informatics Centre (NIC), Indian Meteorological Department (IMD), Customized Rainfall Information System (CRIS), and Water Resource Information System (WRIS) to describe the trends in climatic factors and examine the effect of variations of climate on the yield of the crop. Principal Component Analysis (PCA) was performed using the STATISTICA tool which showed that the temperature is the most influential factor on the climatic model. Thus the temperature is affecting the crop production the most. Considering the increase in population and food demand, the need is to produce sufficient food to satisfy the food demand in the near future that is around 10 years down the line. Population was forecasted using the arithmetic increase method for the year 2031. Cropwater requirement of the crops is calculated using CROPWAT 8.0 software. The land use and land cover pattern was devised using the Geographic Information System to analyze the amount of culturable command area and culturable uncultivated area present. The outcome of the study showed that about 34% of culturable cultivated area is still not cultivated though it is fit for agricultural purposes. Temperature is considered to be a crucial weather element for climate change. The statistical tests such as Mann-Kendall (MK) and SEN'S Slope Estimator test were conducted in this work to study the variability and long-term trends. The average temperatures of 12 years are considered for analysis. A significant trend (at 95% confidence level) was identified in the station with a slope value of 0.273. The findings of the research are significant and this work has addressed long-standing burning issues of the society and is a novel step in the right direction.

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Keywords Principal component analysis · CROPWAT · Mann-Kendall · Sen's slope

1 Introduction

Due to climate change and the continuous rapid increase in population, there is an urgent need to increase crop production. Considering the Hirakud command area as the study area, effective methodologies have been adopted to perform trend prediction, food demand, and irrigation demand to calculate the culturable command area present for crop cultivation in the future (Banihashemi et al., 2021). Climatic variables are taken into consideration to analyze the factor which is the most influential one. Trend prediction is done to forecast the values of variables in the upcoming years and as per the area available cropping pattern plans can be devised. Optimized use of land is done to enhance the yield of crops to satisfy the demands possessed by the future. One of the major challenges the people of the study area are facing in the recent times are in starvation and undernourishment. The system needs to address the issues of variations in climate, degradation of environment, and to chalk out a plan for the nourishment of the people. By enhancing nutrition as well as mitigating traces of the network of food which can be done by assorting deliverables of food is pivotal. Plan of action for the food safety concerns, "sustainable intensification" is a procedure of pushing the productivity of the crops without compromising the rights of the next generation to utilize the shore. The picture is hazy that onto which capacity "sustainable intensification" would grant the human beings to assure the requirement of nutriment. Cropping pattern is defined as the section of land for raising a variety of crops at certain periods. Any alteration would result: Discrepancy in land having diversified crops Variations in crop productivity. The condition of the climate in coordination with hydrological model and Soil and Water Assessment Tool (SWAT) to study the influence of change in climatic condition on stream flow were studied (Etchevers et al., 2002; Jha et al., 2004). The RCM simulation to study the remarkable growth of rainfall in winter on the Cevennes region was studied by Quintana et al. (2010). The application HEC-HMS 3.4 to study the effect of the climatic change on the water Resources system was studied at specific locations (Meenu et al., 2012) applied in Tunga-Bhadra River to scrutinize the climatic variation on water resources in River basin.). A study was conducted on climatic variations in the Mahanadi basin with the help of statistics and analyzing the past of climate by Mann-Kendall and Sen's slope test (Samantaray et al., 2018). Research on Spatial-temporal Patterns of Land use/Land cover change in the Bhutan–Bengal Foothill Region was also done (Chamling & Bera, 2020**).** A similar type of study was also done for analyzing land use/land cover changes and its dynamics using remote sensing and GIS in Gubalafito district, Northeastern Ethiopia (Abebe et al., 2022). Some of the important contributions to this specific field were recorded from Aik et al. (2020), Sun and Li (2017), Chuai et al. (2016), Van der Sluis et al. (2016), Song et al. (2015), Sharma et al. (2012). Kumar and Sinha (2010), Shrestha et al. (2008), Brown et al. (2005), Eslamian et al. (2019), Zhang et al. (2019), and Gutierrez et al. (2019).

The objective of the work is to provide a cropping pattern that can increase the crop yield by providing additional cultivated area using the existing land cover of the study area. The cropping pattern, crop water requirement and irrigation scheduling are done using the CROPWAT tool. Further land use and land cover classification are done using Geographic Information System and prediction of future population by doing population forecasting using arithmetic mean method. The statistical tests such as Mann-Kendall (MK) and Sen's Slope estimator test were conducted in this work to study the variability and long-term trends.

2 Study Area

The adopted region for analysis is a chunk of the Hirakud canal of western Odisha as shown in Fig. 4.1. Trait of the concerned place is that it is sub-humid with clime on a hotter side, also having some cold with varying levels of rain. Humidity remains higher during monsoon and lower in summers. Generally, the mean monthly minimum daily temperatures are the lowest in the month of January. From February onwards the temperature starts rising uniformly till April. The relative humidity during monsoon season varies from 75% to 90%. The average annual rainfall of the command area is approximately 1250 mm, and the average number of rainy days for the district is 65. Approximately 90% of the rainfall is received during monsoon season (mid-June to mid-October). The district that receives rainfall during South-West monsoon period is the principal source of rainfall. Two crops are prevalent that is Kharif and Rabi. Rice is the indispensable crop. Around 158,961 ha of culturable command area exists. Soils available in Sambalpur are

- Ulti soils.
- Alfi soils. This area is rich in culture and heritage. Considering the rapid population growth, climate change, and simultaneous decrease in yield of crops, it was felt necessary to improve the irrigation system and cropping pattern. Hence the study area was chosen for experimentation.
- The water from the Hirakud reservoir is used for different purposes like irrigation, hydropower generation, industrial use, and water supply. The amount of water used for water supply is very less as compared to other purposes.

3 Methodology

The following tools are adopted in this study for analysis. The salient features of the methods and the algorithms are presented to give a broad understanding of the methods.

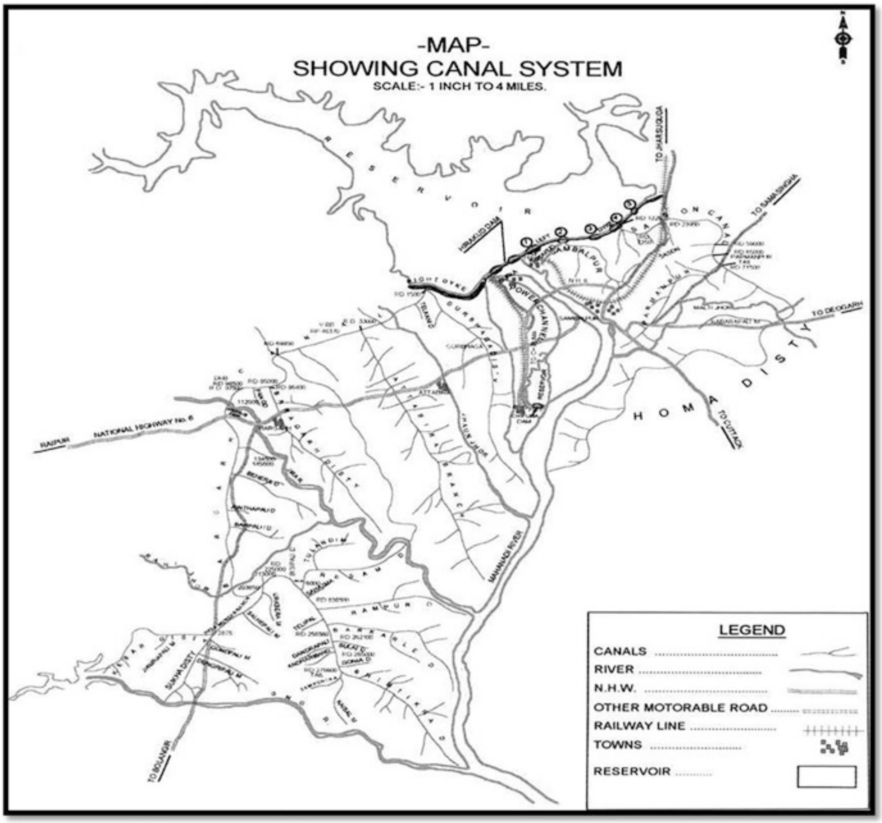


Fig. 4.1 Hirakud dam and its canal system

It describes the process of moving from one standard to comparatively a higher standard. In this work assessment of crop water requirements, measurement of quantity of water supplied have been done. Figure 4.2 describes the details of the methodology applied in the study. Timely supply of water to the agricultural field as per the demand of crops is the major challenge. The National Crime Records Bureau data shows that due to crop failure, there is reoccurrence in the cases of farmers' suicides followed by hue and cries in the State and the Country. Growth in the yield of crops per unit of land is the need of the day to overcome these challenges.

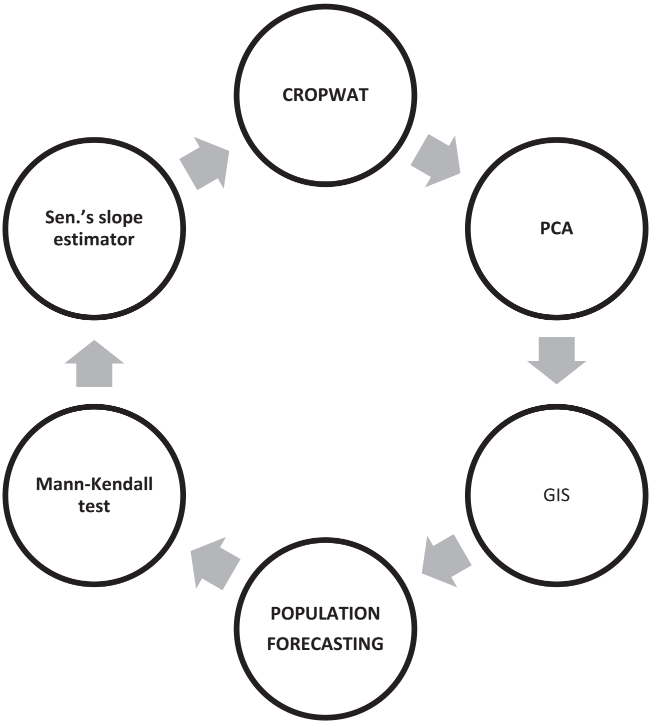


Fig. 4.2 Flow chart for combined methodology

3.1 Principal Component Analysis (PCA)

It is a methodology in which dimensions can be reduced without modifying the features of the original data and keeping the data diversification as low as possible.

STATISTICA
This software was developed to assist in the process of analysis and manage the data for proper visualization of the process.

PCA in STATISTICA
This process is helpful in data analysis by minimizing the data loss and increasing the interpretability. It is a useful tool in the data predictive model. The following steps are followed in the case of a PCA model:

1. Organization of data and calculation of the mean of the data. Calculate the empirical mean.
2. Determination and rearrangement of the eigenvectors and eigenvalues of the respective covariance matrix.
3. Projection of the z-scores to determine the degree of confidence level.

3.2 CROPWAT: 8.0 Software

The water required for the prevailing cropping pattern of the study area is determined by applying CROPWAT: 8.0 software, considering the climatic and soil data. Further, it helps in developing the irrigation schedules for different crops of the study area. The various features of CROPWAT 8.0 are described below.

- To calculate ETO the climatic data for daily, 10 days interval, and monthly are considered as input.
- The absence of some measured climatic data can be predicted.
- Irrigation scheduling and crop water requirements are determined based on some updated calculation.
- As output the soil water balance is calculated on a daily basis.
- Input climatic data, crop water requirements, and irrigation schedules can be presented graphically.
- Provision to conduct the sensitivity analysis.

3.2.1 Crop Water Requirement

Water is a vital cog in the appropriate heightening and development of the crops. The total water required by the crops from sowing to harvesting varies with the types of crops as well as with the places as per the soil and climatic properties. The crop water requirements depend on the rate of evapotranspiration.

CROPWAT based on the Penman-Monteith Equation is given as.

$$ET_o = \frac{0.408\Delta\left(R_n - G\right) + y\dfrac{900}{T+273}u_2\left(e_s - e_a\right)}{\Delta + y\left(1 + 0.34u_2\right)} \tag{4.1}$$

where

"ETo indicates evapo-transpiration [cm or mm/day], R_n is the exclusive radiation from the surface covered with crop surface [MJ m−2 day−1], G stands for soil heat flux density [MJ per m^2 per day], T indicates the air temperature at 2 m height [°C], u_2 shows the speed of the wind measured at a height of 2.0 m from ground surface[m/s], the saturation(e_s) and actual vapor pressure (e_a) are expressed as [kPa], Δ shows slope of the vapor pressure curve [kPa °C−1], ¥ is psychometric constant unit is [kPa °C−1]".

3.3 Land Use Land Cover in GIS (LULC Classification)

GIS is a tool that captures, stores, analyzes, and presents data that are linked to a location. GIS system can be viewed as an integration of three components: hardware and software, data, and people.

Esri ArcGIS,Google Earth Pro, BatchGeo, Google Maps API., ArcGIS Online, Maptitude. ArcGIS Pro and Statistica are the soft- wares through which analysis of can be done. Further, handling and correlation data also can be performed. GIS is a computer-based tool that is applied to create interactive queries and analyze the spatial information output. Land cover: It provides the information related to the various physical coverage of the Earth's surface, such as forests, grasslands, croplands, lakes, etc.

The survey includes both spatial and non-spatial datasets. It plays an important role in planning, management, and monitoring.

LULC classification is one of the most widely used applications. The most commonly used approaches include:

(a) Unsupervised Classification *(calculated by software).*
The analysis is based on software analysis of an image. The process involves the grouping of pixels with common characteristics. The user can select the suitable algorithm for the software to get desire output.
(b) Supervised Classification *(human-guided).*
In this process, a user has the option to select sample pixels in an image which represent a specific classes to direct the image processing software. Training sites (or input classes) are selected based on the knowledge of the user.

3.4 Mann-Kendall Test

Trend analysis is used to detect the trends in the time series analysis of the temperature data.

Mann-Kendall test was suggested by Kendall for testing the non-linear trend.

Let x_1, x_2, x_3………………. . x_n represents the "n" data points and "i", "j" be two sets of data. Then the Mann-Kendall (MK) test is expressed by a formula:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sign\left(x_j - x_i\right) \tag{4.2}$$

The application of the trend test to a time series x_i, that i = 1, 2,……………… $(n - 1)$, and x_j, ranged from $j = i + 1$……………..n. Each of the data point x_i is taken as a reference point which is compared with the rest data point x_j, so that

$$Sign\left(x_j - x_i\right) = \begin{Bmatrix} +1, > \left(x_j - x_i\right) \\ 0 = \left(x_j - x_i\right) \end{Bmatrix} \\ -1 < \left(x_j - x_i\right) \tag{4.3}$$

The variance data set is calculated by

$$Var(\mathrm{S}) = \frac{\mathrm{n}(\mathrm{n}-1)(2\mathrm{n}+5) - \sum_{i=1}^{m} t_i (t_i - 1)(2t_i + 5)}{18} \quad (4.4)$$

The variance of the data set is calculated by:

$$\mathrm{Z} = \frac{\mathrm{S} \pm 1}{Var\sqrt{S}} \quad (4.5)$$

The term $S - 1$ is used if $S > 0$, $S + 1$ is used if the value of the $S < 0$ and the value of the "Z" is zero if $S = 0$. Further the positive value of the "Z" indicates the trend is increasing, but the negative value of the Z indicates the trend is decreasing (Table 4.1).

3.5 Sen's Slope Estimator

The magnitude of the trend is predicted by Sen's slope estimator.

The slope (T_i) of all data pairs. $i = 1,2,3\ldots\ldots\ldots\ldots N$, where the x_i and x_n are considered as data values at time j and k ($j > k$).

The meridian value of the N value of T_i is represented as Sen's slope estimator which is given by

$$Q_i = \frac{(x_j - x_i)}{j - 1}, i = 1,2,3\ldots\ldots N, \quad (4.6)$$

Table 4.1 Determination of confidence level

Confidence level	[Z Value]
90	1.65
91	1.7
92	1.75
93	1.81
94	1.88
95	1.96
96	2.05
97	2.17
98	2.33
99	2.58

The terms x_j and x_i are the data values at the time j and i respectively. If "n" valuesof the x_j in the time series will be considered then the value of the $N = \frac{n(n-1)}{2}$ slope estimates. N = the number of pairs of time series elements

The value of the Q_i is sorted from the smallest value to the greatest value. The Sen's slope median is calculated as follows:

$$Q_{med} = \left\{ \begin{array}{c} Q_{\frac{(N+1)}{2}} \\ \text{If } N \text{ is odd} \\ \text{and} \\ \left. Q_{\frac{N+1}{2}} + Q_N \middle/ 2 \right/ 2 \\ \text{If } \; N \text{ is even.} \end{array} \right\} \quad (4.7)$$

The positive value of the "Q_i" indicates the trend is increasing, but the negative value of the Q_i indicates the trend is decreasing.

4 Results and Discussion

Principal component analysis was performed in STATISTICA and the results were analyzed accordingly. Water requirement of crops was being calculated using CROPWAT and a cropping pattern was devised. The land use land cover pattern was obtained of the Sambalpur district using the geographic information system to know the gross command area and culturable command area value.

4.1 PCA in STATISTICA

The principal component analysis was performed in STATISTICA considering all the climate data in the period 1981–2021. A correlation between two pairs of variables was obtained as shown in Fig. 4.3.

Variable 5 and variable 10 are maximum temperature and intensity of solar radiation respectively. Variable 8 and variable 9 are wind speed and relative humidity respectively as shown in Table 4.2.

Positive coefficient shows direct relation and negative coefficient shows indirect relation. This shows there exists some relation between these pairs of variables. After performing analysis the importance values of the considered climatic factors were obtained. The variable 5 (maximum temperature) got the highest importance with a power of 0.866842 which shows that it is the most influential factor of the considered model.

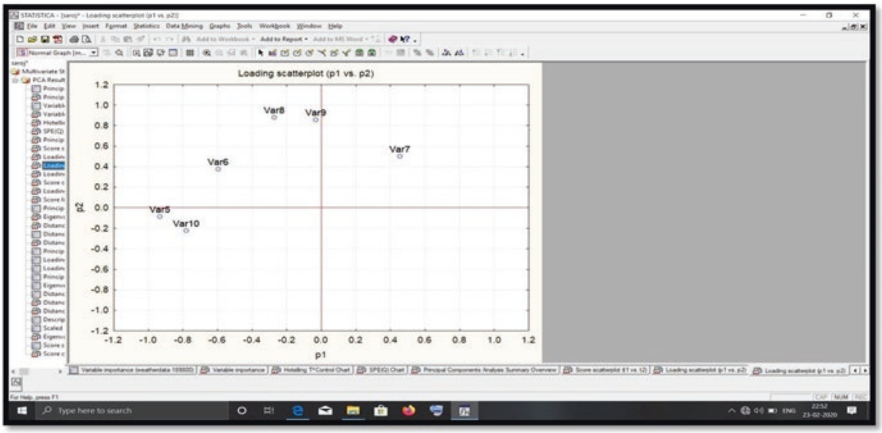


Fig. 4.3 Loading scatter plot between two principal components

Table 4.2 Climatic parameters and correlation coefficient value

Parameters	Correlation coefficient
Maximum temperature and solar intensity	+0.6421
Wind speed and relative humidity	−0.1032

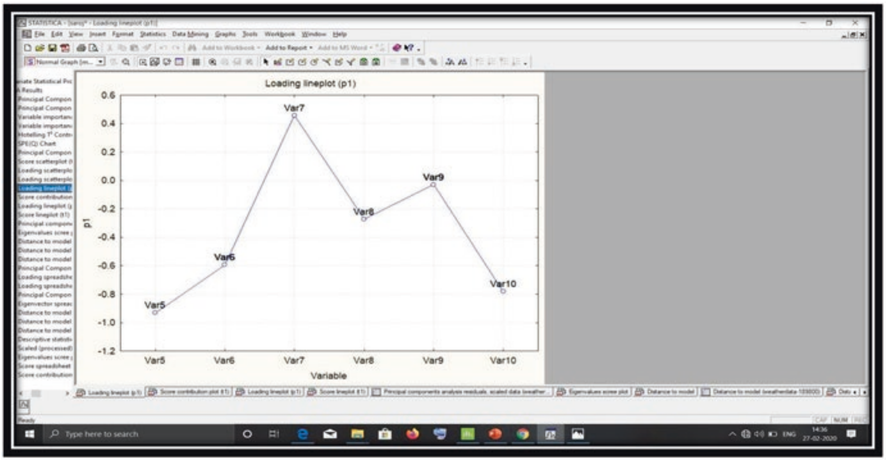


Fig. 4.4 Loading line plot between p1 and variables

In Fig. 4.4 the variable which is far most from the 0 value in the Y-axis is the most influential variable. Considering the curve variable 5(maximum temperature) is the far-most point of a value around 0.95 approximately. This proves that maximum temperature is the most influential factor in the considered model.

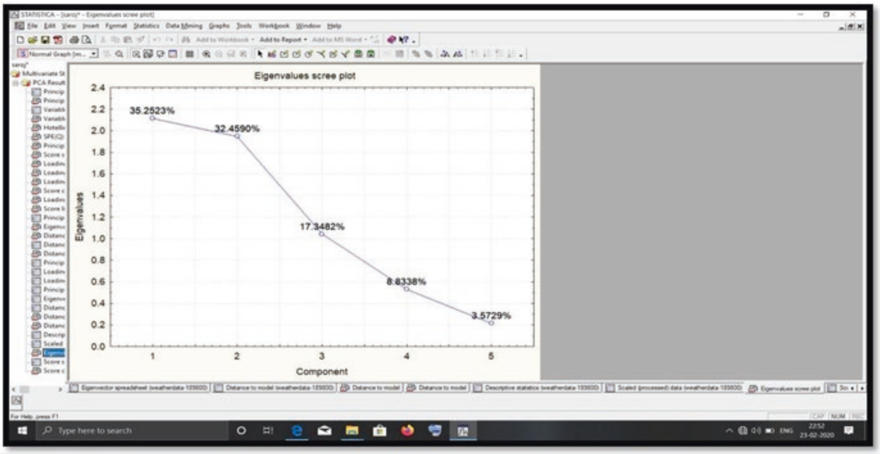


Fig. 4.5 Graph showing component 1 having the highest percentage of variation

The most influential variable causes maximum variation in the model. The maximum temperature being the most influential one produces a variation of 35.2523% in the model (Fig. 4.5).

4.2 LULC in Geographic Information System

The land use land cover pattern of Sambalpur district was obtained to identify the gross command area and culturable command area. The classification was done according to the type of land cover. The categorization helped in calculating the gross command area and culturable command area value. The results are shown in Tables 4.3 and 4.4.

The results from the study can be summarized that the change in the land use pattern is due to rapid growth in the Industrialization in the study area resulting in urbanization and afforestation. The changes have affected both the environment and society. The changes from 2000 to 2010 and 2010 to 2021 are very similar because of development of industries and commercial sector.

GIS application helps to visualize the trend of land use pattern and the shape file of Sambalpur is shown in (Fig. 4.6). The study area has been divided into the following: (1) water bodies, (2) barren land, (3) vegetation, (4) land having construction activities. LULC maps are suitable for better analysis. The overall accuracy of the images is high. It provides in (Figs. 4.7 and 4.8) the insight of spatial distribution of the changes that occur in the land use pattern.

Table 4.3 Land use land cover value of Sambalpur district

Type of land	Area (square kilometer)
Savannas	995.37
Grasslands	338.94
Permanent wetlands	14.59
Croplands	2755.57
Urban and built-up lands	38.85
Cropland/natural vegetation mosaics	140.38
Barren land	6.01
Water bodies	86.72

Table 4.4 Details of the command areas

Type of command area	Area (square kilometer)
Gross command area	4377
Culturable command area	4230
Culturable uncultivated area	1475

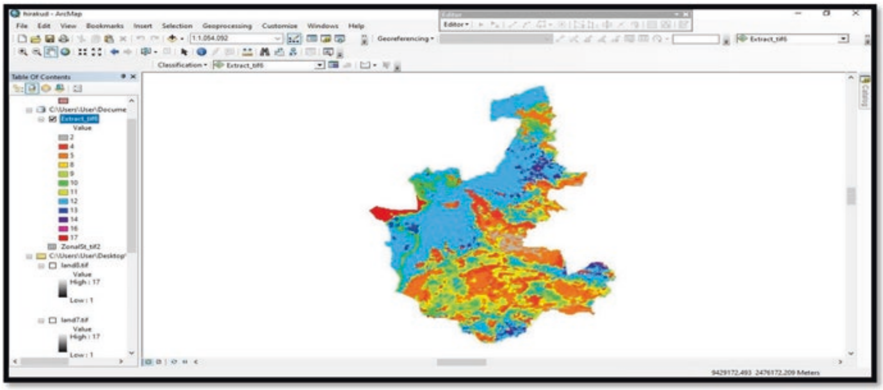


Fig. 4.6 Shape files of Sambalpur district

4.3 Population Forecasting

In this method, the average increase in population per decade is calculated from the past census report.

$$Pn = po + nX \tag{4.8}$$

where,

Pn = population at nth decade. po = population of last given decade.
N = (decade population asked-last known decade population)/10 X = average number of increases in population.

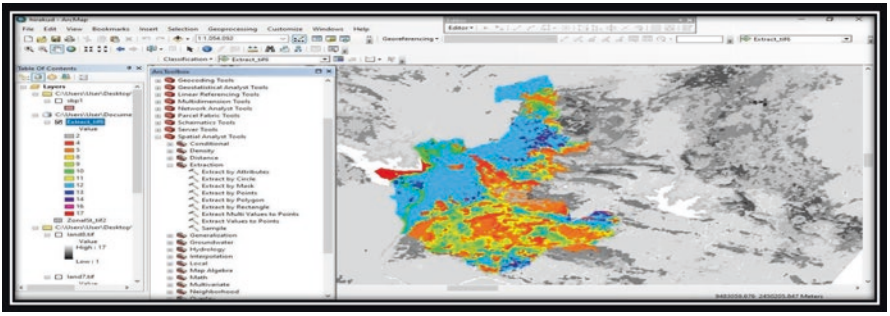


Fig. 4.7 Extract by mask process in GIS

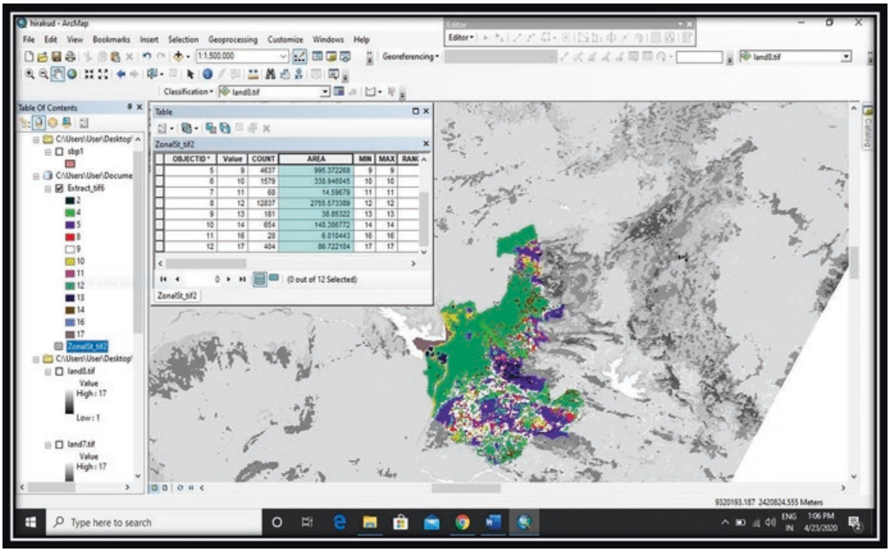


Fig. 4.8 Areas of different types of land with their identification values

The year-wise populations of Sambalpur are given below.

Year	Population
2001	936,000
2011	1,041,000
2021	1,251,000

The population of 2031 is calculated and found to be 1,408,500.

4.4 Water Requirement of Crops and Irrigation Scheduling Using CROPWAT

During CROPWAT 8.0 analysis input data are climate/ETo data, Rainfall data, soil condition, and crop details like yield response, crop height, Kc and Kp value and the output are from this input data crop water requirement (CWR), crop irrigation schedule. Image showing input to output result of considered variables. The other "meteorological parameters" used for calculation of ETo are latitude, longitude and altitude" of the station, maximum and minimum temperature (°C), maximum and minimum relative humidity (%), wind speed (km/day), and duration of sunshine (hours) (Fig. 4.9).

The crop water requirements and the irrigation requirement of rice during different stages like developing stage, mid stage, and end stages are calculated. The irrigation requirement is maximum during May (Fig. 4.10). This is because of the reason that in the month of May, relatively the humidity is very low; the temperature is very high and the climate is dry; but in the month of July, it is minimum (zero) because in the month of July, rainy season continues and hence the humidity is more and the temperature is low.

As an illustration the crop scheduling and the crop water requirements of rice are presented in Fig. 4.11. Evapotranspiration requirements of crop at various stages and the irrigation requirements. It is revealed from the figure that during the month of May the evapotranspiration requirement is highest. The crop evapotranspiration need of rice is presented in Fig. 4.10. The efficiency of the irrigation schedule is 100%. The field capacity of the soil to retain water (mm), readily available moisture, content and the total available moisture of the soil at different stages of the growth of the crop are presented in the graph. Soil water depletion recorded is found to be

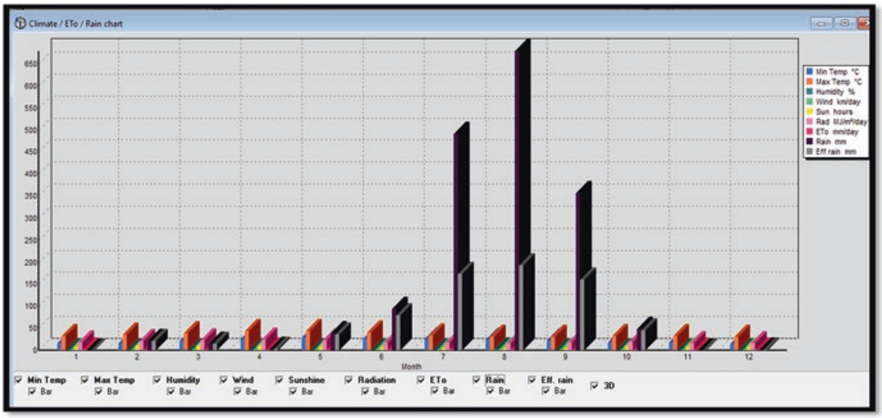
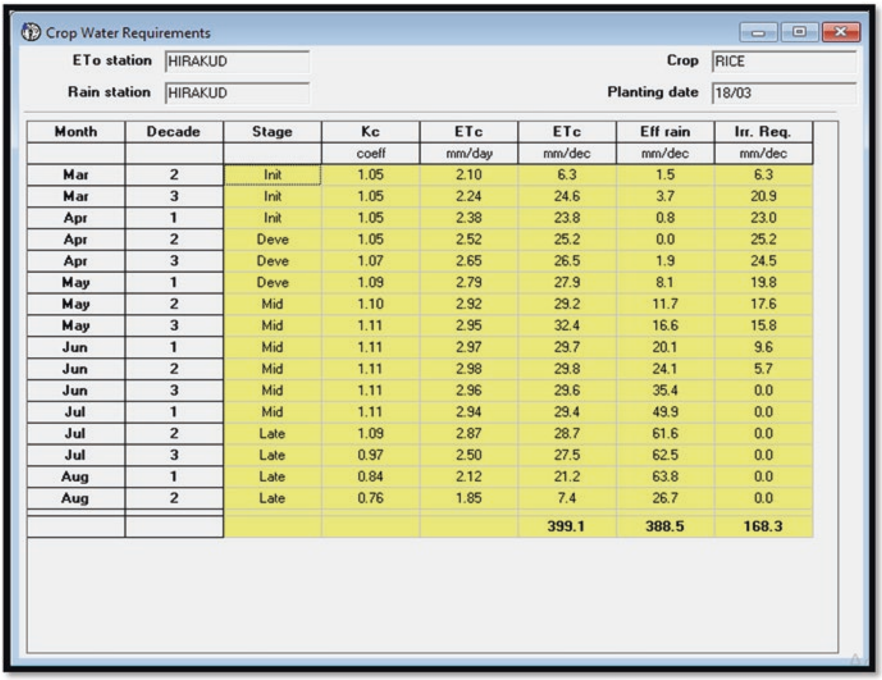


Fig. 4.9 Monthly values of input and output variables



Crop Water Requirements

ETo station: HIRAKUD | Crop: RICE

Rain station: HIRAKUD | Planting date: 18/03

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Mar	2	Init	1.05	2.10	6.3	1.5	6.3
Mar	3	Init	1.05	2.24	24.6	3.7	20.9
Apr	1	Init	1.05	2.38	23.8	0.8	23.0
Apr	2	Deve	1.05	2.52	25.2	0.0	25.2
Apr	3	Deve	1.07	2.65	26.5	1.9	24.5
May	1	Deve	1.09	2.79	27.9	8.1	19.8
May	2	Mid	1.10	2.92	29.2	11.7	17.6
May	3	Mid	1.11	2.95	32.4	16.6	15.8
Jun	1	Mid	1.11	2.97	29.7	20.1	9.6
Jun	2	Mid	1.11	2.98	29.8	24.1	5.7
Jun	3	Mid	1.11	2.96	29.6	35.4	0.0
Jul	1	Mid	1.11	2.94	29.4	49.9	0.0
Jul	2	Late	1.09	2.87	28.7	61.6	0.0
Jul	3	Late	0.97	2.50	27.5	62.5	0.0
Aug	1	Late	0.84	2.12	21.2	63.8	0.0
Aug	2	Late	0.76	1.85	7.4	26.7	0.0
					399.1	388.5	168.3

Fig. 4.10 Crop water requirement of rice (Kharif crop)

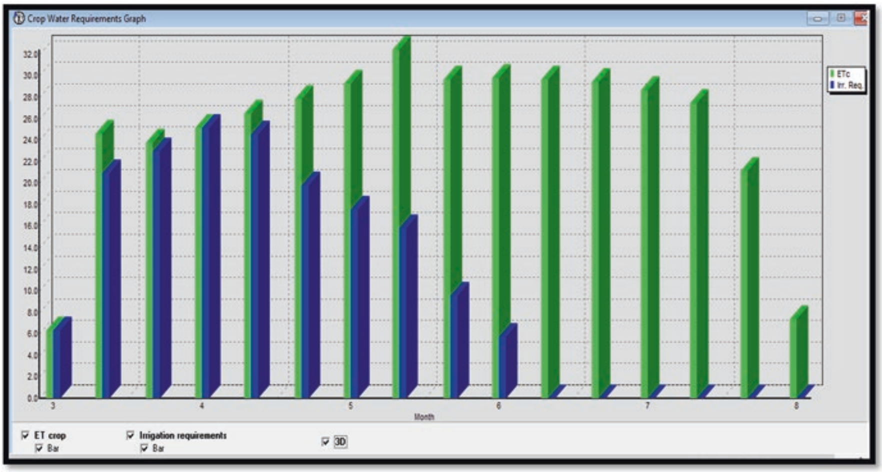


Fig. 4.11 Crop water requirement graph of rice

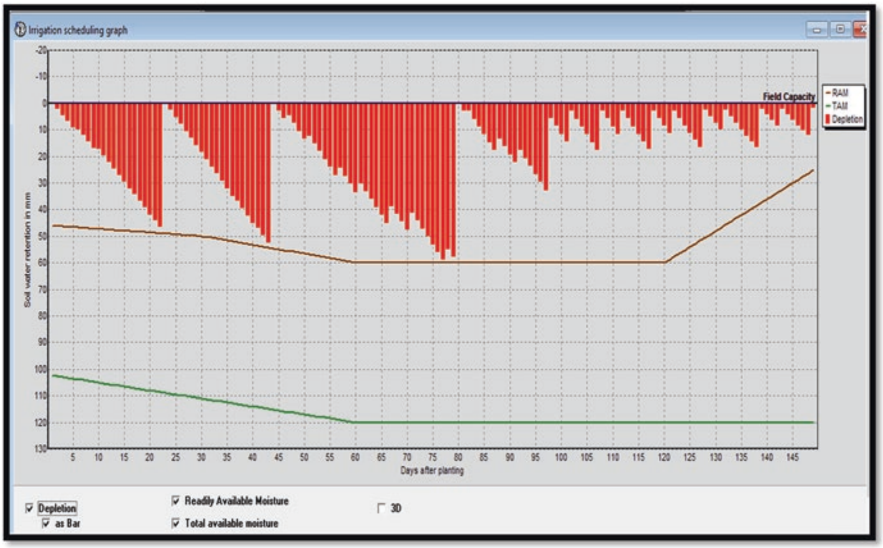


Fig. 4.12 Irrigation schedule of rice

increased with time elapsed after irrigating the land, up to the next watering. From the figure, the frequency of the irrigation is revealed. The field capacity is 100% and the maximum depletion is recorded to be 73%.

The gross irrigation requirement is recorded to be maximum as 104 mm at the end stage.

4.5 Mann-Kendall Test and Sen's Slope Estimator

In the present study, trend of most significant factor, i.e., the climatic change was reviewed for the study area by applying the statistical tools such as Mann-Kendall (MK) and Sen's slope estimator test. The Mann-Kendall (MK) and Sen's slope estimator test results generally demonstrate trends of the climatic factor(temperature). A significant trend (confidence level at 95%) was noticed with a slope of 0.273, as shown in Fig. 4.12. Similarly applying the formula of Sen's slope estimator test the slope is found to be 0.275 which is almost the same (Fig. 4.13).

5 Conclusions

From the above results and discussions, it is revealed that the maximum temperature is the most influential factor among all the climatic factors and disturbs the climatic model the most. By performing land use land cover in geographic information system, 1475 square kilometers culturable uncultivated area is present. The population

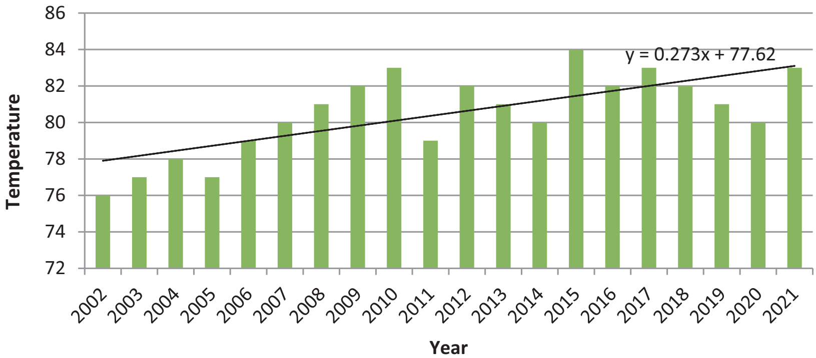


Fig. 4.13 The Mann-Kendall (MK) tests for the analysis of the temperature data

forecasting predicted the population to reach 1,408,500 by 2031 and cropping pattern can be devised using CROPWAT software for meeting crop water requirement and irrigation scheduling. The STATISTICA tool helped to simplify the enormous number of data of the considered variables and by performing the principal component analysis the maximum temperature was found to be the most influential factor of the considered climatic model. The Mann-Kendall (MK) and Sen's slope estimator test results generally demonstrate trends of temperature. A significant trend (confidence level at 95%) was noticed with a slope of 0.273. The outcome of the study showed that about 34% of culturable cultivated area is still not cultivated though it is fit for agricultural purposes. The cropping pattern can be prepared with this extra area available for crop production activities. The extra area available can act as a cushion to support crop yield and to meet the food demand in the near future. Further, the process of forecasting methods can be applied for better analysis and comparisons to obtain a more accurate result. The findings of the research are significant and will be of great importance not only for the researchers but also will help the farmers to improve their standard of living and to address long-standing burning issues of the society.

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Chapter 5
Mitigating the Negative Effects of Plastic Pollution for Sustainable Economic Growth in Nigeria

Benjamin Anabaraonye, Temidayo Olowoyeye, and Charles C. Anukwonke

Abstract Plastic pollution is a leading global environmental challenge negatively affecting Nigeria's economic growth and sustainable development. The high population density, consumption pattern and technological developments are among the significant factors contributing to Nigeria's increasing quantity of plastic waste generated annually. This chapter examined current progress with "Mitigating the negative effects of plastic pollution for sustainable economic growth in Nigeria" through existing literature review and data collection from relevant agencies. This chapter identified technological innovation, policy formulation, advocacy and sensitization, bioremediation as some of the approaches currently used to mitigate plastic pollution in Nigeria. This chapter also highlighted the need to encourage, enhance, and disseminate scientific research on mitigating the harmful effects of plastic pollution in Nigeria. It concluded with a clarion call for people at all levels to play their part in correctly disposing of plastic waste, which will go a long way to reducing the menace of plastic pollution in Nigeria.

Keywords Bio-remediation · Climate Change · Economic Growth · Mitigation · Plastic Pollution

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1 Introduction

Plastic is a generic term for polymeric materials that may contain other substances (additives) to improve efficiency, reduce cost and produce desired colour (Hahladakis et al., 2018). Plastic has become one of the most widespread and globally used materials, and thus gives rise to 9% in increased global production per year since 1950, attaining 367 million tonnes per annum in 2020 (Plastics Europe, 2021). Plastics are organic polymers (synthetic or semi-synthetic) that are lightweight, robust, durable and low cost (Van Eygen et al., 2017). Due to their unique key characteristics, plastics have become integral to everyday human life. Derived from a wide range of synthetic polymeric materials from fossil hydrocarbons, such as PET or PETE (polyethene terephthalate), HDPE (high-density polyethene), PVC (polyvinyl chloride), LDPE (low-density polyethene), PP (polypropylene) or PS (polystyrene), plastics are designed to meet varying needs of thousands of end products (Leal et al., 2021). Kings and Queens, Servants and Masters, Peasants and Paupers, Young and Old will find something useful to do with plastics in our twenty-first century. According to Bourguignon (2017), plastic materials are primarily classified into three groups based on their physical attributes, which include: i) thermosets (hard plastics that cannot be re-melted and reshaped), ii) thermoplastics (plastics that can be re-melted back into a liquid and reshaped or recycled repeatedly), and iii) elastomers (soft elastic plastic). The practice of accumulating plastic objects and particles in the Earth's environment that adversely affects aquatic life, wildlife, wildlife habitat, animals and humans is called plastic pollution (Britannica, 2013; Laura, 2018). Plastic pollution can also be defined as the indiscriminate disposal of plastic waste, which constitutes a nuisance to the environment, thereby inhibiting sustainable development. Plastic pollution has become such a severe problem in Nigeria that it has practically become a sign of human activity. Many people who visit beaches, riverbanks, parks, and waterfalls frequently dump their plastic bottles carelessly, despite the dangers that such plastics pose to the environment (Chironda, 2022; Okolo et al., 2022). At other times, many passengers dispose of their plastics carelessly on the road while in their vehicles, especially when travelling, without considering the negative effects of their ill-informed actions leading to pollution in Nigeria. Plastic pollution has profound negative impacts on Nigeria's health, socio-economic and agricultural sectors, but this menace can be curbed via plastic waste recycling (Anabaraonye et al., 2022). Traditional methods like burning in the open field, mostly adopted to dispose of post-consumer plastics, especially in developing countries like Nigeria, are of global environmental concern. The release of harmful substances from smoke containing mercury, polychlorinated biphenyls, dioxins, and furans, which are injurious to health and the environment, into the atmosphere during the open burning of plastics leads to air pollution which consequently contributes to climate change and global warming (Webb et al., 2013). Plastic pollution negatively affects the atmosphere and environment, leading to global warming and climate change. Apart from direct landscape problems, plastic pollution in soil, marine and freshwater ecosystems causes severe problems to both macro and micro-organisms and may endanger human health (Filho et al., 2019). Living organisms, mainly marine animals, can be harmed by exposure to chemicals within plastics that interfere with their physiology, mechanical effects such as entanglement in plastic objects, and problems related to the ingestion of plastic waste. The harmful impact of plastic waste can come through the disruption of various hormonal mechanisms, indirect consumption (by eating animals) and direct consumption (i.e. in tap water) (Babayemi & Dauda, 2018; Economist, 2018; Eslamian & Eslamian, 2022). This chapter examined current progress with "Mitigating the detrimental impact of plastic pollution for sustainable economic growth in Nigeria" through existing literature review and data collection from relevant agencies. The primary purpose of this research work was to survey theoretical backgrounds and previous studies on the above subject matter and the current progress in implementing these mitigation strategies towards ensuring sustainable economic growth and development in Nigeria.

2 Results and Discussion

2.1 Trends of Plastic Usage in Nigeria

More than 23,400,000 tonnes of plastics were imported into Nigeria's technological sector between 1996 and 2014, yet less than 12% of the ensuing garbage was recycled. There is a need for sustainable management of this significant waste and resource category, given the threats this volume poses to local and global habitats and human health (Ugochukwu et al., 2018). Furthermore, the amount of plastic produced worldwide increased from 1.5 million tonnes (Mt) in 1950 to 245 million tonnes (Mt) in 2008, and a threefold increase could be seen by 2050. In the last fifty (50) years, the use of plastics has multiplied 20-fold, and in the following twenty (20) years, it is predicted to double once again as metals, glass, ceramics, and wood are progressively in a steady manner replaced by plastic in various items (Geyer et al., 2017). The food, beverage, and other fast-moving consumer products industries now use plastic packaging materials (*see* Fig. 5.1).

Plastic recovery and recycling rates are poor in African nations, which could be attributed to improper solid waste management, a significant issue that contributes significantly to plastic pollution (Babayemi & Dauda, 2018). Leal et al. (2021) identified the need for further investigation to comprehend people's motivation to purchase biodegradable plastic products. In many developing nations in Africa, improper solid waste management is a significant issue that contributes significantly to plastic pollution (Babayemi et al., 2019; Babayemi & Dauda, 2018). Babayemi and Dauda (2018) emphasized that plastic waste and other polymers wind up at dumpsites with other discarded waste in more significant quantities because there is no source separation of solid waste. Another critical factor is the gap in technology and inefficient waste-collecting methods that have exposed the region to difficulties.

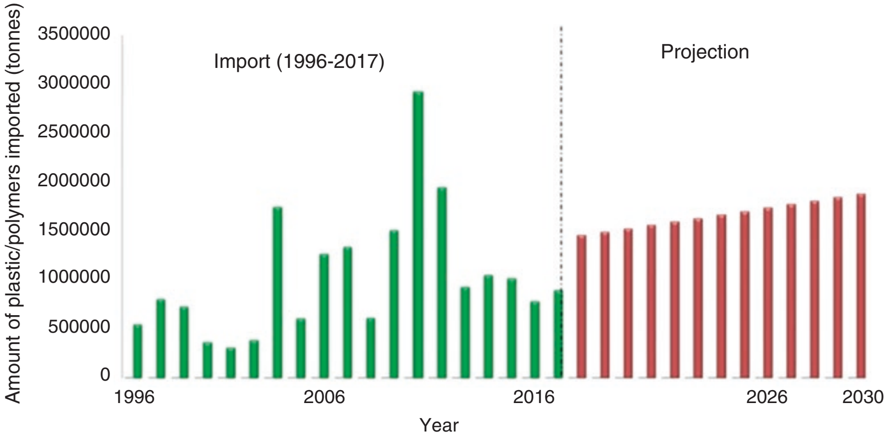

Fig. 5.1 Plastic importation into Nigeria. (Source: Babayemi et al. (2019))

Thus, there is a great need for technological advancement to increase the capacity and efficiency of plastic waste management infrastructures in Nigeria.

Also, due to the extensive use of plastics in the production of bottles, polythene bags, disposable items, waste containers, margarine tubs, milk jugs, and water pipes, polythene makes up 64% of all synthetic plastic (Lee et al., 1991). However, it has been discovered that ethylene polymers play a significant role in many daily activities. They are used for various purposes across several industries, including packaging, consumer goods, and food wrapping. The demand for these synthetic polymers has reportedly increased from 500 billion to 1 trillion tonnes, representing what is used globally (Anani & Adetunji, 2021). Additionally, it has been stated that during the past five decades, the amount of plastics polluting marine ecology has significantly increased. The rise in human requirements linked to population growth and the technological revolution has resulted in a commercial upsurge in the manufacture of plastics at an accelerated rate (Anani & Adetunji, 2021). Globally, 6300 million tonnes (Mt) of virgin plastics were manufactured between 1950 and 2015, resulting in around 8300 Mt. of plastic garbage, of which about 9% have been recycled, 12% have been burned, and 79% have accumulated in landfills (Geyer et al., 2017). Around 300 Mt./year of plastics is being manufactured globally, with 57 Mt./year coming from the European Union (Ratnasari et al., 2016). Worldwide, the average annual plastic usage per person is 43 kg (WEF, 2019). To combat the global challenge of plastic pollution, developed and developing nations have taken a variety of measures, ranging from banning plastic bags (such Kenya and Rwanda) to passing legislation in the European Parliament that will outlaw the top ten single-use plastics found in European beaches as well as fishing gear (E.U., 2019). Despite being one of the top six importers and consumers of plastic, calls for a reduction in the amount of plastic generated remain divisive, and Nigeria has not yet adopted regulations on single-use plastic items like other African nations have (Babayemi et al., 2019).

2.2 Factors Contributing to Increasing Quantity of Plastic Waste in Nigeria

The ease of processing for a variety of products used for carrying food items, packing textiles, producing scientific instruments, and creating automotive components from plastics in various forms, such as polythene, finds a wide range of applications in people's daily lives in Nigeria (Akinola et al., 2014; Anabaraonye et al., 2019). Due to the growing number of applications that rely on plastics' beneficial properties, including their light weight, strength, durability, affordability, resistance to corrosion, and low production costs, plastic production and consumption have expanded in recent decades (Li et al., 2016). Over the years, many plastics have entered Nigeria, but there are a lot of information gaps in Nigeria regarding plastics and the waste that goes with them (Jambeck et al., 2015). More plastics and plastic items are being produced now than what has been produced in history. Between 2015 and 2016, its production rose by 13 million tonnes in just one year (Kehinde et al., 2018). Since they are single-use plastic items and packaging materials, 50% of the plastic products fall under the category of disposable items. Similarly, disposable packaging is the leading market segment for plastic resins and production; consumption of single-use plastics is rising in Nigeria (Emeka & Lesley, 2020). There are many factors contributing to the increasing quantity of plastic waste generation and accumulation in Nigeria which include:

2.2.1 Improper Disposal of Plastic Wastes

It is common to observe in many states in Nigeria that many plastic waste products are not collected in trash cans for further processing, recovery, and standard disposal via landfills, incinerators, or recycling facilities but rather are carelessly scattered or thrown into areas that are inaccessible for waste collection, ending any chance of recovery or recycling (Anabaraonye et al., 2019). Plastic bottles and containers are frequently tossed on the ground, thrown out of cars, hipped around tight spaces, or blown away by the wind, which litters the area and ultimately pollutes the nearby ecosystem. Thus, the ecosystem in Nigeria is now seriously threatened by the ongoing accumulation of plastic waste products, a severe global environmental concern.

2.2.2 Consumption Pattern

The Nigerian populace depends heavily on plastic materials because of their affordability, flexibility and versatility as packaging materials. Studies revealed single-use plastic as the principal constituent of plastic products used in Nigeria (Kehinde et al., 2018). A study by Nnaji et al. (2013) in Nsukka, a city in Enugu State, Nigeria, shows that single-use plastics contribute 23% of packaging potable water in the suburban metropolis, which could be higher in an urban metropolis like Lagos, Abuja, Port Harcourt, Calabar, Onitsha, Kano, and Aba. In Nigeria, water sachets/bottles and shopping bags are the major constituents of plastic waste (Dumbili & Henderson, 2020). Single-use plastic is mainly used for packaging food items and drinks, shopping, and other items such as drinking straws, textile materials, and footwear. According to Kehinde et al. (2018), single-use plastics constitute fifty per cent of plastic products used in Nigeria. These forms of plastic, known as polyethylene terephthalates (PET), are very common plastic wastes found in the streets of Nigeria. These plastics are usually burned in the open air or dumped on the roadsides, constituting potential environmental health hazards.

2.2.3 High Population Density

Nigeria, presently known as the giant of Africa, has a high population density. The high population density in Nigeria is one of the leading causes of the country's inadequate plastic waste management (Kehinde et al., 2018). Being the most populous African country, Nigeria is a major consumer of plastics and contributes mainly to global plastic pollution (Dumbili & Henderson, 2020). Nigeria generates around 2.5 million tonnes of plastic waste annually and ranks ninth among the highest plastic waste-generating countries (Dumbili & Henderson, 2020; Obiezu, 2019). As a local recycling company reported, Lagos, the most densely populated state in Nigeria, generates an estimated 870,000 tonnes of plastic waste annually (Dania, 2022). Plastic wastes generated in densely populated cities of Nigeria are higher compared to the rural, less densely populated regions because of the high demand for plastic products in the form of sachet water, food packs, clothing, shoes, and automobile tyres. High population density is a significant factor contributing to Nigeria's poor waste management. High population density results in high solid waste generation and hence creates difficulty in adequate waste management infrastructure by the relevant agencies, which presently need to be adequately equipped.

2.2.4 Consumer Ignorance

Ignorance is a deadly disease which usually wreaks havoc on communities and institutions in Nigeria and beyond. Many Nigerians are ignorant of the potential environmental and health hazards plastic waste poses, which results in the lackadaisical handling of plastic waste among Nigerian residents. It is commonly observed in several streets and markets that a significant amount of plastic waste is not disposed of in trash cans for proper disposal and recycling; instead is carelessly scattered or discarded on the roadsides, drainage or dump sites hindering effective waste handling by the waste management agencies.

2.2.5 Lack of Implementation of the National Plastic Waste Management Policy

After numerous advocacy at both international and national levels for sustainable plastic waste management in Nigeria, the national plastic waste management policy emerged under the supervision of the Federal Ministry of Environment in 2019 (Isaac, 2021). The Federal Executive Council 2020 approved the newly formulated policy, which is yet to be implemented (Isaac, 2021). They stated, "Whatever strategy the government employs will be ineffective unless the long-awaited 'plastic pollution bill' is passed by Nigerian legislators and swiftly signed into law". The plastic ban bill presented by the National House of Representatives in 2019 aimed at regulating the use of single-use plastics is yet to be assent into law, suggesting the Nigerian government's lack of passion and political will to solve the plastic waste pollution menace (Raji, 2021). Other frameworks of the national policy on plastic waste management, such as extended producer responsibility, are yet to be fully implemented.

2.2.6 Poor Waste Management Infrastructure

In Nigeria, there are insufficient functional waste collection and recycling facilities. The government agencies monopolize waste collection services in Nigeria with poorly trained personnel, outdated and inadequate facilities and are not sufficiently funded (Ike et al., 2018). Waste management involves diverse stages, which include "generation and storage, collection and transfer, sorting, treatment, material recovery and disposal" (Nnaji et al., 2013). According to UNIDO (2021), solid waste management (which includes plastic waste management) is one of the most daunting environmental sanitation challenges currently encountered in Nigeria. This could be attributed to the poor waste management infrastructure, lack of trained waste management personnel, and lack of willpower by Nigerians and the waste management agencies in effective waste management (Salami, 2018).

There is a high level of inconsistency in waste collection services due to poor funding in the major cities of Nigeria. Furthermore, organized waste management services are absent in many towns and cities; hence waste needs to be adequately handled. The uncollected wastes are discarded carelessly and constitute health and environmental hazards. Nnaji et al. (2013) noted that 80 per cent of people living in Nigeria do not receive the services of waste collectors. According to Kofoworola (2007), an increased percentage of waste in Lagos State, Nigeria, is left uncollected from the streets due to inadequacy and inefficiency of the waste management system. In Abuja, the Department for International Development (2004) estimated that the waste collection agency serves about 56% of individuals living in the Federal Capital Territory. Nigeria's tertiary institutions are among the country's highest consumers of plastic products, but waste management in these institutions is far from satisfactory. According to reports, less than 12% of plastic waste generated in

Nigeria is recycled (Sogbanmu, 2020), which is very poor for a country ranked ninth globally in plastic consumption.

2.2.7 Packaged Foods, Sachet and Bottled Water Preference

In Nigeria, the use of sachet water, bottled water, bottled drinks, takeaway food packs, straws, cups, and spoons, among others, in homes and occasions is alarming. These packages come in handy for most people and are widely accepted by many Nigerians because one doesn't need to remain at the point of purchase or service to consume them (Okolo et al., 2022). Plastic wastes are toxic. Most are non-biodegradable and consequently constitute a nuisance in the environment. The burning of these plastics is a common practice in Nigeria. Emeka and Lesley (2020) opined that the single daily use of plastic takeaway packs and shopping bags is enormous, while the consumption and disposal of sachet water bags have risen to over 60 million in Nigeria. Nigerians eat and drink from these different packages comfortably anywhere as the need arises, hence the increase in the rate of plastic waste generation (Okolo et al., 2022). Beyond the toxicity of plastic waste, they find their way to different environmental media. They pollute soils and clog drains and waterways, eventually causing water and sewage overflow. Subsequently, this becomes the breeding ground for disease-spreading germs and bacteria (Akinola et al., 2014).

2.3 Strategies for Mitigation of Plastic Pollution in Nigeria

In mitigating the adverse effects of plastic pollution in Nigeria, it is vital to understand the nature and characteristics of plastics. Plastics are inexpensive and durable, making them adaptable for different uses; as a result, humans produce a lot of plastics (Hester & Harrison, 2011). However, the chemical structure of plastics renders them resistant to many natural degradation processes and results in slow degradation (Le Guern, 2018). It is essential to know microplastic's prospective sources and sinks, the process by which its distribution is affected, and their uptake and exchange in ecosystems to understand the potential ecological harm microplastics do (Jang et al., 2015). It is assumed that there was a stock of over 86 million tonnes of plastic and marine debris in the ocean in 2013, with an assumption that 1.4 per cent of global plastics production from 1950 to 2013 entered the sea and has accumulated (Jang et al., 2015). In the UK, more than five million tonnes of plastic are used yearly, of which only an estimated 25 per cent is recycled, with the remainder ending up in landfills. In some regions, there have been substantial efforts to lessen plastic pollution by promoting plastic recycling and reducing the consumption of plastic(Walker & Xanthos, 2018). Many researchers suggest that by 2050 there may be more plastic waste than fish in the world's oceans by weight (Sutter, 2016).

The following are the innovative strategies for mitigating the negative effects of plastic pollution in Nigeria:

2.3.1 Bioremediation

Bioremediation is defined as engineered or enhanced bio-degradation. Some researchers view it as a sustainable and environment-friendly tool to clean up post-consumer plastic bottles that already accumulate on land, soil, and water bodies (Idowu et al., 2021). Bioremediation refers to cleaning up contaminated environments by exploiting and harnessing the metabolic abilities of micro-organisms to convert contaminants into harmless products by mineralization, generation of carbon (IV) oxide and water or by conversion into microbial biomass through living organisms or biological processes (Baggot, 1993; Boopathy, 2000; Sardrood et al., 2013). Bioremediation, as evolving environmental biotechnology, adopts micro-organisms in the degradation process and can be optimized to achieve a better result (Borasiya & Shah, 2007). Micro-organisms are primarily used in biodegradation investigations on polymers.

Enzymatic processes that result in a chain cleavage of the polymer into monomers cause the microbial breakdown of plastics. Plastics are partially degraded due to micro-organisms using waste polythene as their only carbon source. Numerous authors have described how different bacteria, including Aspergillus (Khan et al., 2000), Streptomyces sp. (Ibrahim et al., 2011), Pseudomonas, and Bacillus, have been involved in the microbial degradation of polyethene (Lee et al., 1991). Micro-organism application is a sustainable method of cleaning up a severely synthetic plastic-polluted environment. It was claimed that many micro-organisms could oxidize or hydrolysate various polymers through biodegradation (Idowu et al., 2021).

The regulation of plastic waste in Nigeria and elsewhere has been the subject of attempts in several parts of the world to preserve ecosystem components while avoiding ecological and health problems. The use of bacteria and fungi in plastic biodegradation has gained popularity. They foretell success due to their effectiveness, affordability, environmental friendliness, and sustainability (Anani & Adetunji, 2021). This process involves secreting metabolites that help break down polymers. When other management techniques are unsuccessful, it is necessary to use well-engineered native micro-organisms that actively participate in the cleanup of plastics (Anani & Adetunji, 2021). The biodegradation of plastics has been tried in many economies with encouraging results. This is relevant to Nigeria, where plastic pollution has continued to be a significant problem. In Nigeria, reducing plastic waste is a sustainability strategy. The effectiveness of the approach of biodegradation has been shown in numerous research. These distinctive techniques must be carefully considered and applied in Nigeria (Senthilkumar et al., 2016).

In a preliminary investigation, Odusanya et al. (2013) identified, characterized, and assessed the breakdown of plastic bottles by micro-organisms in Nigeria. The LLDPE (linear low-density polyethylene) potable plastic container was employed, and it was powdered and solubilized using a straightforward proprietary solvent procedure. Eight bacterial colonies that could convert LLDPE into a usable carbon source were identified using enrichment culture procedures. Serratia marcescens was the organism that was found to be most prolific. The isolated and characterized organisms were gram-rod bacteria, which could degrade plastic trash (Muthukumar & Veerappapillai, 2015; Odusanya et al., 2013). Senthilkumar et al. (2016) wrote a

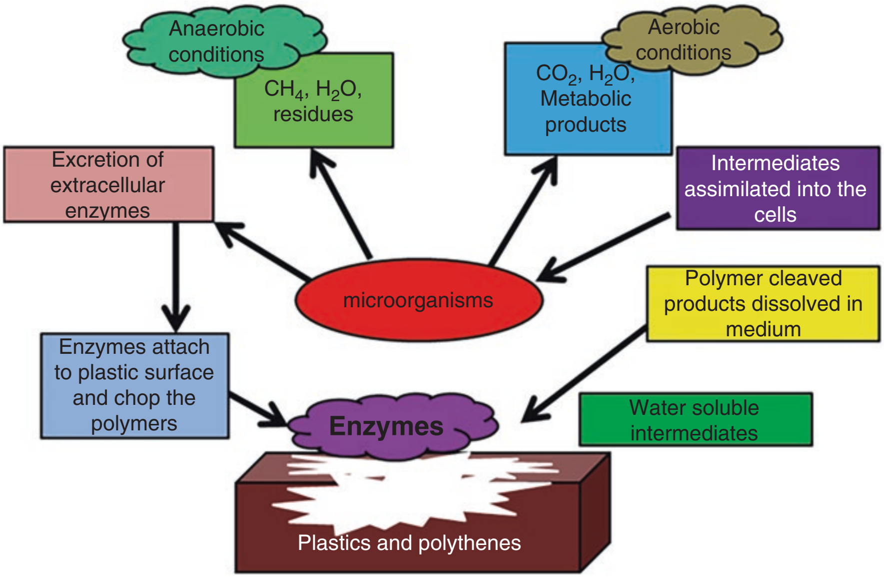

Fig. 5.2 Microbial approach to bioremediation of polyethylene and plastic. (Source: Sharma (2018))

thorough review on isolating beneficial micro-organisms with the capacity to break down synthetic polymers from the soil. With the use of enzymes and the cloning of genes for biodegradation, these soil bacteria can break down these polymers. These enzymes naturally come in the form of lignin peroxidase and manganese peroxides. According to the authors, different soil micro-organisms with the potential to break down various plastics and polymers, particularly those from varied sources, must still be isolated using the technique of bio-stimulation (Senthilkumar et al., 2016). When exposed to multiple environments, the application of various bacteria for the bioremediation of plastic was reviewed by Muthukumar and Veerappapillai in 2015. According to the authors, bioremediation of plastic using unconventional methods could provide a future free of several risks caused by micro-plastics and plastics, particularly those used in packaging and commercial polymers, which are the most prevalent types of plastic wastes (Muthukumar & Veerappapillai, 2015) (*see* Fig. 5.2).

2.3.2 The Use of 3Rs of Plastic Waste Management

The three plastic waste management strategies are the 3Rs (Reduce, Reuse, and Recycling) (Mohamed, 2016; Yosi et al., 2019; Olowoyeye, 2021). Recycling plastic waste is the best solution to managing plastic waste from an environmental and socio-economic aspect (Woldemar, 2019). However, recycling is one of the most effective ways to collect plastic trash, landfilling, and incineration. Even though most plastic trash comes from underdeveloped nations, some come from Western countries, primarily because of the inadequate capacity of collection systems and the low recycling rates. On the other hand, Horodytska et al. (2019) emphasized the need for recycling to reduce the quantity of waste that must be disposed of and prevent the trash from entering rivers, oceans, and other habitats.

Generally, there are two types of recycling: primary and secondary. However, alternative techniques such as pyrolysis/thermal degradation, catalytic degradation, and gasification were mentioned in 2019 (Bhongade, 2019). Plastic recycling is a technique that has drawn much interest from enthusiastic people and businesspeople. Environmentalists and experts in the attenuation of plastic waste, such as Anabaraonye et al. (2022), asserted that plastics recovered from solid waste become a source of valuable raw materials for industries, reducing the need for countries to import those materials from abroad while allowing for the export of excess production (Anabaraonye et al., 2022). According to the authors, recycling plastic would make cities more resilient to extreme weather events that disrupt communities and their way of life and cause pollution, flooding, and infrastructure damage. Recycling plastic can promote regional industrial competitiveness, fight poverty, create more jobs, and save municipal expenditure on various costs (Anabaraonye et al., 2022, 2019; Olowoyeye, 2021). One important step would be implementing a fully operational plastic waste management, recycling, and environmentally responsible disposal system to guarantee almost zero plastic waste discharge to the environment. Plastic waste recycling is one of those plastic pollution mitigation strategies involving reducing, reusing and recycling plastic waste materials to ensure that our environment is a cleaner, healthier and greener place to live in (Anabaraonye et al., 2019). Plastic waste recycling will also help provide employment for many unemployed or underemployed youths in Nigeria, thereby eradicating poverty and hunger to achieve sustainable economic growth. The demand for plastic products is on the rise, with increasing demand in different sectors of communities and institutions in Nigeria. This amounts to the generation of plastic waste nationally at an alarming rate. Mitigating the harmful effects of plastic pollution in Nigeria will undoubtedly enhance climate resilience in Nigeria.

2.3.3 Education, Advocacy and Community Engagement

Communities, businesses and other institutions in Nigeria can benefit economically from plastic waste management and recycling, achieving sustainable economic growth (Anabaraonye et al., 2019). The waste management systems can reduce significant amounts of plastic garbage with the help of campaigns to make plastic litter socially unacceptable and educate consumers along the supply chain about designing for recycling (Asase et al., 2009). Communities, businesses, and institutions can be engaged in plastic waste management efforts by putting marked containers out in the open for public use or giving bins to house and company owners for strategic garbage disposal and waste collection for recycling. It is encouraged to design interactive activities that can raise awareness of the issues of plastic pollution and our shared obligation to address them. Increased public and societal participation in plastic pollution and potential solutions would result from raising awareness.

Making plastic waste recycling a cultural norm would lessen plastic pollution on land and the amount of plastic that enters the marine ecosystem (SAPEA, 2019a, b). This is demonstrated by a European study, where teachers and students were given the tools to work with plastic waste to address the issue through an online training course and instructional film competition on marine debris (Hartley et al., 2018). Another crucial step is designing specialized evidence-based education to raise awareness of the risks of plastic pollution and inspire change among Nigerians. This action has helped reduce environmental debris in other places (Creel, 2003).

3 Further Recommendations

(a) Plastic recycling businesses need to be well subsidized by the Nigerian government. The Nigerian government and other multilateral organizations must fund and construct infrastructure in Nigeria that will facilitate waste collection, plastic recycling, repurposing, and reuse (Okolo et al., 2022).

(b) Due to society's reliance on single-use plastics, an outright ban may not be possible. Nigeria would benefit significantly from a perfect reduction in plastic waste production and availability in society through policy and enforcement, as well as by adopting cleaner lifestyles, more ecologically responsible choices, and optimum plastic waste management.

(c) To respond to the great need for plastic waste reduction, recycling, and reuse in Nigeria today, environmentalists, engineers, scientists, and related environmental fields must band together (Anabaraonye et al., 2019) to achieve this common goal. This will significantly mitigate the harmful effects of plastic pollution in Nigeria.

(d) Using bio-plastics instead of fossil-based plastics will help improve the end-of-life management of plastic waste because most bio-plastic materials can degrade under controlled conditions (Filho et al., 2022).

(e) Nigerian artists could use plastic garbage in their creations. These actions could lessen the burden of uncollected plastic waste and the careless disposal of plastic sachet bags and items contributing to Nigeria's plastic pollution (Wagner-Lawlor, 2018).

(f) Efficient disposal methods should be implemented, such as the supply of waste bins that differentiate between biodegradable and non-biodegradable waste. When other methods fail, it is also necessary to use well-engineered native micro-organisms, actively participating in the micro-plastic cleanup.

(g) More efforts have to be put towards increasing people's awareness about bio-based and biodegradable products, their properties, their use, and the environmental and human health impacts (Filho et al., 2022).

(h) Promotion of specific monthly or annual leadership summits to attract individuals or groups to invest funds to mitigate plastic pollution in Nigeria.

(i) There should be a constitutional review to let Nigerians be aware of the impacts of plastic pollution in various socio-political and economic dimensions with new strategies to tackle them.

(j) Granting loans and incentives to individuals and organizations engaged in plastic recycling businesses by Nigeria is greatly encouraged.
(k) Carrying out intensive research to be aware of communities or cities that have suffered the harmful effects of plastic pollution in Nigeria. Knowing these communities or cities enables the government to better plan and invest in them.
(l) Attracting the increasing inflow of funds from International establishments such as the World Bank and United Nations Environment Programme (UNEP) by the Nigerian government to mitigate the adverse effects of plastic pollution is greatly encouraged.

4 Conclusions

There is a great need for communities and institutions to unite to devise the means of ensuring a cleaner and healthier environment through proper plastic waste management and recycling strategies, which will help guarantee sustainable economic growth and sustainable development in Nigeria (Anabaraonye et al., 2019). Proper plastic waste management has been identified as a viable strategy for mitigating the harmful effects of plastic pollution in Nigeria (Okolo et al., 2022). Recognizing and maximizing the green entrepreneurial opportunities in the plastic recycling industry is a mitigation strategy to eradicate plastic pollution and ensure sustainable economic growth in Nigeria (Anabaraonye et al., 2022). Through capacity building supported at all levels of government, it is vital to raise people's understanding of the hazards posed by plastic waste in the environment. We must manage our environment by using our plastics sustainably, properly disposing of plastic debris and thereby eradicating plastic pollution, attaining the United Nations Sustainable Development Goals (SDG 13) (Okolo et al., 2022). Policies should focus on reducing plastic waste and recycling while addressing the hierarchy. Potential mitigating tactics may include waste plastic reuse, bioremediation, recycling, waste conversion to energy, and proper malleable control policy frameworks (Olowoyeye, 2021). Additionally, people must contribute at all levels to the correct disposal of plastic waste, and ill-mannered disposal must be shelved, thereby achieving economic growth and sustainable development in Nigeria.

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Chapter 6
Teaching of Climate Change in the Official Documentation: An International Review for Improving the Resilience

Álvaro-Francisco Morote, Jorge Olcina, and Saeid Eslamian

Abstract This research aims to analyze how is teaching climate change from the main international official documents. The main results show that at the international level, issues on climate change education are proposed with interesting measures but without concreteness. To sum up, it should be noted that after reviewing this official documentation, it has been possible to verify that over the years, education and teaching on climate change has been gaining prominence, with greater detail of specific measures on a national scale, with effects, likewise, in the actions of the regional administrations.

Keywords Education · Resilience · Climate Change · Documentation · Measures

1 Introduction

Climate change has become one of the most important socio-environmental problems facing society in the XXI century (Muñoz et al., 2020; Romero & Olcina, 2021). This phenomenon has been aggravated by the action of the human being, as revealed in the Sixth Report of the Intergovernmental Panel on Climate Change

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(IPCC, 2021, 2022) and in which it warns about the impact that this global warming process can have if adaptation and mitigation actions are not adopted in the short and medium term. Climate change, according to climate modeling and as indicated by different authors (Arnell et al., 2019; Pausas & Millán, 2019), will have different consequences depending on the geographical area and receiving society. Together with other global problems (pandemics, migrations, poverty, terrorism, wars, etc.), this phenomenon has become the main axis of public policies and private actions. It is, therefore, a global risk that demands the concerted action of the entire society (González-Gaudiano et al., 2020; Romero & Olcina, 2021; Olcina, 2020).

Climate change has managed to capture the attention of society, and perhaps more and more people are aware of the need to act. In recent years, different works have been carried out in which it is clear that one of the actions to mitigate the effects of this problem involves linking and greater dedication to this issue from the educational field as a means of social transformation (Cruz & Páramo, 2020; Eilam, 2022; Méndez et al., 2020; Morote & Moreno, 2021). This interest was already recognized in the Kyoto Protocol (1997) (Article 6), reaffirmed in Article 12 of the Paris Agreement (2015) that expresses the importance of education to modify long-term habits and the promotion of a better understanding and training to deal with this phenomenon and its associated effects (UNESCO & UNFCCC, 2016). The IPCC, in its Fifth Report (2014) recorded this, as did the United Nations Organization (UN, 2015) in the 2030 Agenda (Sustainable Development Goals [ODS]) where it is explained that education is the most effective tool for reducing the effects of climate change (Objective 13, "Climate Action").

In the educational field, climate change faces several challenges for its correct teaching in the classroom: (1) the complexity of teaching content that even the scientific community finds complex due to the amalgamation of factors involved (Eilam, 2022; Ferrari et al., 2019; Olcina, 2020); (2) the need to teach this subject with scientific rigor (Caride & Meira, 2019; Escoz et al., 2020; Ferrari et al., 2019; Jeong et al., 2021; Kurup et al., 2021; Masters, 2020; Nelles & Serrer, 2020; Rudd, 2021); (3) poor teacher training (Morote & Moreno, 2021; Morote & Hernández, 2020); and (4) the stereotypes and non-rigorous information that are disseminated in the media and that are influencing what both students and teachers think and perceive about this phenomenon (León et al., 2021; Morote et al., 2021; Rudd, 2021).

It should be noted that the main information received on climate change is made from digital information media and social networks (Morote et al., 2021). Kažys (2018) gives relevance to this problem (falsehood and manipulation of the information received from the media), while Allen et al. (2018) add interest in the risk that the so-called "fake news" can have. Another added problem is the scant importance given by teachers to the education factor as a measure to mitigate the risks associated with climate change, as Morote and Hernández (2020) have verified. Even this information is being reproduced without scientific rigor in textbooks (Morote &

Olcina, 2020; Olcina, 2017). For example, in the case of the Geography manuals (Secondary Education and Baccalaureate), Olcina (2017) has detected notable shortcomings: little rigorous information, excessive catastrophism, and an almost total absence of real data from academic works.

Regarding scientific production in the international context, practically all territorial areas have been covered: North America and Central America (McWhirter & Shealy, 2018; Sezen-Barrie & Marbach-Ad, 2021); South America (Da Rocha et al., 2020); Europe (Jeong et al., 2021; Kurup et al., 2021; León et al., 2021); Africa (Anyanwu & Le Grange, 2017; García-Vinuesa et al., 2020); Asia and Oceania (Haq & Ahmed, 2020; Liao et al., 2019; Pfautsch & Gray, 2017; Yu et al., 2020).

The objective of this work is to carry out a review of how the treatment of climate change teaching is being carried out in the main international organizations. The idea is to check if the necessary attention is devoted to a decisive factor for the awareness of society, such as education and its effects on the development of measures for the adaptation and mitigation of the effects of this process of global impact. As a starting hypothesis, it is established that the organizations and official documentation would take into account the teaching of climate change as a tool for the fight against this phenomenon given its social imprint as a basic right of the human being, but, they would be good intentions with little precision.

2 Sources and Methodology

In order to fulfill the objectives of this research, a review of the international documents of official organizations developed in recent years to combat climate change has been carried out, analyzing in detail the issues related to the teaching of this phenomenon. For this, the documentation from their respective web pages has been consulted (see Table 6.1).

The main working method has been inductive: from the detailed analysis of the official documents indicated, a diagnosis of their strengths and weaknesses has been made. All this in order to highlight those proposals that can be presented as examples of good practices in the different work scales and make proposals for improvement, for the correct assessment of teaching as a tool to combat climate change.

For the consultation of these reports and official documentation, the following analysis criteria have been followed: inclusion of information on the adaptation and mitigation of climate change and analysis of the measures related to education as an important factor for said actions. Based on this diagnosis, the specific actions that each official body dedicates to teaching climate change as an action to mitigate or adapt to this global phenomenon have been assessed.

Table 6.1 Organizations and documents where the measures from the educational field to face climate change have been consulted (own elaboration)

United Nations (UN)
United Nations Framework Convention on Climate Change (1992) https://unfccc.int/resource/docs/convkp/convsp.pdf *Doha work program (2013–2020)* https://unfccc.int/resource/docs/2012/sbi/eng/l47.pdf *Sustainable Development Goals (SDG) (2015) (2030 agenda)* https://www1.undp.org/content/undp/es/home/sustainable-development-goals.html
Intergovernmental Panel on Climate Change (IPCC) https://www.ipcc.ch/languages-2/spanish/ipcc-en-espanol-publications/
First Report (1990) *Second Report (1995)* *Third Report (2001)* *Fourth Report (2007)* *Fifth Report (2014)* *Sixth Report (2021; 2022)*
International Protocols
Kyoto Protocol (1997) https://unfccc.int/resource/docs/convkp/kpspan.pdf *Paris Agreement (2015)* https://unfccc.int/es/process-and-meetings/the-paris-agreement/el-acuerdo-de-paris
Climate summits
26ª Climate Summit (COP 26; Glasgow, 2021) https://unfccc.int/es/node/307746 https://unfccc.int/conference/glasgow-climate-change-conference-october-november-2021

3 Results. Education and Climate Change from the International View. Good Intentions Without Concrete Measures

The first document analyzed was the United Nations Framework Convention on Climate Change (1992). Issues related to the education of this phenomenon are included in Article 6 ("Education, training and public awareness"). This article establishes that, in order to achieve their objectives, the signatory Parties shall promote and facilitate: (1) the development and implementation of education and public awareness programs on climate change and its effects; (2) public access to information on climate change and its effects; (3) public participation in the study of climate change and its effects and in the development of appropriate responses; (4) the training of scientific, technical and managerial personnel; and (5) cooperation, at the international level, in these fields. Likewise, it should be noted that the development of the actions provided for in this Article 6 has been specified, for more than a decade, in different programs: Delhi Work Program (2003–2007), Delhi Work Program Amended (2008–2012), and Doha Work Program (2013–2020), currently in force (Table 6.2).

Table 6.2 Article 6 ("Education, training and public awareness")

1. The preparation and application of education and public awareness programs on climate change and its effects.
2. Public access to information on climate change and its effects.
3. Public participation in the study of climate change and its effects and in the development of appropriate responses.
4. The training of scientific, technical and managerial personnel.
5. Cooperation, at the international level, in these fields.

Source: United Nations Framework Convention on Climate Change (1992). (Own elaboration)

Table 6.3 Main indications of the Doha Work Program (2013–2020)

Appoint a National Focal Point for Article 6 who will be assigned specific tasks.
Prepare needs assessments around the topics of Article 6, using, among others, social research techniques.
Prepare national strategies for the development of the issues included in article 6 of the convention.
Develop communication strategies on climate change aimed at achieving behavioral changes.
Strengthen educational and training institutions that develop educational actions on climate change.

Source: UN (2022). (Own elaboration)

The Doha Work Program (2013–2020) recognizes that a key objective of education is the promotion of changes in lifestyles, attitudes, and behaviors to promote sustainable development. Likewise, it is reaffirmed that public participation and access to information are crucial to develop effective policies, as well as to actively involve all those interested in their application. The most notable indications in terms of education can be seen in Table 6.3. The program, specifically, in terms of education, pursues the dissemination and dissemination of climate change, such as (1) creation of active networks of organizations and people for the development of activities in the thematic fields related to Article 6 (Framework Agreement); (2) inform the population about the causes of climate change, the sources of greenhouse gas emissions and the actions that can be developed at all levels to address climate change; and (3) disseminate relevant information that is generated in relation to climate change. Other suggestions include preparing and disseminating disclosure versions of key documents, including the IPCC Assessment Reports.

A third documentation analyzed has been the reports published by the IPCC since 1990. The IPCC prepares comprehensive assessment reports on knowledge about climate change, its causes, potential impacts, and response options. Likewise, it prepares special reports, which are an evaluation on a specific topic, and methodological reports, which provide practical guidelines for the preparation of greenhouse gas inventories. Since 1990, six reports on the state of the climate have been published, in which an evolution can be observed in the treatment of education as a measure to combat climate change. Only the Sixth Report (2021; 2022) gives notable importance to educational actions as a tool for mitigation and adaptation and the achievement of resilient societies based on the design of public education programs aimed at explaining environmental changes and their effects and early warning systems for atmospheric hazards that states must implement (IPCC, 2021, 2022).

Fourth, the documentation regarding the Sustainable Development Goals (SDG) (UN, 2015) (2030 Agenda) has been reviewed. This Agenda, under the slogan "Transforming our world: the 2030 Agenda for Sustainable Development", was signed on 25th September (2015). It is, to date, the largest international commitment reached for the protection of the planet and its inhabitants and constitutes a roadmap with 17 objectives, 169 goals, and 232 monitoring indicators. The general objectives pursued by the SDGs are: to end poverty in all its forms; reduce inequality; create an inclusive future; create a resilient future; and achieve sustainable and equitable economic growth. Regarding climate change issues, it is necessary to refer specifically to Objective 13 "Action for the climate" ("adopt urgent measures to combat climate change and its effects"). It should be noted that there are several goals linked to the education and awareness of the population, such as Goal No. 1 ("resilience and the ability to adapt to risks related to climate and natural disasters in all countries") and Goal No. 3 ("improve education, awareness, and human and institutional capacity regarding climate change mitigation, adaptation, reduction of its effects, and early warning") (see Table 6.4).

These international initiatives are completed with the approval of the legal documents linking the countries to the commitment established by the aforementioned 1992 United Nations Convention on Climate Change. Since then, two binding international agreements have been developed for the signatory countries: Kyoto Protocol (1997) and Paris Agreement (2015), which are the only two international agreements sponsored by the United Nations. In the first, there are hardly any references to education as an instrument of action against climate change. Article 10 states that the countries will cooperate at the international level, resorting to the development and implementation of education and training programs aimed at

Table 6.4 Targets of Goal 13 ("Climate Action")

Goal 1. Strengthen resilience and adaptive capacity to climate-related risks and natural disasters in all countries.
Goal 2. Incorporate measures related to climate change in national policies, strategies, and plans.
Goal 3. Improve education, awareness, and human and institutional capacity regarding climate change mitigation, adaptation, reduction of its effects, and early warning.
Goal 4. Fulfill the commitment of the developed countries that are parties to the United Nations framework convention on climate Change to achieve by 2020 the objective of jointly mobilizing 100,000 million dollars annually from all sources, in order to address the needs of developing countries regarding the adoption of concrete mitigation measures and the transparency of their application, and to fully operationalize the green climate fund by capitalizing on it as soon as possible.
Goal 5. Promote mechanisms to increase capacity for effective planning and management in relation to climate change in least developed countries and small island developing states, with particular emphasis on women, youth, and local and marginalized communities.

Source: UN (2015). (Own elaboration)

training specialists in this field, with special interest in developing countries. It is, in any case, a declaration of intentions that is not very ambitious and without specificity.

Regarding the Paris Agreement (2015), in general terms, it has the objective of providing a global response to the threat of climate change by maintaining the global increase in temperature during the XXI century below 2 °C compared to pre-industrial levels. The preamble to this document recognizes "the importance of education, training, public awareness and participation, public access to information and cooperation at all levels on climate change". Article 11 states "…apply adaptation and mitigation measures, and should facilitate the development, diffusion and deployment of technology, access to climate finance, relevant aspects of education, training and public awareness and communication of information in a transparent, timely and accurate manner" (p. 19); and in Article 12 it is indicated that "the Parties shall cooperate in the adoption of the corresponding measures to improve education, training, awareness and participation of the public and public access to information on climate change, bearing in mind the importance of these measures to enhance action under this Agreement" (p. 20). Nor does it detail the actions to develop these aspects. In short, the Paris Agreement includes all the aspects contained in Article 6 of the Framework Convention on Climate Change (access to information, awareness, education, training, and public participation), but it does not add any significant value to education as a tool for mitigation and adaptation to climate change. So these two international agreements do not establish a firm commitment to promote education for risk and climate change in the countries of the world as an important element in the fight against this global process.

The latest information consulted in the international view was the conclusions drawn after the Climate Summit (COP26) concluded in Glasgow (November 2021). Only the last summit has been analyzed since it is a good example to check the current state of treatment of climate change teaching as a tool for mitigation and adaptation. In it, new climate objectives have been set, complementing the existing ones, as well as agreements to contain the increase in global temperature to a maximum of 1.5 °C. Among the main points of discussion are land use, climate, biodiversity, and sustainable development. Measures from the educational field are non-existent. There can only be a certain link in point II "Adaptation" of the proposed measures, which insists on what is established in the Paris Agreement (2015, p. 2): "Recognize the importance of the global adaptation objective for the effective implementation of the Paris Agreement and welcome the launch of the full two-year Glasgow-Sharm el-Sheikh work program on the global adaptation goal".

4 Conclusions

In this work, it has been possible to verify how climate change education is treated from the main organizations and official documentation at the international level. Regarding the starting hypotheses, these are fulfilled: "the official documentation and organisms would take into account the teaching of climate change as a tool for the fight against this phenomenon given its social imprint as a basic right of the human being, but, they would be good intentions without just concrete. Specificity that would increase for the Spanish territorial scope".

After reviewing these organizations and documentation, for the international case, it should be noted that the information related to climate change has to do with 2 main axes: (1) execution of training programs (society in general); and (2) improvement of dissemination and access to climate change information. This can be seen in the United Nations Framework Convention on Climate Change (1992) in its Article 6 ("Education, training and public awareness"), the measures of the Doha Work Program (2013–2020), the Agreement on Paris (2015) in its Articles 11 and 12 which, in turn, are based on those established in Article 6 of the Framework Convention, and the IPCC reports. Regarding the latter, and like the 2030 Agenda (Goal 13, "Action for the climate"; Goals 1 and 3), it is worth noting the importance given to the education factor as a variable for adaptation and resilience to climate change. They are, therefore, at best, basic guidelines and training programs that states must follow. Even here, it has been verified that there is practically no information regarding climate change education in the Kyoto Protocol (1997) and the recent Glasgow Climate Summit (2021; COP 26).

Education is a fundamental instrument in the fight against climate change. It is an element of generating social awareness through true messages on this issue, which must always be supported by scientific research. It is a very effective tool for implementing individual and collective actions to mitigate and adapt to climate change. But as a means of disseminating science and culture, it requires detailed and prolonged programming (years of educational training) that only has results in the medium and long term. Hence, despite its recognition by organizations and administrations at all levels of work (international to local), it does not find a development of concrete actions in accordance with its social importance.

It should also be noted, as a limitation of this study, that the most important official documents that establish the main lines of action in the organizations analyzed have been consulted, but they are not the only ones in existence. Hence, consulting reports from other entities (citizens' associations, environmental organizations) and even blogs of fans on weather and climate issues were raised as a challenge for future research. And this is especially at the regional and local scales.

Education is an essential commitment of any society (Alatorre et al., 2016; ALLEA, 2020; González & Maldonado, 2014; Greenwood, 2018; Jodelet, 1991; Kindelan, 2013; Martínez-Fernández & Olcina, 2019). It must be aimed at training citizens, from the teaching of basic content on the subjects that make up the necessary training to develop in the world. Current climate change is an essential issue for the present and future of our planet, which will guide the policies and practices of institutions and administrations, if its undesired effects are to be effectively limited (Eslamian et al., 2011). The teaching of climate change, in the classroom (at all educational levels) and in society in general, requires greater attention than what organizations and governments have devoted so far, in order for it to be an effective tool for mitigation and adaptation.

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Part III
Hydrologic Disasters: Risk Assessment and Mitigation

Chapter 7
Hydrologic Disasters: Assessing Hazard and Risks

Gianfranco Becciu, Mariana Marchioni, Anita Raimondi, and Umberto Sanfilippo

Abstract Hydrologic disasters can be more frequent and especially severe in highly urbanized areas, causing considerable human and property losses. Climate alterations may lead to more extreme rainfall events on small portions of the watershed, while urbanization increases impervious surfaces, reducing subsoil infiltrations and leading to an increment in runoff peak flow and volume. An essential tool to reduce damage and improve hydrological disaster management and mitigation is a proper assessment of hazards and risks. Hazard estimation requires detailed knowledge of watershed characteristics and hydrological processes. Semi-probabilistic approaches can be used for hazard estimation, allowing to derive the probability distribution functions of runoff variables from those of input variables. Risk assessment includes also the evaluation of exposure, that is human lives and other values which may be involved, and vulnerability, which represents the lack of resistance to damaging or destructive forces. Risk maps and matrixes can be used as tools to identify and prioritize risk mitigation actions. This chapter covers hazard and risk assessment for hydrologic disasters and presents two applications in case studies located in highly urban watersheds in Milano (Italy) and San Paolo (Brazil).

Keywords Hydrologic disasters · Risk assessment · Hazard assessment · Floods · Milano · San Paolo

1 Introduction

Hydrologic processes rule the transformations, the movement, and the storage of water in time and space, inside the Water Cycle. These natural processes, happening all over our planet with different features, are well-known in their general forms and can be analyzed and modeled at different time and space scales.

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Risks may arise from hydrologic processes when quantitative features, in time and/or in space, of one or more components of the Water Cycle (precipitation, surface runoff, evapotranspiration, etc.) become significantly different from mean values. This shift from the “normality” of a hydrological event is usually measured in terms of probability of occurrence or, more empirically, of rank in the historical range of records. Often, adjectives like “extreme”, “rare”, or “exceptional” are used for this kind of event, to express the concept that a limit threshold was passed. More formally, this threshold is defined as the 5–10% quantile in the right or left tail of the probability distribution of a hydrologic parameter or as the 5–0% upper or lower ends in the range of its records.

Extreme events are considered disasters when they lead to human, material, economic, or environmental losses and impacts (UNDRR, 2007). Disasters resulting from the hydrologic process include storms (hurricanes, typhoons, and cyclones), floods, droughts, tsunamis, landslides, dam breaching, mud and debris flow, and sea-level rise (Singh, 2012). Disasters are more frequent and significant in highly urbanized areas, where extreme events may cause more losses and impacts, due to the greater density of population, infrastructures, and social and economic activities. In these areas, the risk of flooding is often the main concern.

Floods are normally a consequence of extreme rainfall events, but they can also happen because of infrastructure failures, such as dam breaches or river embankment collapse. They are often affected by anthropic land alterations, such as changes in soil use, floodplain reduction and occupation, and riverbed covering (Jah et al., 2012; Pahl-Wostl et al., 2008; Schuman, 2011; Lamond et al., 2011). Floods in the urban areas can also result from sewer system insufficiency (Becciu & Raimondi, 2014). Climate change also leads to an increase in flooding risk, due to hydrological alterations, including warming seas, changing patterns of precipitation and rising sea levels can also lead to flood risk increase (Singh, 2012).

The EM-DAT public database registered 5621 floods from 1900 to 2019, with the Asian continent being the most affected with 42% of the registered flood events and 98% of the total deaths, where the six first events on the total deaths ranking took place in China. In the last ten years, from 2010 to 2019, 179 flood disasters were registered, with a total of US$ 395,342,939 of estimated total damages, affecting a total of 697,227,310 people and causing 60,722 deaths (EM-DAT, 2020).

Hazard and risk assessment is an essential issue in the reduction of adverse effects of extreme events. The term “hazard” refers to the occurrence probability of a potentially damaging event, while the term “risk” refers to the extent of consequential damages and losses (Eslamian et al., 2021). Risk is generally expressed as a function of hazard and usually also of other two factors: exposure, which represents the potential loss in terms of human lives and other valuable elements, and vulnerability which represents the lack of resistance to the damaging event. Several procedures, less or more detailed, are available in the scientific literature for the assessment of these components, in most cases designed to achieve maps or charts from the combination of probabilistic analysis, historical records and geographic information knowledge (Rausand, 2013). In many countries, standard procedures are also available, mainly for planning purposes. An example is the EU Flood Directive 2007/60/EC (EC, 2007), which gives a framework for the assessment and management of flood hazards and risks.

In this chapter, an introduction to risk and hazard assessment is presented, with particular reference to flood disasters.

2 Assessment of Hazards

A proper assessment of hydrological hazards requires the reference to a watershed, especially when the effects of runoff are of concern. In most cases flood hazard can be assessed in terms of probability of flooding, that is estimating the probability that flow rates become higher than the conveyance of the drainage system. However, when the extent of flooding and/or the water depths are to be estimated, other characteristics of the flood than just flow peak are to be considered, such as flood volume and duration, time to peak, number of peaks, and, more in general, hydrograph shape.

Joint modeling of the rainfall stochastic process and the rainfall-runoff transformation is needed for the flood hazard assessment. Continuous simulation of runoff, flow rates, and water depths in the drainage network can be performed for this purpose, from long series of rainfall events, either recorded in the past or synthetically generated by Monte-Carlo methods (Kottegoda, 1980). A possible alternative is a semi-probabilistic approach (Eagleson, 1972; Adams & Papa, 2000). This approach mainly relies on the coupling of probabilistic analysis of functions of random variables and deterministic models of hydrological processes. When the semi-probabilistic approach is considered for hazard assessment, rainfall events and hydrological processes must be described in terms of conceptual models, random variables, and deterministic parameters. To overcome the correlation among variables, copula functions can be used (Salvadori et al., 2007), although independence is often assumed.

2.1 Hydrological Events and Random Variables

The rainfall stochastic process is defined as a sequence of non-zero rainfall events and dry periods (Fig. 7.1). The number of events and the amount of rainfall (rainfall depth) can vary according to the minimum dry time interval that is assumed to consider independent events.

Probabilistic analysis of hydrologic processes is often performed under the following hypotheses: (Adams & Papa, 2000):

- Stationarity of rainfall stochastic process.
- Independent rainfall events.
- Statistically homogeneous rainfall characteristics (i.e., each drawn from the same population).
- Large sample size, enough to warrant the reliable fitting of probability distributions.

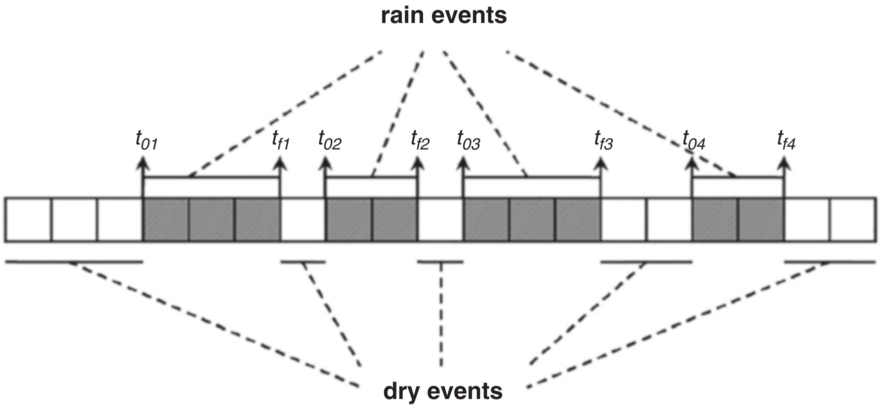

Fig. 7.1 Definition of rain and dry events. (From Garcia-Marin et al., 2008)

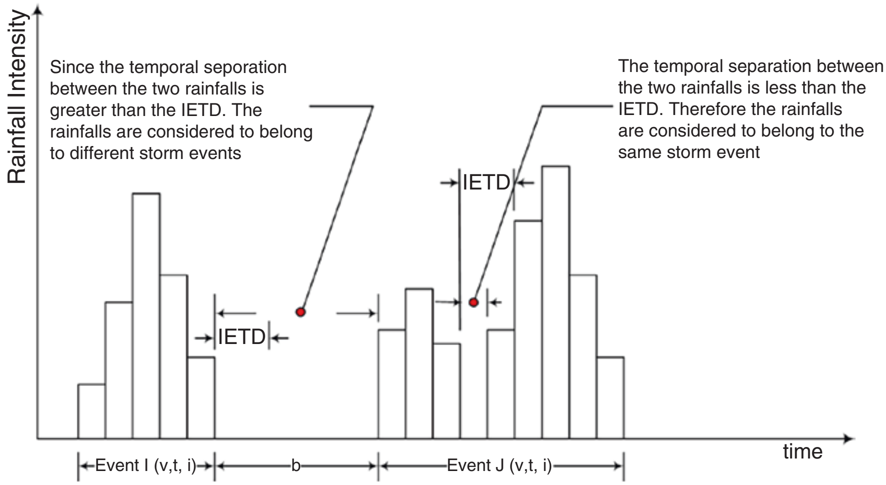

Fig. 7.2 Inter event time definition, IETD. (From Joo et al., 2014)

A minimum interevent time, called Inter Event Time Definition (IETD), is used to identify independent rainfall events in a series of records (USEPA, 1986; Bonta & Rao, 1988; Bonta, 2001; Huff, 1967; Wenzel & Voorhees, 1981). If the interevent time is smaller than IETD, the two events are joined into a single event, with depth equal to the sum of depths and duration equal to the sum of durations plus the inter-event time. Otherwise, they are assumed independent (Fig. 7.2). IETD values can range from 3 min to 24 h, though values of 6–8 h are usually adopted. Improper identification of the independent events may alter rainfall statistics, leading to wrong design and analysis (Adams et al., 1986).

To select the IETD, autocorrelation analysis (Restrepo-Posada & Eagleson, 1982; Grace & Eagleson, 1967; Sariahmed & Kisiel, 1968) and coefficient of variation analysis (Nix, 1994) were often used. Lee and Kim (2018) compared the PDFs of continuous rainfall events with the confidence range of the regression curve generated from the exponential distribution for different IETD values. Joo et al. (2014) proposed a method for the assessment of IETD that considers watershed characteristics and defines IETD as the time from the end of a rainfall event to the end of direct runoff; to ensure a one-to-one correspondence between rainfall and runoff events, IETD should be greater than the watershed time of concentration. A shorter IETD must be kept for small urban watersheds, with small concentration times, while for large rural watersheds IETD can be of several hours (Adam & Papa, 2000). In literature, also other criteria, different from IETD, were proposed to identify independent rainfall events. They include:

– A minimum rainfall depth (Ziegler et al., 2006; Balme et al., 2006; Vernimmen et al., 2007).
– A minimum rainfall duration (Cutrim et al., 2000; Formis et al., 2005).
– A minimum rainfall rate for a period within the event (Fornis et al., 2005).
– A minimum rainfall rate to identify the beginning and the end of storm events (Powell et al., 2007).

Balme et al. (2006) proposed the joint use of different criteria, including IETD, minimum duration, and minimum rain depth.

The main random variables involved in hydrological processes are rainfall depth, rainfall duration, rainfall intensity, and inter-event time. Rainfall variables are recorded at discrete time intervals, (minutes, hours, days), depending on gauging devices, and can be transformed on different time scales, according to the aim of the study. The daily scale is frequently used for hydrological analyses (Kou et al., 2007; Xie et al., 2016; Yin et al., 2015; Goswami et al., 2006), although this choice may limit a detailed statistical analysis of rainfall characteristics (Wang et al., 2019). Event-scale rainfall data are often required in studies on the hydrological effects of rainfall (Renard et al., 1997; USDA-ARS, 2013; Wischmeier, 1959).

2.2 Probability of Events and Distribution Functions of Hydrological Random Variables

Several studies on different watersheds concluded that rainfall variables can be considered exponentially distributed (Chow; 1964; Eagleson, 1972, 1978; Bedient & Huber, 1992; Howard, 1976; Chan & Bras, 1979; Adams & Bontje, 1984; Adams et al., 1986; Wanielista & Yousef 1993). This assumption is often accepted to reduce the computational complexity in semi-probabilistic approaches. Considering Italian watersheds, for example, the assumption of exponential PDFs is suitable for rainfall duration but is not fully satisfied for rainfall depth and inter-event time (Becciu & Raimondi, 2015a, b). Bacchi et al. (2008) verified that for most Italian watersheds the Weibull PDF is a better choice, giving a better fitting to the frequency distribution function. Becciu and Raimondi (2012) suggested the use of the double-exponential PDF, which showed to be proper for rainfall records in Milano (Italy). Studies on rainfall data recorded in Toronto (Adams & Papa, 2000) showed that, for specific locations, Gamma PDF better fits histograms, especially for rainfall depth and inter-event time; for the duration, the two PDFs are very similar, while for rainfall intensity the exponential PDF ensures a better fitting.

The use of such distributions, however, entails more complex mathematical models than exponential PDFs. If hydrological variables are assumed as exponentially distributed, their PDFs result:

$$f_h = \xi \bullet e^{-\xi \bullet h} \tag{7.1}$$

$$f_\theta = \lambda \bullet e^{-\lambda \bullet \theta} \tag{7.2}$$

$$f_d = \psi \bullet e^{-\psi \bullet (d - \mathrm{IETD})} \tag{7.3}$$

where h, θ, and d are respectively rainfall depth, rainfall duration, and inter-event time; ξ, λ, and ψ are parameters equal to the reciprocals of their average values. The sum of rainfall depths is generally considered a Gamma PDF (Raimondi & Becciu, 2014). For more simplicity, an exponential PDF can be also assumed for the sum of two random variables with exponential distribution (Becciu and Raimondi (2015a, b).

If rainfall duration is much smaller than inter-event time and it is assumed that inter-event time has an exponential distribution, a Poisson stochastic process can be assumed (Restrepo-Posada & Eagleson, 1982; Rodriguez-Iturbe et al., 1987; Edient & Huber 1992) and the PDF of the number of storm events in a defined period is:

$$f_N = \frac{M^N \bullet e^{-M}}{M!} \tag{7.4}$$

where N is the number of independent events in the period and M is the mean of N.

2.3 Correlation Among Hydrological Random Variables

Correlation among rainfall variables is negligible except for the correlation between rainfall duration and rainfall depth (Adam & Papa, 2000; Raimondi & Becciu, 2017). Figure 7.3 reports the correlation among rainfall variables measured at the Milano-Monviso rain gauge station in the period 1971–2005. While the correlation between inter-event time and rainfall depth and between inter-event time and rainfall duration is negligible, the correlation between rainfall depth and duration is quite high.

To properly consider the correlation between rainfall depth and rainfall duration, a joint distribution should be used. Although classic inference techniques can be

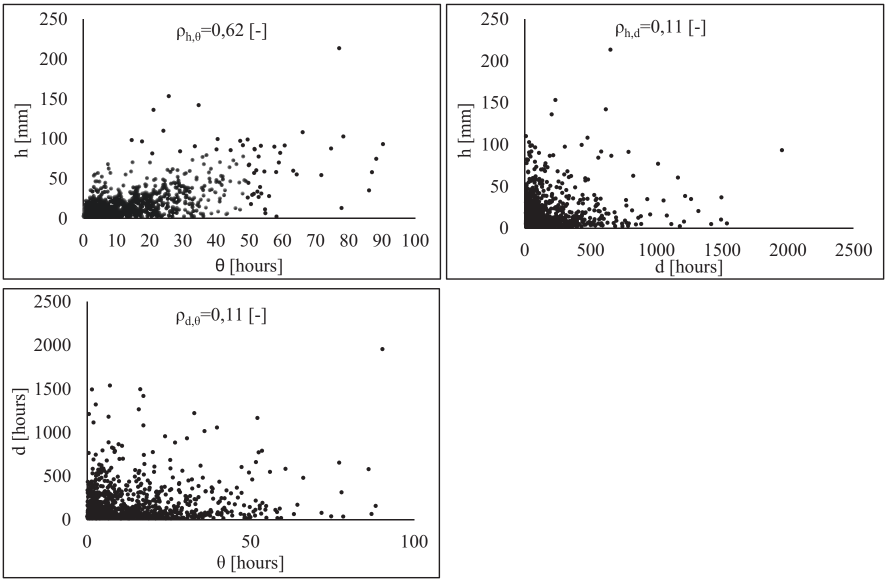

Fig. 7.3 Correlation among hydrological variables. (Milano-Monviso station, 1971–2005)

used to assess multivariate joint distribution functions, they can lead to unsatisfactory results. A significant improvement can be obtained using copulas (Joe, 1997; Nelsen, 2006; Balistrocchi & Bacchi, 2011). With this approach, the joint distribution functions can be developed from different marginal distributions. For example, in Italy, a Gumbel copula with Weibull marginal distributions seems the most appropriate (Bacchi et al., 2008; Balistricchi & Bacchi, 2011).

2.4 Conditional Probability

A fundamental variable for hydrological hazards assessment is surface flow (*I*). Considering a runoff coefficient (*f*) of the runoff surface area (*A*) and an initial abstraction (*IA*), it results:

$$I = \begin{cases} j \cdot A \cdot (h - IA) & if \;\; h > IA \\ 0 & if \;\; h \le IA \end{cases} \tag{7.5}$$

The randomness of surface flow depends mainly on the natural variability of rainfall depth; the term ($h - IA$) is defined as net rainfall depth (h_n):

$$h_n = \begin{cases} h - IA & if \;\; h > IA \\ 0 & if \;\; h \le IA \end{cases} \tag{7.6}$$

It is a non-negative continuous random variable which PDF can be derived from that of h (Benjamin & Cornell, 1970):

$$f_{h_n}(x) = f_{h/[h>IA]}(x+IA) = \frac{f_h(x+IA)}{1-F_h(IA)} \quad x>0; h>IA \tag{7.7}$$

where F_h is the cumulative density function (CDF) of rainfall depth h. Neglecting the uncertainty of runoff coefficient and runoff surface area, the PDF of surface flow results (Becciu et al., 2018b):

$$f_I(x) = \frac{1}{\varphi \bullet A} \bullet f_{h_n}\left(\frac{x}{\varphi \bullet A}\right) = \frac{1}{\varphi \bullet A} \bullet \frac{f_h\left(\frac{x}{\varphi \bullet A} + IA\right)}{1-F_h(IA)} \quad x>0; h>IA \tag{7.8}$$

Once defined the surface flow, Guo and Adams (1998) derived the peak discharge rate PDF, by means of conditional probability. Semi-probabilistic approaches were also used to assess different characteristics of runoff processes and evaluate the performance and reliability of structures for stormwater control, such as stormwater detention facilities and sustainable urban drainage systems, SUDSs (Raimondi & Becciu, 2014a, b, 2015, 2020; Raimondi et al. 2020a, b).

2.5 Trend and Autocorrelation in Stochastic Processes

Hydrological processes are ruled by complex interrelations among different kinds of natural dynamic phenomena. The series of hydrological variables, therefore, are often recognized as affected by both trends and autocorrelations. These features of the stochastic processes are particularly common in runoff series. Although several well-known techniques are available to consider these features, it is often convenient to perform the probabilistic analysis of hydrological variables under the simpler hypotheses of stationarity and stochastic independence (Kottegoda, 1980, Adams & Papa, 2000). This simplification is justified by the weak autocorrelation and trend that are observed in many cases.

3 Assessment of Risks

A very general definition of risk assessment was given by the American Association of Safety Engineers (ANSI/ASSE, 2011; Manuele, 2016): "Risk assessment is that part of risk management which provides a structured process that identifies how objectives may be affected and analyses the risk in term of consequences and their probabilities before deciding on whether further treatment is required. Risk assessment attempts to answer the following fundamental questions:

- What can happen and why (by risk identification)?
- Which are the consequences?
- What is the probability of future occurrence?
- Are there any factors that mitigate the consequence or that reduce the hazard?
- Is the level of risk tolerable or acceptable and does it require further mitigation actions?"

A similar general definition was given by the American Society of Safety Professionals (ASSP, 2019): "risk assessment serves many purposes for any organization, including reducing operational risks, improving safety performance, and achieving objectives. While many individuals are involved in the process and many factors come into play, performing an effective risk assessment comes down to three core elements: risk identification, risk analysis, and risk evaluation".

The first step required is then the risk identification. According to the ISO 31000-2018 standard, the following factors should be addressed by safety professionals and stakeholders:

- Tangible and intangible sources of risk.
- Threats and opportunities.
- Causes and events.
- Consequences and their impact on objectives.
- Limitations of knowledge and reliability of the information.
- Vulnerabilities and capabilities.
- Changes in external and internal context.
- Indicators of emerging risks.
- Time-related factors.
- Biases, assumptions, and beliefs of those involved.

Risk assessment matrices can be used to compare hazards and prioritize actions. Classifying risks, based on the probability and extent of a potentially damaging event, and placing them on a matrix or a map allows for determining the highest risk levels to address.

The second step is then the risk analysis, where the information obtained through risk identification can be used to analyze the risk level for each hazard and define actions according to a chosen criterion, for example, based on existing controls.

As specified by Rausand (2013), risk analysis must provide answers to these three needs:

(a) Hazard identification, which means not only identifying which are the hazards and the threats, but also the people and the assets that may be armed.
(b) Frequency analysis, with the identification of the causes of dangerous events, also based on experience and/or expert judgment.
(c) Consequence analysis, with an inductive analysis to identify all the potential final consequences, both direct and indirect.

Risk analysis may be performed either in a qualitative or quantitative way, depending on the object of the analysis. In the first case, both probabilities and consequences are evaluated in an empirical way. In the second, numerical estimates are performed, often along with associated uncertainties.

- Qualitative risk analysis is a risk analysis where probabilities and consequences are determined purely qualitatively.
- Quantitative risk analysis is a risk analysis that provides numerical estimates for probabilities and/or consequences, sometimes also with associated uncertainties.

Risk evaluation is the third and final step of risk assessment. It strictly depends on three main factors: hazard, which is the probability of occurrence of the threatening event, exposure, which represents the potential losses in terms of human lives and other valuable elements, and vulnerability, which represents the lack of resistance to damaging or destructive forces.

According to Kottegoda and Rosso (2008), the risk that a system does not meet the demand can be defined as the probability of failure p_f over the system's lifetime. This probability depends on the system operating conditions. System reliability, which can be denoted as r, is the complementary probability of non-failure, that is $r = 1 - p_f$.

It is worth to highlight that the definition of failure must be related not only to the collapse or to the complete loss of functionality of a system, but also to a reduced capacity to respond to project requirements or to meet users' demands. For example, a catastrophic flood that exceeds the design value may cause the break of a dam, but also only partial damages that, maybe together with a poor design, may cause low performance in the future use of water resources. Although engineers are primarily asked for the assurance of system performance and safety, economic and social constraints influence the acceptable levels of risk. Therefore, an accurate cost-benefit and environmental analysis must be performed before planning and designing an engineering system.

The simpler and most effective approach, especially in natural disaster analysis, is to define the risk as the combination of the probability of a potentially dangerous event and its adverse consequences (Kron, 2002; Bignami et al., 2019). Without damages or losses of any kind, there is no risk, whatever the importance or the level of the potential danger of an event is. Similarly, an event is considered a catastrophe when damages and losses are huge.

So, the probability of a potentially dangerous event (hazard) has to be combined with the number of values in the area in which effects are expected (exposure), as well as their susceptibility to losses (vulnerability). Hence, the risk can be expressed as a function of these three quantities.

All the factors that determine risks are variable. Although the occurrence and the intensity of threatening natural phenomena are beyond human control capacity, their effects can be mitigated through proper measures. For instance, for a given rainfall event, the hazard related to the consequent flood volume and peak flow downstream a watershed can be reduced by regulations on land use, agricultural practices, and defense works. In addition, the exposure can be controlled by avoiding hazard-prone areas and settlements. Moreover, increasing the structural and water resistance of buildings and infrastructures reduces vulnerability.

The usual approaches analyze these factors (i.e., hazard, vulnerability, and exposure) separately, merging results empirically, with the major aim of just ranking the risk levels. This implies that the three factors are assumed to be mutually independent, without considering their mutual relations. Although this approach is simpler and can be useful in most cases, it can cause significant bias in risk evaluation and also on real effects of mitigation measures in more complex scenarios (Danielsson & Zhou, 2016).

However, taking into account these interactions requires complex analysis, and achieving a proper insight into the mechanisms and feedback involved, independently of the kind of deterministic or stochastic methods adopted, is generally difficult. For instance, considering the flood risk there is a need for merging knowledge from hydrology and social sciences (Sivapalan et al., 2012; Di Baldassarre et al., 2015; Gober & Wheater, 2015) and/or ecology and hydrology (Eagleson, 2002; D'Odorico & Porporato, 2006; Good et al., 2015).

Particularly, it is enough clear that vulnerability to natural disasters is mostly linked to the country's development level and also to the quality of its environment (Peduzzi et al., 2009). Different degrees of vulnerability are observed in different social groups in both developed countries (Cutter & Finch, 2008; Fekete, 2009; Dzialek et al., 2016) and developing ones (Adger, 2006; Rasch, 2015; Salami et al., 2017).

A risk matrix can be used for risk assessment, merging the probability of the event and the severity of its consequences. This is a simple approach, useful in decision-making. Although standard risk matrices were proposed to be used in certain contexts (e.g., ISO, 2018), general matrices can be developed. For example, the consequences in terms of life losses (Severity) can be categorized as:

- Catastrophic or fatal, in case of multiple deaths.
- Critical or major, in case of one death or multiple severe injuries.
- Marginal or moderate or minor, in case of one severe injury or multiple minor injuries.
- Negligible or trivial, in case of one minor injury.

The probability (likelihood) of an harmful event might be categorized as "certain", "likely", "possible", "unlikely", and "rare" or "remote". The resulting risk matrix could be qualitative (Fig. 7.4), quantitative (Fig. 7.5), or a mix (Fig. 7.6):

Risk matrices allow the estimation of different levels of risk associated with different events. Although a risk matrix is a very powerful tool, it has some limits (Cox, 2008):

- Poor resolution. Typical risk matrices can correctly and unambiguously compare only a small fraction (e.g., less than 10%) of randomly selected pairs of hazards. They can assign identical ratings to quantitatively very different risks ("range compression").

	Negligible	Marginal	Critical	Catastrophic
Certain	High	High	Extreme	Extreme
Likely	Moderate	High	High	Extreme
Possible	Low	Moderate	High	Extreme
Unlikely	Low	Low	Moderate	Extreme
Rare	Low	Low	Moderate	High

Fig. 7.4 Example of a qualitative risk matrix

Severity \ Likelihood	Remote	Unlikely	Possible	Likely	Certain
Fatal	5	10	15	20	25
Major	4	8	12	16	20
Lost time	3	6	9	12	15
Minor	2	4	6	8	10
Trivial	1	2	3	4	5

Fig. 7.5 Example of a quantitative risk matrix

- Errors. Risk matrices can mistakenly assign higher qualitative ratings to quantitatively smaller risks. For risks with negatively correlated frequencies and severities, they can be "worse than useless", leading to worse-than-random decisions.
- Suboptimal resource allocation. Effective allocation of resources to risk-reducing countermeasures cannot be based on the categories provided by risk matrices.
- Ambiguous inputs and outputs. Categorizations of severity cannot be made objectively for uncertain consequences. Inputs to risk matrices (e.g., frequency and severity categorizations) and resulting outputs (i.e., risk ratings) require subjective interpretation, and different users may obtain opposite ratings of the same quantitative risks. These limitations suggest that risk matrices should be used with caution, and only with careful explanations of embedded judgments.

The most significant limitation is that risk matrices can give an arbitrary risk ranking (Thomas et al., 2014). The design of the matrix, such as the way likelihood and severity are classed, may influence risk rankings.

		Consequence				
		Negligible 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	5 Almost certain	Moderate 5	High 10	Extreme 15	Extreme 20	Extreme 25
	4 Likely	Moderate 4	High 8	High 12	Extreme 16	Extreme 20
	3 Possible	Low 3	Moderate 6	High 9	High 12	Extreme 15
	2 Unlikely	Low 2	Moderate 4	Moderate 6	High 8	High 10
	1 Rare	Low 1	Low 2	Low 3	Moderate 4	Moderate 5

Fig. 7.6 Example of a qualitative and quantitative risk matrix

Risk communication is another important issue, and it must be indeed a further fourth element of the risk assessment process, threaded throughout all the already mentioned three steps and equally crucial to effective risk management. Results of risk identification, analysis, and evaluation must be communicated to all the stakeholders to provide a proper understanding and evaluation of possible mitigation actions. Particularly, the population should be aware of the risks in their area and how to behave in case of an extreme event. Finally, it must be stressed the importance to clarify the criteria on which risks are managed and correlating them to the consequent actions, also implementing the proper monitoring tools for risk management (Ranke, 2016).

3.1 Risk

As already mentioned, three components determine the risk, *R*:

1. Hazard, *H*, represents the threatening natural event in terms of its probability of occurrence.
2. Exposure, *E*, represents the human lives and the other values that are involved.

3. Vulnerability, V, represents the lack of resistance to damaging (or destructive) events.

While hazard H is definitively a probabilistic quantity, given a chosen average return interval (ARI) and a probability distribution of the random variables characterizing the event, apparently vulnerability V and exposure E are deterministic quantities. But, indeed, also these last two are subject to relevant uncertainties and their values could vary according to several factors (e.g., in the case of flood risk analysis: peak flow rate, flood volume, initial conditions in the area, etc.).

A formal probabilistic approach, that is far too complex for most of the practical applications, is:

$$R = R(H,E,V) = \iiint p(H,E,V) \cdot \mathrm{d}H \cdot \mathrm{d}E \cdot \mathrm{d}V \tag{7.9}$$

where p (H, E, V) is the joint probability density function of H, E, and V.

In its simpler form, the risk is computed just by multiplying the three components:

$$R = H \bullet E \bullet V \tag{7.10}$$

Indeed, for any approach, it is generally quite difficult to attribute proper values to these three parameters, especially to E and V. Nevertheless, exposure E and vulnerability V can be combined to form a quantity C representing the consequences resulting from a single event with an occurrence probability P (Kron, 2002):

$$R = P \bullet C \tag{7.11}$$

Very often, however, disasters (especially the natural ones) do not present themselves just in the form of one single event, with a given probability of occurrence, but in many different forms, with different possible outcome values which can be even infinite. A typical situation of this kind is the risk created by flood discharges Q:

$$R = \int_{\infty}^{Qa} C(Q) \bullet p(Q) \bullet \mathrm{d}Q \tag{7.12}$$

where:

$C(Q)$: costs of the losses caused by a given discharge rate Q;
$p(Q)$: probability density function of the discharge Q;
Qa: flood value above which losses start to occur.

In general, integration cannot be carried out analytically, except for combinations of $C(Q)$ and $p(Q)$ originating simple mathematical expressions of the quantity $C(Q) \cdot p(Q)$.

3.2 Hazard

Hazard H is the probability that a potentially damaging event, which may harm people, economic assets, infrastructure, environment, and so on, will occur in a given period and in a given place. The possible values of H range from 0 (impossible event) to 1 (certain event). If the potentially damaging event is characterized as a quantity with a variable intensity I, then hazard H can be expressed as $H = H(I)$. In hydrology, a typical example is the hazard of flooding, where the characterizing quantity is the flood peak flow Q and therefore the hazard can be expressed as $H = H(Q)$. A detailed discussion of the probability distribution functions suitable for hazard description has been discussed in Sect. 2.2.

3.3 Exposure

Exposure E is a measure of the importance of the elements exposed to the damaging event. It can be expressed either in terms of money, using other dimensional indicators, or with dimensionless values ranging from 0 (no value) to 1 (invaluable). The use of a range between 0 and 1 is suitable especially when the aim of risk analysis is just to define a heuristic risk ranking of the considered threats. If the potentially damaging event is characterized as a quantity with a variable intensity I, then the exposure E can be expressed as $E = E(I, G)$, where G summarizes the group of elements that can be affected. Table 7.1 shows an example of the main factors and related indicators of exposure for, respectively, structures, population, and economy.

3.4 Vulnerability

Vulnerability V is a measure of the weakness in front of a possibly damaging event of human communities, structures, infrastructures, services, and environments in a risk-prone area that are likely to be damaged or disrupted, on account of their nature or location (Wanga et al., 2012). It is also related, especially considering also

Table 7.1 Example of main factors and related indicators of exposure

Main factor	Indicator name	Indicator
Structures	(E1) Number of housing units	Number of housing units (living quarters)
	(E2) Lifelines	Percentage of homes with piped drinking water
Economy	(E3) Total resident population	Total resident population
Population	(E4) Local gross domestic product (GDP)	Total locally generated GDP in constant currency

Bollin and Hidajat (2006), UNU-IEHS and NNSUACE (2006) climate change, to the lack of resilience of the exposed element or system to cope with and adapt to dangerous events (Cardona et al., 2012). The numerical values of the vulnerability are dimensionless and range between 0 (no damage) to 1 (destruction).

In general, if the potentially damaging event is characterized as a quantity with a variable intensity *I*, then vulnerability *V* can be expressed as $V = V(I, G)$, where *G* summarizes the group of elements that can be affected.

As summarized by Fuchs et al. (2012) and Papathoma-Köhle (2016), vulnerability matrices (Sage, 2005; Islam & Ryan, 2016), vulnerability curves (Papathoma-Köhle et al., 2012, 2017; Papathoma-Köhle, 2016), and vulnerability indicators (Bollin and Hidajat, 2006; UNU-IEHS and NNSUACE, 2006; De Ruiter et al., 2017) are most commonly used for assessing physical vulnerability.

For example, Fig. 7.7 shows a Typical Vulnerability Risk Matrix and related Vulnerability Prioritization Scale (Sage, 2005), while Fig. 7.8 shows an example of different vulnerability curves fitting the experimental data of the case study of Martell Valley, South Tyrol (Papathoma-Köhle et al., 2012), and Table 7.2 shows an

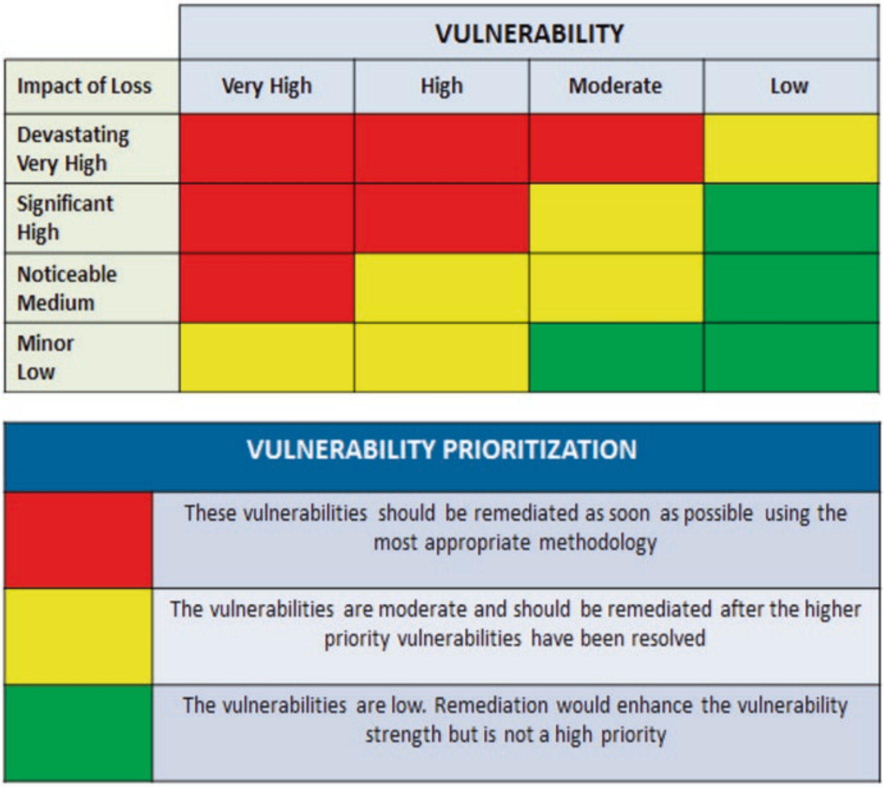

Fig. 7.7 Typical vulnerability risk matrix and related vulnerability prioritization scale. (From Sage 2005)

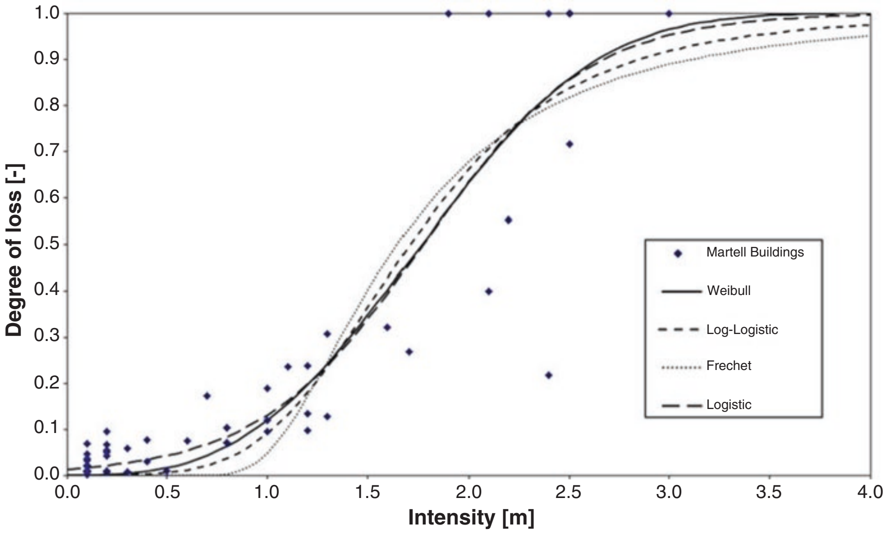

Fig. 7.8 Relationship of the degree of loss for buildings in the Martell Valley, South Tyrol, and the debris flow intensity expressed as deposition height. (Papathoma-Köhle et al., 2012)

Table 7.2 Example of main factors and related indicators of vulnerability

Main factor	Indicator name	Indicator
Physical/ Demographic	(V1) Density	People per km^2
	(V2) Demographic pressure	Population growth rate
	(V3) Unsafe settlements	Homes in hazard-prone areas (ravines, river banks, etc.)
	(V4) Access to basic services	Percentage of homes with piped drinking water
Social	(V5) Poverty level	Percentage of population below poverty level
	(V6) Literacy rate	Percentage of adult population that can read and write
	(V7) Attitude	Priority of population to protect against a hazard
	(V8) Decentralization	Portion of self-generated revenues of the total budget
	(V9) Community participation	Percentage of voter turnout at last municipal elections
Economic	(V10) Local resource base	Total available local budget in US$
	(V11) Diversification	Economic sector mix for employment
	(V12) Small business	Percentage of business with fewer than 20 employees
	(V13) Accessibility	Number of interruptions of road access in the last 30 years
Environmental	(V14) Area under forest	Percentage of the municipality area covered with forest
	(V15) Degraded land	Percentage of the area that is degraded/ eroded/desertified
	(V16) Overused land	Percentage of agricultural land that is overused

From Bollin and Hidajat (2006), UNU-IEHS and NNSUACE (2006) example of main factors and related indicators of vulnerability (Bollin & Hidajat, 2006; UNU-IEHS and NNSUACE, 2006).

4 Case Studies

4.1 Seveso River in Milano, Italy

The Seveso river is a small stream flowing from North toward the city of Milano (45°29′10″ N, 9°12′13″ E). The Seveso watershed, when reaches Milano metropolitan area, has approximately 226 km^2 area, of which about 100 km^2 is highly urbanized. The river flows across the city of Milano in an underground channel for about 7 km, before merging into the river Lambro in the south. Although is considered a minor river in Italy, the Seveso is well known for the frequent flooding and resulting damages to the city of Milano. In the last 140 years, more than 340 floods (i.e., 2.4 per year) were registered, of which about 110 since 1976. To reduce the frequency of flood events, a by-pass channel (called CSNO) was built in the 1980s of twentieth century before the river reaches the city, to divert part of the flow to the river Ticino. Although this measure seemed to be effective at first, after a few years, with the growing urbanization, the efficiency became negligible and a new plan for large detention reservoirs was prepared and is currently in construction (Becciu et al., 2018a). Hydraulic-hydrologic modeling was used to assess flood risk in the city of Milano from the Seveso river watershed. The assessment framework was based on the joint estimation of hydrological hazard, expressed in terms of critical rainfall intensity probability (i.e., corresponding to peak discharges over the underground channel hydraulic conveyance), and of vulnerability, expressed in terms of flooded urban area extension. According to Italian regulations, in compliance with EU Flood Directive 2007/60/EC, the hazard is classified into three classes, from P1 (Low) to P3 (High) (Table 7.3). The vulnerability is classified into four classes, expressed in terms of the degree of damages, from D1 (Low) to D4 (Very High) (Table 7.4).

Combining hazard and vulnerability, the risk is classified into four classes, from R1 (low) to R4 (very high) (Table 7.5).

Figure 7.9 shows the hazard and risk map of the north area of Milano, where the R4 area is highlighted, meaning the area with class hazard P3, meaning a high

Table 7.3 Classification of flooding hazards

Class of hazard	Probability of flooding	ARI [years]
P1	Low	200 ÷ 500
P2	Medium	100 ÷ 200
P3	High	20 ÷ 50

Table 7.4 Classification of vulnerability to flooding

Class of vulnerability	Damage	Type of area and effects
D1	Low	Non-urbanized, free of manufacturing activity
D2	Medium	Minor infrastructures and manufacturing activities. Limited effects on people and economy.
D3	High	Risk for people and economy. Major manufacturing activities and lifelines.
D4	Very High	Risk of life losses. Relevant damages to buildings, infrastructures, heritage, economy, and environment.

Table 7.5 Classification of flooding risks

Class of risk		Class of hazard		
		P1	P2	P3
Class of Vulnerability	D1	R1	R1	R1
	D2	R1	R2	R3
	D3	R2	R3	R4
	D4	R2	R4	R4

probability of flooding for an ARI of 20–50 years, and vulnerability D4, meaning a very high risk of life losses and property damages. Risk mitigation measures to reduce floods considering 100 years ARI would require the implementation of at least five retention reservoirs with an estimated cost of around 130 million Euros (Becciu et al., 2018a).

4.2 *Anhangabaú Watershed, San Paolo, Brazil*

The Anhangabaú watershed is in San Paolo (23° 33′ 0.9925″ S, 46° 38′ 29.5523″ W), the most populous city in the Americas, covering an area of approximately 5.4 km^2 with 78% impermeable surface and most of watercourses culverted. The area is frequently affected by floods, with an average of 147 registered flood events in the years 2008–2012. A risk assessment study held by FCTH (Fundação Centro Tecnológico de Hidráulica) and the San Paolo municipality provided watershed hazard and risk maps considering three risk mitigation solutions and the effect on the watershed of adopting source control measures for stormwater. The considered risk mitigation structural measures were: the implementation of two storage tanks with a total of 80,000 m^3 capacity (alternative A), a by-pass channel discharging to a downstream basin (alternative B), and the implementation of "superpipes", i.e., substituting stretches of the existing drainage system with pipes with >3 m cross-section diameter that would function as reservoirs (alternative C) (Silva et al., 2014). Hydrologic modeling was used to assess hazards by the PCSWMM package for the current scenario and three risk mitigation solutions for 100 years ARI. The existing

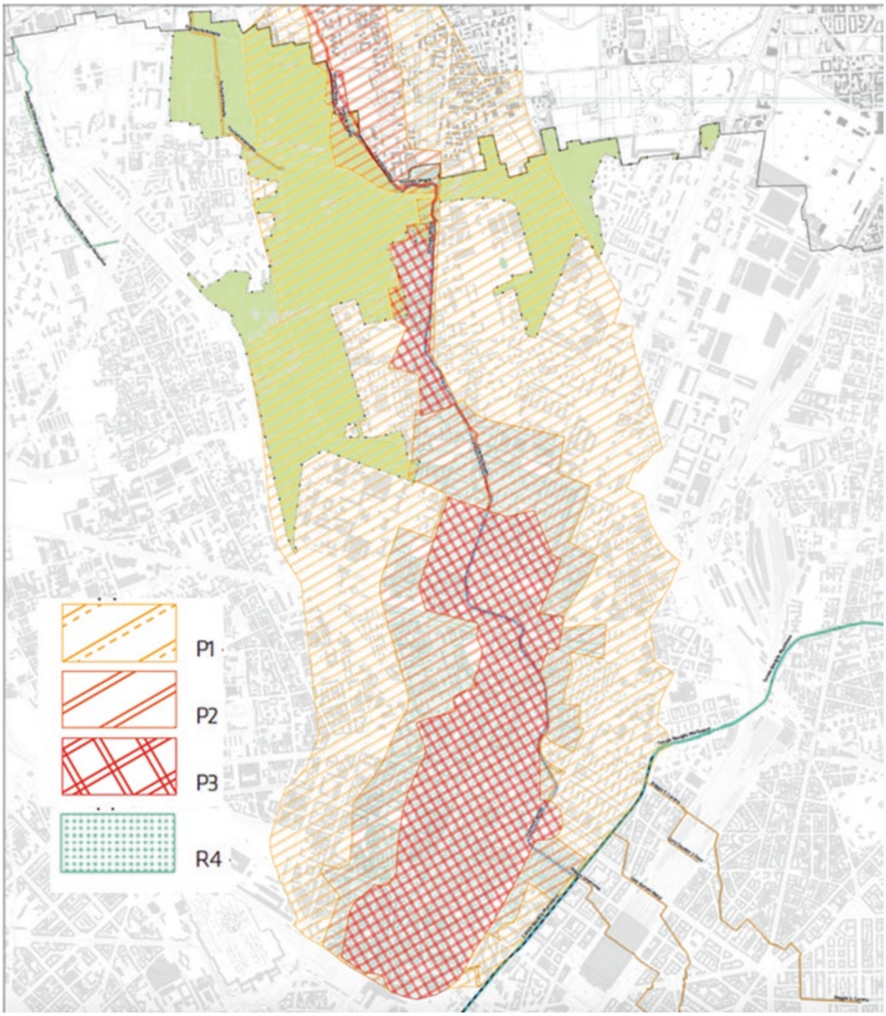

Fig. 7.9 Map of flooding hazard and risk in the north area of Milano

network considered in the model consisted of a total of 110 km of roads, 50 km of drainage network system, and 2802 nodes representing curb inlets and drainage grates (Fig. 7.10). Precipitation data were gathered in five stations within the watershed and tree rainfall-runoff events were used for model calibration (Silva et al., 2014).

Water depth can reach over 50 cm on 15% of the watershed area for a 100-year ARI, with flooding concentrating on the square Praça da Bandeira located on the floodplain where the two major streams of the watershed affluence on the Anhangabaú stream. Risk assessment in the current scenario: 21.6% of buildings are considered under high risk, 43.5% under medium risk, and 34.8% under low risk.

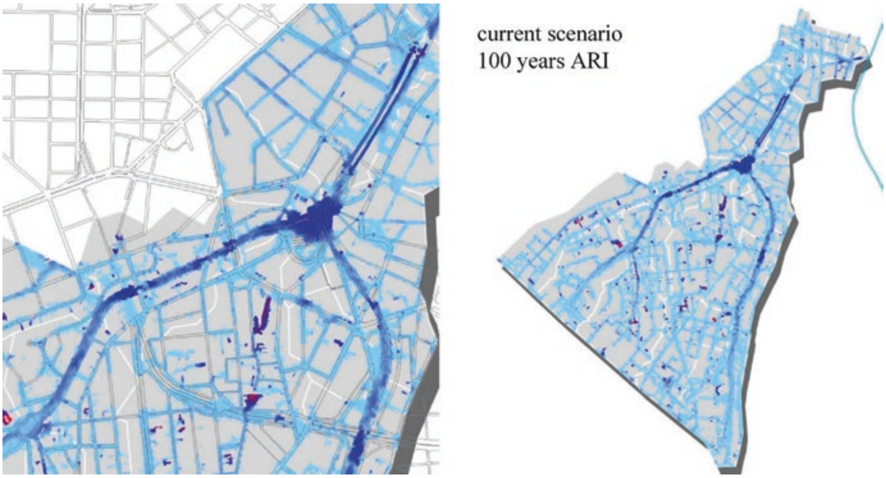

Fig. 7.10 Flooding hazard map of the Anhangabaú in current scenario for 100 years ARI; floodplain (left) and the entire watershed (right). (Silva et al., 2014)

Table 7.6 Risk level on the percent of buildings within the watershed considering different scenarios for ARI = 100 years

Risk level	Current scenario (%)	Solution A (%)	Solution B (%)	Solution C (%)
Low	34.8	35.8	37.9	48.0
Medium	43.5	45.8	45.7	44.2
High	21.6	18.4	16.4	7.8

Among the possible risk mitigation measures, the alternative C results to be the most effective, being the areas with water depth above 50 cm in case of flooding reduced to 3% of the watershed surface.

The risk assessment used the criteria in Table 7.5, which considered low risk when water depth was confined to street level, medium level when water depth reached sidewalks, and high risk when water depth reached 15 cm above sidewalks. Considering a 100-year ARI event, the risk analysis showed that 35% of buildings are under low risk, 44% under medium risk, and 22% under high risk. Solution A allows a reduction of the buildings under high risk for 100-year ARI event from 21.6% to 18.4%, solution B from 21.6% to 16.4%, and alternative C from 21.6% to 7.8% (Table 7.6).

5 Conclusions

The assessment of hazards and risks is a complex task. Indeed, all the different pieces of information have to be considered and analyzed, with uncertainties due to, among others, system evolution in time and space, weak or strong correlation among various factors, and even the lack of reliable data (Frewer et al., 2003; Rougier et al., 2013). Moreover, the random nature of meteo-climatic factors is an additional element of complexity in the evaluation of hydrologic disasters (Sahani et al., 2019).

Although well-established approaches are available from the literature for this assessment, as synthetically presented in this chapter, some current and future challenges are worth to be considered. Particularly, more research efforts should be devoted to developing conceptual and practical frameworks for the analysis of issues such as multi-hazard scenarios (Sadegh et al., 2018), infrastructure interdependency (Hickford et al., 2018; , resilience capability (Rehak et al., 2018), and fast-changing systems.

An increasing awareness must be focused on the possible combination and interrelation of hazards of different kinds, especially in densely populated areas, with particular concern for the Na-Tech (natural and technological) risks. Sometimes this condition is due to the same event, others it's due to cascade effects, in which a triggering event is at the origin of others. An example of the first case is intense rainstorms, that at the same time increase both river flows and water stage in receiving water bodies. A classic example of the second case is the earthquake that may induce landslides over river channels, with the formation of flood waves both upstream and downstream, or a chain of catastrophic events amplified by a lack of adequate prevention, like the Fukushima tsunami and consequent nuclear accident (IAEA, 2015; Synolakis & Kânoğlu, 2015).

Also, the mutual interdependency of infrastructures may lead to a possible increase in risks (Giannopoulos et al., 2012; Wang et al., 2019; C40, 2017, Heino et al., 2019). Flooding in urban areas, for example, may produce a failure of electric and data networks, with the consequent outage of control devices, such as flood gates and pumps, while intense rainstorms may damage sensors on which alert systems rely. On the other hand, current technology offers new opportunities for increasing both the real-time, space-distributed knowledge of system status and the capabilities of real-time defensive reactions.

So, more and more efforts are being made in this field, in terms of both research and technology, to fill the knowledge gaps and improve the procedures for risk assessment. Nevertheless, many open issues are still present on the stage, and current and future challenges are waiting to be accepted.

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Chapter 8
Floods in Tutong District, Brunei Darussalam and the Role of Tutong River: Approaches for Mitigation Measures

Shafi Noor Islam, Sandra Reinstädtler, and Khairunnisa Haji Ibrahim

Abstract Brunei Darussalam is a small country located in Southeast Asia, divided into four administrative regions, the districts of Brunei-Muara, Tutong, Kuala Belait, and Temburong. The country has enormous natural and water resources. Rainfall is an essential phenomenon in Brunei Darussalam. Brunei's saline seawater and significant rivers play an important role in protecting the natural landscapes and developing and fertilizing the apartment lands. Tutong District is located in the country's middle and shows proximity to the South China Sea to the west. The Tutong River basin carries water from the Rambai region to the South China Sea, with a tidal distance upstream covering the Tutong catchment area. The monsoon rains and extreme rainfall resulting from climate change will likely cause challenges in managing increased river flow, causing flooding in the Tutong District floodplain. Floods or flash floods are the most common natural disasters that frequently affect Brunei Darussalam and the low-lying flood-prone areas of Tutong District. The trend of wet days in Brunei is increasing, which can be seen from rainfall data and flooding conditions in four districts in Brunei. Tutong District has experienced several floods over the past two decades. In 2014 alone, over 115 cases of flooding and 105 landslides were reported. This study examines the trends and patterns of flooding and flash floods in Tutong District. The impact of climate change in the affected areas in Tutong District is mapped. The study will seek alternative environmental solutions to develop sustainable flood mitigation strategies for sustainable natural hazards measures and management in Brunei Darussalam.

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1 Introduction

The Nation of Brunei is located in Southeast Asia on the North side of the island of Borneo and has Bandar Seri Begawan (BSB – 100.3 km^2 extent) as the main city and capital of the country of Negara Brunei Darussalam. General hazard risk is high being impacted by global climate change as well as by the country's local geography and Brunei's relative location in the Asia–Pacific Region (Gupta, 2010; Saxena et al., 2012; NIDM, 2014; Ndah & Odihi, 2017). Floods and landslides are the most prevalent hazards (NIDM, 2014; Irlapati, 2017). Thereby the types of monsoon floods or flash floods are predominant. With especially 97% of the Bruneian population living in the western lowland region (NIDM, 2014) and, in general, low-lying areas being more flood-prone, this research is most important for the country and one of four districts of Brunei Darussalam, Tutong District. Also, next to district perspectives, similar worldwide situations are given, for which this regional case study is comparable to many other countries and regions with similar initial situations (NIDM, 2014; Gupta, 2010).

So the main observation and case study area of this research, Tutong District, has an area extent of 1116 km^2 (NIDM, 2014) while the entire area extent of the country is 5765 km^2 (2226 sq. mi) (land: 5265 km^2 (2033 sq. mi); water: 500 km^2) (Hassan, 1988; CDD, 1993, 2008; Ibrahim, 2005; Khatib & Sirat, 2005; Omar, 2005; Osman & Lim, 2018). Tutong District grew from 19,151 people in 2021 (World Population Review, 2021), while Brunei Darussalam's total population was 423,200 in 2014 (NIDM, 2014). The Tutong River system's catchment area is about 1300 km^2 with a multi-layered estuarine structure that has formed two sandpits over time. Tutongs' height above water (sea) level accounts for 7 m, and elevation is up to 13 m (FloodMaps, 2020). Although Brunei Darussalam is consecrated with minimal occurrence of natural phenomena, Brunei is still vulnerable to flooding activity because of the country's geographical location or climate conditions, for instance. Moreover, the natural hazard of flooding increases the risk of further environmental catastrophes (Islam, 2020, 2021), such as landslides, which frequently happen in Brunei. On top of that, climate change and environmental degradation are increasingly discussed and recognized topics in today's society (Islam & Gnauck, 2007, 2009, 2011). In addition, the Tutong area, especially the rural areas of Tutong, is highly vulnerable to flood hazards compared to the other three districts: Flooding has subsided most areas of Tutong District, and these low-lying areas are especially prone to flooding during the monsoon season (Islam et al., 2019). Therefore, authorities and residents remain on high alert: For example, heavy rains on December 7th, 2020 caused a rise in water level and affected 47 families, with at least evacuations being unnecessary (Bakar, 2019). The heavy rains also triggered two landslides in kampongs (Kg) of Kg Ukong and Kg Lamunin. As heavy thunderstorms were afterward expected and may have caused flash floods in low-lying areas, the Brunei

Darussalam Meteorological Department continued to issue weather warnings (Islam et al., 2018, 2019). These weather warnings are some of the important measures for further crisis prevention and risk reduction.

Therefore, approaches for mitigation measures have to be further developed next to an early warning system and other initiatives that have been or still must be considered to reduce the risk of flooding in vulnerable areas (Islam, 2010a, b; Reinstädtler, 2022a, b, c). So this chapter highlights the involvement of mitigation measures against flooding at the Tutong River in the affected area. In general, this research emphasizes the function of rivers in flooding by focusing on the Tutong River case in Negara Brunei Darussalam. As it is essential to know the main driving forces and pressures within natural hazards such as (monsoon) floods or flash floods in order to develop adequate risk preparations in the form of mitigation approaches, the following research requests were set up for a further structured assessment:

(a) Is Tutong River playing a potential role in creating a flood in Tutong District, or which other sources of floods are important?
(b) And/or are natural or other phenomena the most important drivers for flooding in Tutong besides the general human influences as well as climate change impacts functioning as a driving force in flooding Tutong District (Islam et al., 2014a, b, 2018)?
(c) Which impacts of floods on the socio-economy of the flood-prone areas exist?
(d) How will the mitigation approach(es) be developed in correlation to these results so that better risk reduction and prevention for Tutong District result in chances?

This research examined the trends and patterns of flooding and flash floods in Tutong District in Brunei Darussalam. An analysis of the conceptual model will be investigated to understand the people's perception of the flood-prone concept.

Based on the aim of this study, the specific objectives have been considered that will meet up the aim of this study in Tutong District:

(a) To investigate the flooding and the impacts of floods in the affected areas in Tutong District.
(b) Mapping the flood-prone areas in Tutong District and examining the impacts on human livelihoods and socio-economy.
(c) To seek alternative environmental solutions to develop a sustainable flood mitigation policy for sustainable management of natural hazards in Tutong District as well as for the entire Brunei Darussalam.
(d) To prepare potential recommendations for floods and natural disasters mitigation measures for Tutong District and Tutong River Basin (TRB).

In this way, the chapter on floods in Tutong District in Brunei Darussalam and the role of Tutong River with its approaches to mitigation measures are structured by first describing data and methodology, followed by the description of the geographical location, physical setting and cultural characteristics of the case area. This description of natural and cultural characteristics is essential for a further assessment of flooding drivers, impacts, or solution findings. The results are such as following with highlighting the sources of floods in Tutong District in Brunei Darussalam, the flood disaster risk in Tutong District, the role of the Tutong River for flooding in the catchment area, impacts of floods on the socio-economy in the flood-prone areas, and a closing up approach for flood mitigation measures and solutions. The discussion part, conclusions, recommendations, and a summary complete the chapter outcome.

2 Data and Methodology

This research utilizes various materials and methods to study the effects of the annual flooding in Tutong District in Brunei Darussalam. The study has been designed based on the primary and secondary data sources. Data collection for this study is a combination and collection of quantitative and qualitative research methods. Qualitative methods were used to develop and collect new ideas and perceptions about the involvement of Tutong River Basin (TRB) in the hazardous occurrence of flooding. Quantitative research data, such as analytical observations and some primary data, have been collected from field observation and field-level interviews with the senior citizens and the victim or flood-affected people in Tutong District. Partially, several field visits were processed, where observations on the flood-affected areas took place, especially within the almost every year flood-affected kampongs such as Tanjong Maya, Sungai Damit, Penapar, Keriam, Telisai, Kiudang, Lamunin, Rambai, and Ukong (flood-prone areas have been indicated in Figs. 8.2 and 8.3) (also comp. DI, 1992). The primary data and information concerning yearly flood-affected areas, affected people, and houses were collected in a database on field level in Tutong District. It includes statistical data and interpretation of the data collected. Google Earth (2020), FloodMaps (2020; with further data sources of Leaflet, Esri, OpenStreetMap, Mapzen, TNM, SRTM, GMTED, ETOPO1), and GlobalFloodMaps (2020) (in comparative form) are three of the applications used to show and display flood-prone areas.

Nevertheless, it has to be stated that flood mapping applications, in general, do not show historical or current flood levels. It depicts, for instance – and depending on the input – an area below the set elevation (Islam, 2016). The collected data have been rearranged and developed for analysis. The excel program has been used for graphs or tables, and some further software has been used for analysis and displayed. ArcGIS 10.5 has been used for flood mapping of the case area. The satellite images of the affected areas have been used to map and interpret flood impacts. The primary data sources from field investigation and data collection were from the years 2019, 2020, and 2021, often just after the floods.

Moreover, secondary data have been used to make the participatory flood mapping on the flood-prone areas in Tutong District. These areas are evaluated and monitored for the events that could trigger such a disaster in the affected areas. The Tutong flood-prone area maps have been prepared based on primary and secondary data. Especially field observation (primary data) as well as partially newspaper information (a smaller part of the secondary data partially using Borneo Bulletin daily News Paper and MOH) have been considered for data arrangement or even rearrangement.

3 Geographical Location, Physical Setting, and Cultural Characteristics of the Case Area

Brunei Darussalam, officially Nation of Brunei, the Abode of Peace, is lying in the Southeast Asian Malay Archipelago and is situated on the equatorial line between the southern and northern hemispheres and is placed at latitudes and longitudes of approximately 4° 30′N and 114° 40′E, respectively. Brunei Darussalam is located on the northwest coast of Borneo Island, which also belongs to Indonesia and Malaysia (Fig. 8.1). Its capital city is Bandar Seri Begawan. Tutong Town, named in Malay Pekan Tutong, is as district city of Tutong District, the third largest district town in Brunei Darussalam. The country is divided into east and west areas throughout the Malaysian northern part and the state of Sarawak the Island. The western part of Brunei is predominantly hilly lowland, whereas the eastern part consists primarily of rugged mountain terrain. So, apart from the Brunei Darussalam coastline to the South China Sea, it is surrounded by the East Malaysian state of Sarawak. Brunei shares a 266 km (165 mi) (CFE-DM, 2018) border with Malaysia, and Sarawak has an enclave, the district of Limbang, along the Limbang River that splits Brunei Darussalam into that two separate parts (Fig. 8.1; GIS Lab UBD, 2020; comp. FloodMaps, 2020) (Brown, 1970, p. 132; Hassan, 1988; CDD, 1993, 2008; Ibrahim, 2005; Khatib and Sirat, 2005).

Brunei Darussalam is the one state located entirely on the island of Borneo (named in Indonesia Kalimantan Island). The summit ridge of Bukit Pagon, in the western part, contains the country's highest point, with an elevation of 1850 m above sea level. The lowest point is the South China Sea (0 m). The coast has a vast, tidal, and swampy plain.

Important for any to be developed recommendations or suggestions on approaches to mitigation measures is the appearance of the regional spatial organization of any geographical location in order to provide possible adaptability on the ground – and so for this case study location of Tutong District, together with its direct district surroundings: Brunei Darussalam consists of four districts (or daerah): (1) the extensive Belait District in the south-west, (2) the here assessed Tutong District in the middle, (3) the Brunei-Muara District that surrounds the capital Bandar Seri Begawan, and (4) the separate Temburong District in the East (Fig. 8.1, Table 8.1) (CDD, 1993, 2008; Ibrahim, 2005; Khatib & Sirat, 2005). The daerah of Temburong is physically separated from the rest of Brunei by the Malaysian state of Sarawak (Fig. 8.1).

The case study area of this research, Tutong District, is one of the four districts of Brunei Darussalam, making it the third-largest of the districts (comp. Fig. 8.1, Table 8.1). The District borders the South China Sea to the north, the Malaysian state of Sarawak to the East, and the Belait District to the west, which the Bruneian government owns. The District is located at latitude 4.801890, longitude 114.652090 (or GPS coordinates of 4° 48′ 6.804″ N, 114° 39′ 7.524″ E) (Fig. 8.1) (GIS Lab UBD, 2020; comp. FloodMaps, 2020). The countries – and partially Tutong Districts – land boundaries being covered together with the neighboring country of Malaysia is approximately 381 km (Hassan, 1988; CDD, 1993, 2008; Ibrahim, 2005; Khatib & Sirat, 2005; Omar, 2005).

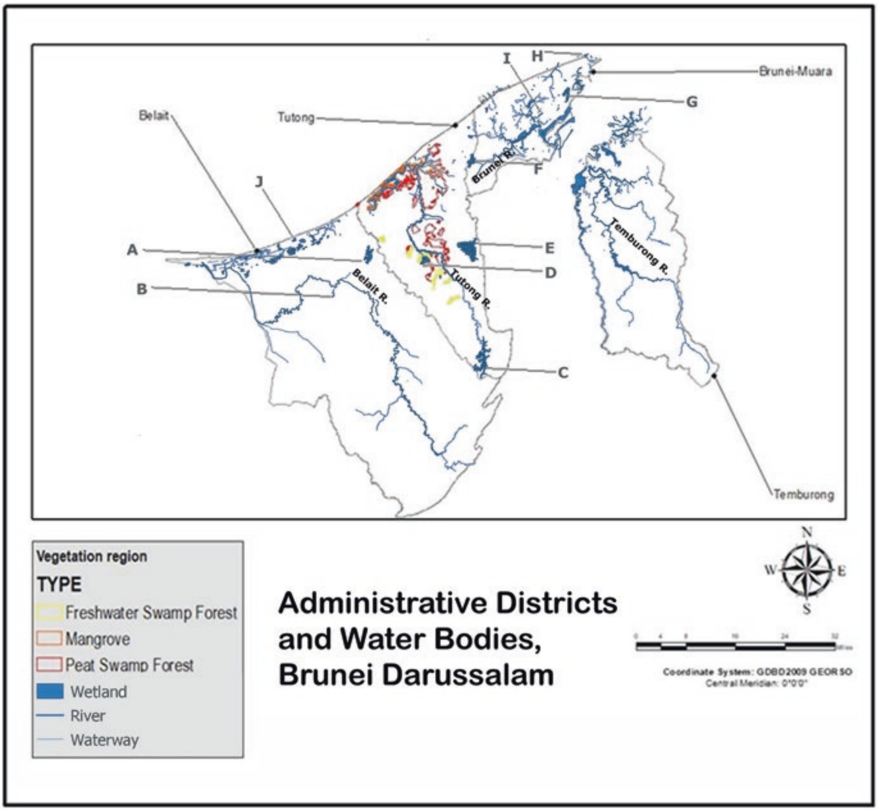

Fig. 8.1 The physiographic map and river system in Brunei Darussalam. (A – Andulau Reservoir, B – Lalak Lake, C – Belaban Ulu Tutong Golden Jubilee Reservoir, D – Tasek Merimbun, E – Benutan Reservoir, F – Imang Reservoir, G – Mengkubau Reservoir, H – Api-Api Wetlands, I – Tasek Lama Dam, J – Anduki Recreational Park. The Information for Tutong Golden Wetlands: A –Benutan Reservoir, B – Tasek Marimbun, C – Belaban Ulu Tutong Golden Jubilee Reservior) (Source: GIS Lab, Department of Geography & Environment, FASS, University of Brunei Darussalam (UBD) at 18.06.2020 (GIS Lab UBD, 2020)

Table 8.1 Four districts (daerahs) in Brunei Darussalam

No.	District – *Capital*	Population (2019 Census)		Area (km^2)
		Population	%	
1.	Belait –*Kuala Belait*	75,900	(16.5%)	2724
2.	Tutong – *Pekan Tutong*	52,700	(11.5%)	1166
3.	Brunei-Muara – *Bandar Seri Begawan*	319,500	(69.5%)	571
4.	Temburong – *Pekan Bangar*	11.400	(2.5%)	1304

NIDM (2014)

Fig. 8.2 The overview of the physical features and geomorphological pattern of Tutong Town in Tutong District (2020)

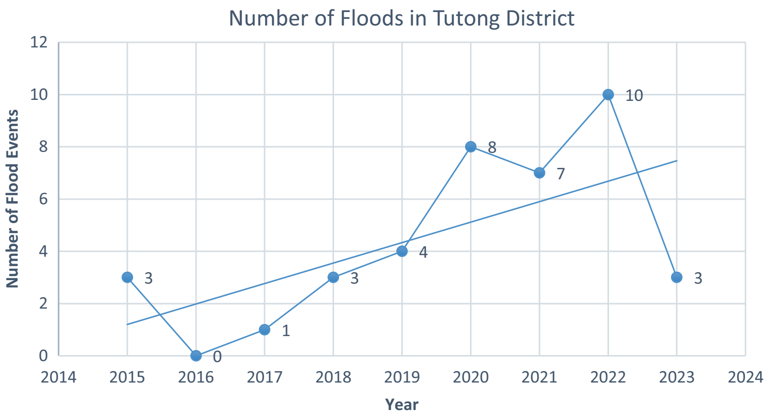

Fig. 8.3 Frequency of flood events in Tutong District (2015–2022). (Data source: Long, 2023)

Tutong Districts' main town is Pekan Tutong (Tutong Town) (Fig. 8.2 and later Fig. 8.3), one of the eight sub-districts called mukims. So each district consists of several sub-districts (mukims), which are 38 mukims in total. A mukim itself further consists of a group of kampongs or villages. The further Kampongs (Villages) are Tanjong Maya, Keriam, Telisai, Kiudang, Lamunin, Rambai, and Ukong (DI, 1992). They are administered by a district officer being responsible for all district affairs, such as general administration, welfare, development, and progress.

In addition, the country has a tropical equatorial climate characterized by uniformly high temperatures (Table 8.2), high humidity, and heavy rainfall within episodic monsoon rains with an average precipitation amount of about 2909 mm per

Table 8.2 Mean maximum and minimum monthly temperature and average monthly rainfall in Brunei Darussalam

Month/ Temperature/ Rainfall	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year average
Mean maximum (°C)	258	248	272	271	275	271	284	28.3	280	265	244	240	28.3
Mean minimum (°C)	221	220	225	239	239	247	241	24.3	253	231	222	236	26.2
Average rainfall (mm)	278	138	113	200	239	214	229	216	258	320	329	343	2877

NIDM (2014), Weather and Climate (2021)

year (NIDM, 2014; Weather and Climate, 2021). So annual rainfall varies from 2500 mm on the coast to 7500 mm in the country's interior (Gupta, 2010). The dominant influences on the climate are the northeast monsoon from November to March and the South-west monsoon between May and September.

The rainfall regime contains a wet season from November to January (North East Monsoon) and a minor rainy season from May to October (South-West Monsoon) (comp. Weather and Climate, 2021). An occasional drought may occur between the monsoons between late January and April. Temperatures range from 23 to 32 °C (Gupta, 2010; NIDM, 2014) (comp. Table 8.2). The average annual temperature is 26.1 °C (79.0 °F), with the April–May average of 24.7 °C (76.5 °F) and the October–December average of 23.8 °C (74.8 °F) (NIDM, 2014) (Table 8.2). The regional climate, temperature, rainfall, and landscape change pattern are potential factors of a region to manage and conserve nature, culture, and heritage (Tyler, 2004).

The physical overview and geomorphology of Tutong District display an excellent overview. Tutong District is in its north territory one part of the Brunei coastline, which extends about 161 km (100 mi) from near the mouth of the Baram River in the south-west to the headland of Muara in the northeast and borders the South China Sea. Brunei Bay lies to the East of Muara and northeast of Tutong District (comp. Fig. 8.1), which is a large and protected shallow embayment. So especially the variety of sloping patterns, different landscapes, and their unique landscape beauty, vegetation, and rainforest availability are identity-building. Brunei is predominantly a hilly lowland in its western part, whereas the eastern part consists primarily of rugged mountain terrain. The summit ridge of Bukit Pagon, also lying in the western part, inhabits the country's highest point with an elevation of 1850 m above sea level, and the lowest point is the South China Sea (0 m) (Gupta, 2010). The coast consists of a tidal, vast, and swampy plain (Gupta, 2010).

The second-largest river in its catchment extent and length within the entire river system in Brunei is the Tutong River, with a length of 137 km and flowing through the district from southeast to northwest (comp. Fig. 8.1). Within the Bruneian river systems next to this for Tutong District mainly important Tutong River, the Belait, and Temburong Rivers are the further main rivers in Brunei. These rivers and their tributaries are part of two major drainage basins: the Bram drainage basin in the west and the Brunei bay drainage basin in the East. The Brunei River is the smallest

Table 8.3 Catchment details of the four major rivers in Brunei Darussalam

River	The catchment area (km^2)	Length Km
Belait River	4700	209
Tutong River	1300	137
Temburong River	1000	98
Brunei River	765	41

river, with a catchment area of about 765 km^2. The river's upper reaches are a major freshwater source, particularly for the western part of the country. The tidal Tutong River drains an area of around 1300 km^2 in the central part of the country directly into the South China Sea (Muhmud, 2017). Originating from the hilly catchment while carrying flash flows, the Tutong River flows uncontrolled, and saline water intrusion during high tides creates a saline river, historically damaging standing crops and lands by flooding and salinity (Shafiuddin, 2014). Some further details of the four major rivers in Brunei Darussalam are shown in Table 8.3:

Adversities of flood damages affect the TRB as a whole (Shafiuddin, 2014): drainage congestions, flash flows, inadequate irrigation application for lack of infrastructures and water sources, and thus failing in the agro-projects and especially in the rain-fed paddy schemes. So the most important natural resource in Tutong District is water, for which interdisciplinary mitigation approaches might be advantageous for Tutong Districts water resources, especially in the negative effect of saltwater intrusion from the Tutong River mouth. Drinking water for the district is supplied by the Sungai Layong Reservoir (SuLaRes) (later Fig. 8.3), which also supplies the areas of Brunei/Muara District closest to Tutong District. In addition, the recently completed Benutan Dam, with a catchment area of 23 km^2 and a storage capacity of 44 million cubic meters, serves as a backup supply when water levels in the SuLaRes are low. In 1991, the water consumption of the district and the adjacent areas in the Brunei/Muara District was about 22.09 million cubic meters (DI, 1992).

Also, Tutong District inhabits next to a higher biodiversity richness (SCBD, 2022) and a diverse ecosystem (GBD, 2014), a vast forest reserve, Bukit Ladan Forest Reserve, covering an area of 25,000 hectares, and an offshoot in Pekan Tutong. In general, Brunei – and partially Tutong – consists of mainly mountainous rainforests and lowlands, being among the countries with high forest cover (GBD, 2014; comp. GBD, 2018): Around 75% of the country's total land area is covered by the natural vegetation of tropical evergreen rain forests, which are composed primarily of old growth forests (GBD, 2014). Moreover, 41% of the country's total land area inhabits the national forest reserves, being protected by law (GBD, 2014). This fact might be of interest for preventing or mitigating parts of the adverse effects of floods in Tutong District due to better soil stability throughout forests and absorption capacity, especially of water through the vegetation cover. Here especially the sort of forest, primary or secondary, as well as the general sort of vegetation cover or intensity of land use (production forest, forest plantation areas, or protection, conservation, recreation forest, or national park) (comp. GBD, 2014) might be of interest. Also, the lowland character must be considered as creating a higher-risk exposition.

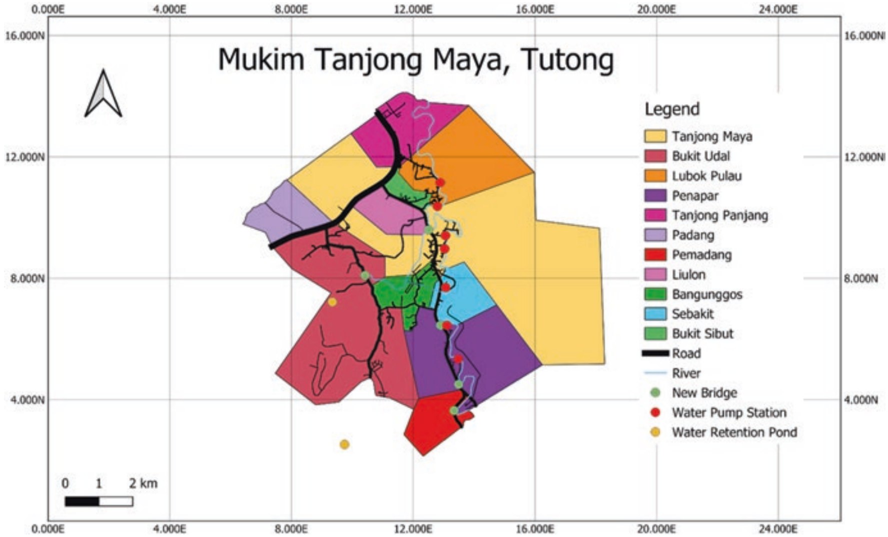

Fig. 8.4 The flood affected areas in Mukim Tanjong Maya, Tutong District. (Map source: Long, 2023)

Figure 8.3 demonstrates the flood events in Tutong District; the pattern of flooding in Tutong District is gradually increasing. The graph (Fig. 8.3) also shows that the flood trend line is very clearly displaying the floods increasing trends from low to high. In general, the trend was one or two flash floods were occurring in Tutong, but recently the number of flood events is getting high like in 2020 the floods event occurred 8 times and in 2022 the flood events occurred 6 times, the duration of floods are also getting longer time and the range is 4 days to 25 days (Long, 2023). The longer time is creating hardship moment for the affected people especially children and women of Tutong flood-prone areas. Figure 8.4 shows the flood-prone areas in Muking Tanjong Maya in Tutong District. This area was one of the most flood vulnerable areas in Tutong District. The drainage system and the geomorphological pattern is not flood-protective character, moreover the natural landscape displays the lowland and wetlands characters which ensure more vulnerability in the Tanjong Maya flood-prone areas (Long, 2023; NDMC, 2021).

Figure 8.4 shows the Mukim Tanjong Maya flood-prone areas in Tutong District where the geomorphological character and Tutong River catchment area and drainage pattern was not suitable for dispersing the rainwater or floods water through the drainage or river basin. The drainage system from Bangunggos to Pemadang in Mukim Tanjong Maya has been reconstructed which was very poor drainage character before and recently through Government initiative engineering construction has made in Tanjong Maya floodplain area, as a result there was no food in Tanjong Maya areas in Tutong District although the people of Tutong District has faced 10 floods and the duration of the floods was minimum 25 days in December 2022. The data and Fig. 8.3 show that almost every month the citizen of Tutong town are facing flood problems in every month of the year.

Tutong District is further considered a cultural district in Brunei Darussalam due to its commitment to preserving its traditional customs and culture. It enables Tutong District to have its selling point to the international market, especially in the tourism industry. Historically, Borneo Island, while inhabiting Tutong District, is the place of case research for geomorphic, anthropogenic, cultural, and language diversity. It makes the whole Borneo region a unique island in the South East Asian region. Tutong District is also influenced by Brunei being a diverse country, being derived from the country's diverse historical links with the Hindu empire in the neighboring regions and modern-day Indonesia and Malaysia (BBY, 2014, 2015). From the point of cultural heritage further, an interesting fact is that Tutong District includes five major ethnic communities, the Tutong, Dusan, Kedayan, Iban, and Chinese: In mid-1990, an estimated 28,800 people were living in the District, of whom 23,700 were Malays, 2100 were other indigenous people, 2100 were Chinese, and 900 other ethnic groups. Of the total population, 15,000 were male and 13,800 female (DI, 1992). Indigenous groups such as the Tutong and Kedayan live in the urban and suburban areas, while the Dusan and Iban are mainly found in the rural and remote parts of the District. The majority of the population is Muslim. The rest, like the Chinese, Dusan, and Iban, practice their faith through their respective customs and traditions (DI, 1992). The herefrom evolving cultural and indigenous habits, traditions, and heritage are the same important for understanding, on the one hand, the role of Tutong River and its basin also in correlation to the implementations of cultural traditions and, on the other hand creating and developing approaches to mitigation measures, which are consent to exactly these cultural habits and traditions.

4 Results and Discussions

Brunei and Tutong District are located in the South China Sea, so it is prone to various disasters. Though Brunei Darussalam is free from major natural disasters such as earthquakes, volcanic eruptions, and typhoons, it experiences low-level hazards from earthquakes, cyclonic storms, thunderstorms, monsoon floods, anthropogenic-induced disasters, landslides, forest fires, seasonal smoke, hazes resulting for instance from forest fires in Indonesia (Gupta, 2010). Floods and landslides are the most prevalent hazards (NIDM, 2014; Irlapati, 2017), for which floods, especially monsoon and flash floods, are getting implemented in case of future mitigation approaches. The main importance is deriving since 97% of the population lives in the western lowland region of Brunei (comp. NIDM, 2014) and, therefore, partially within Tutong District. In order to find solutions to the floods in Tutong District within Brunei Darussalam, the possible sources of floods were observed for Tutong District in Brunei Darussalam. Also, the flood disaster risk in Tutong District played an active part in achieving solutions. The role of Tutong River for flooding at the catchment scale was a further vital investigation in receiving results in sorts of approaches to mitigation measures. The viewpoint on the impacts of floods on the socio-economy in flood-prone areas helped to reach a higher community-based acceptance of the to-be-implemented mitigation measures. Moreover, an understanding and overview of the weather- and climate-related disaster form of floods in Brunei Darussalam could have been improved.

4.1 Sources of Floods in Tutong District in Brunei Darussalam

Floods or inundations are defined as the overflow of river water from the river banks surrounding the alluvial areas due to high runoff. Flooding is a natural phenomenon that occurs on the Earth's surface. However, human disturbances in the river floodplain cause the weakening of the river's geomorphological condition and, as a result, increase the risk and vulnerabilities of the alluvial plains against floods (Smith, 2013; comp. Ali et al., 2019). This phenomenon of flooding is difficult to control and sometimes inexorable. Regarding river systems, the human dimension and influence get clear: First, rivers are natural water resources for dwellings on the Earth's surface.

Nevertheless, channels cover about 75% of the Earth's crust and play a dynamic role in the hydrological cycle, serving as a drainage system for surface water. Thus, floods occur when the available water in the river exceeds the capacity to absorb it. Flood or inundation is a natural hazard that occurs on the surface of the Earth and are natural phenomena in tropical and sub-tropical regions. There are various reasons in any region of the world for these hazards, the risk, and the severity of flooding. "Regular" annual flooding is a desirable event for farmers and local inhabitants in the rural and urban areas of Brunei Darussalam. It commences at the right time for cultivation and lasts for an appropriate time to benefit paddy rice, other vegetation, and other major crops (Haque, 1997). The local landscapes, sloping patterns, drainage system, temperature, wind, and monsoon rainfalls are the most influential flooding factors in a particular region, such as Tutong District (Figs. 8.5 and 8.6).

Besides, the climate change impacts, drought, other natural and anthropogenic influences, and development activities are also responsible for arranging a flood in a particular area and region: rising sea levels (with saltwater intrusion), heavy rainfall, or increasing urbanization are some of the reasons for an increase of areas being flood-prone in Brunei (Saxena et al., 2012) and therefore in Tutong District in the future (Saxena et al., 2012).

However, excessive water in the rainy season often endangers human lives, livelihoods, agricultural crops, and other tangible assets. This negative aspect of floods is locally expressed by the term flood, meaning abnormal flooding (Haque, 1997). Therefore, the socioeconomic impact of such riverine hazards is more extensive and

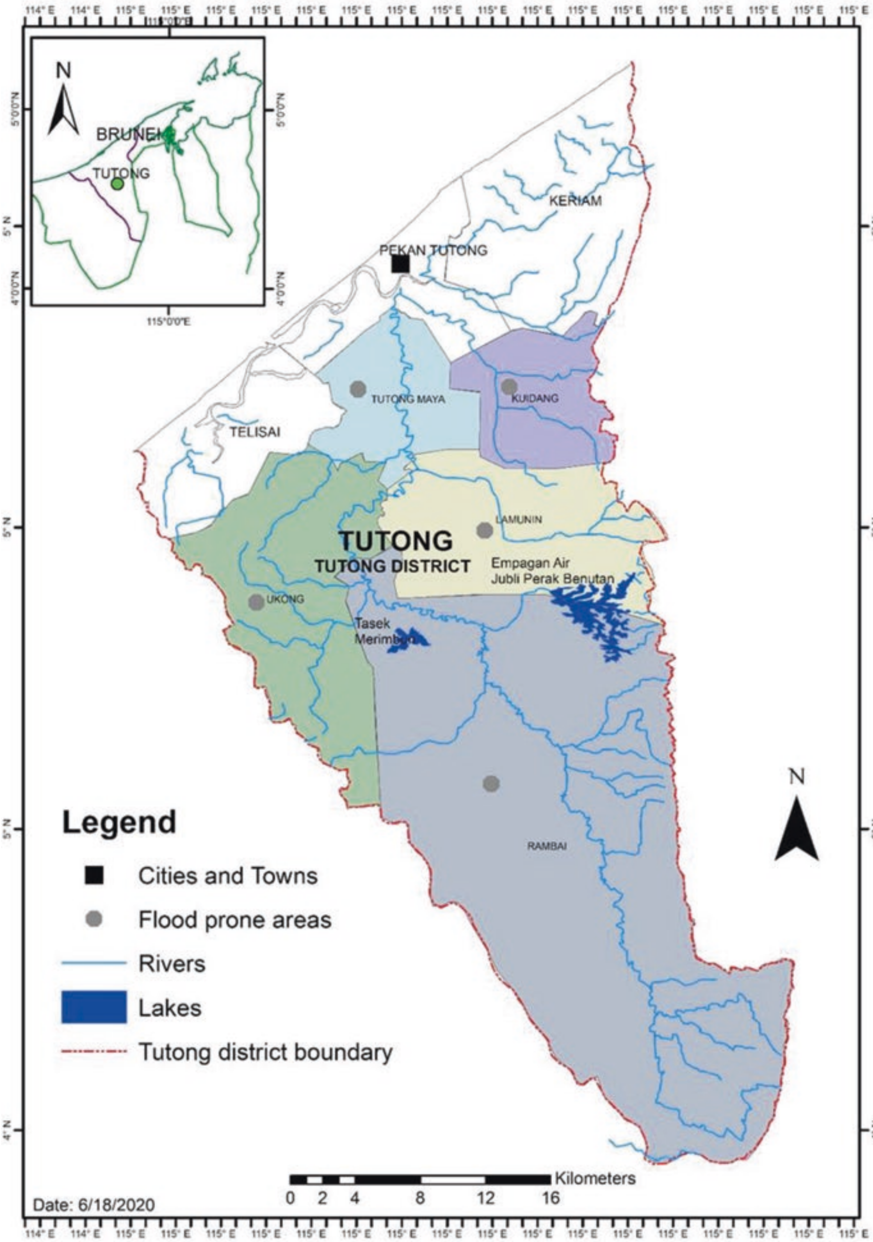

Fig. 8.5 Location of Tutong District and the flood-prone areas. (Source: GIS Lab, Department of Geography & Environment, FASS, UBD at 18.06.2020 (GIS Lab UBD, 2020))

Fig. 8.6 In the Pekan Tutong River Basin area in Pekan Tutong flooding scenario in 2020, the upper and lower scenario with flooding scenario in 2020. (Source: photographs made by Islam, 2020)

devastating than other types, such as droughts, tornadoes, cyclones, and massive riverbank erosion in the region (Haque, 1997).

The example of the Tutong flood in 2020 (Fig. 8.5) shows that several low-lying parts across the country were submerged in water following continuous heavy rainfall in many country areas. Especially low-lying areas are prone to floods, monsoon floods, or flash floods, which might create fallen trees, causing massive traffic jams on roads and other more serious impacts. The Tutong River, with its channels, might also be one source of overflowing parts of the Tutong District, possibly flooding infrastructure, houses, streets, or several shops in Pekan Tutong (Figs. 8.5 and 8.6). Areas affected by that flood in Tutong included Mukim Keriam, Mukim Kiudang, Tanjong Maya, and Ukong. For example and fortunately, the water level at Hassanal Bolkiah Mosque in Pekan Tutong receded just before the mid-day prayer in 2020 (Fig. 8.5). The whole mosque and mosque complex was inundated, and two third the height of the Mosque building was inundated in the 2020 floods. The Fire and Rescue Department's Tutong branch received six reports of uprooted trees, four landslides, and five flash floods and urged motorists to use alternative routes.

So human intervention also impacts the severity of the unfolding disaster as such dam breaches cause severe and explosive downstream flows leading to flash floods or overflowing channels that might inundate such infrastructure, religious places, streets, and different places. Human influence needs to get balanced with natural space. In addition, human interventions lead to climate change, triggering back in a cumulative or synergistic way the further partially also human-induced natural hazards such as floods (Islam, 2014).

4.2 Flood Disaster Risk in Tutong District

The number of flood-prone areas could increase in Brunei (Saxena et al., 2012) and, therefore, in Tutong District. After the exposure map of Brunei Darussalam with its districts and depicted hydrological exposure index, the hydrological exposure in Tutong District is high. After the vulnerability map, the integrated vulnerability index is moderate (Kumar et al., 2021). Tutong districts' proximity to the riverside is very less. Up to that, the district is facing the maximum number of rainfall days and maximum flood durations (Kumar et al., 2021). So flooding in Tutong District is getting a regular annual climatic phenomenon. Also, Tutong areas are well below sea level. Brunei's and, therefore, Tutong's flood-prone (Figs. 8.6, 8.7 and 8.8) or hilly areas are at further risk of landslides. In these redrawn flood risk maps of the case of 3 m (Fig. 8.7) and 6 m (Fig. 8.8) above sea level, higher rising overall water levels are simulated over FloodMaps (2020): The elevation unit layered on the map is in meters. It starts from a height of sea level, which is zero. A negative elevation means depth below sea level (Figs. 8.7 and 8.8). Data sources were Mazpzen, TNM, SRTM, GMTED, and ETOPO1, with additional data sources of Leaflet, Esri, and OpenStreetMap. Inland lilac areas are the concerned inland areas (next to blue colored ocean area), which are the water-inundating and, therefore, future potential flood-prone places in case of these heights of water rise with the need for stronger or most substantial protection (Source: FloodMaps, 2020; with additional data sources of Leaflet, Esri, OpenStreetMap, Mapzen, TNM, SRTM, GMTED, ETOPO1).

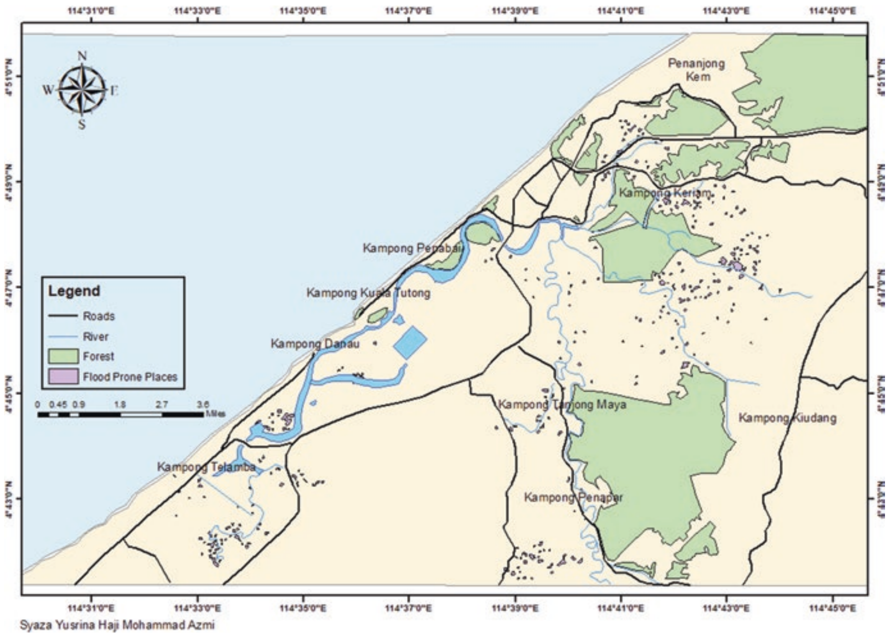

Fig. 8.7 Redrawn excerpt of the map for Tutong District with three meters above sea level higher overall water level: inland lilac areas are the concerned areas, which are the water-inundating and therefore flood-prone places with a need for stronger protection. (Source: FloodMaps, 2020; with further data sources of Leaflet, Esri, OpenStreetMap, Mapzen, TNM, SRTM, GMTED, ETOPO1)

It spatially verifies the high grade of exposure index for Tutong District by Kumar et al. (2021). In case of sea level rise, these simulations might also serve for partial answers on endangered low-lying areas being the same endangered throughout flash floods, thunderstorms, and monsoon floods. However, these elevation flood maps on their own might not be sufficient to analyze flood risk. Many other factors are involved, such as surface runoff, land type, soil type, flow diversion, etc. Those are the same responsible for the flood coverage in addition to elevation.

As seen in Fig.8.7, Tutong river and its catchment or Tutong River Basin (TRB) is another sensitive area and source of flooding, of which the Public Works Department (JKR) is aware. The nearby lying dam is another sensitive place in mitigation measures (NDMC, 2021). When a flood appears, the choice is to release the water or let it break and wash up as far as the Tanjong (TG) Maya-Lubok Pulau area. As the main transport way and access point to the district, the highway might have a high-to-be-observed infrastructure and security function. Also, severe damage to crops and property is caused due to uncontrolled flash flows in the TRB (Shafiuddin, 2014).

Further on, historical records of disasters in Brunei (Table 8.4) show the emergency for future mitigation measures and strategies. In its hazard profile, historically, Brunei is one of the least vulnerable countries to natural hazards (Gupta, 2010). Nevertheless, it faced a few disasters, such as in 2009, Brunei faced floods, a pandemic, landslides, a severe fire outbreak, and a haze (Gupta, 2010). Brunei was

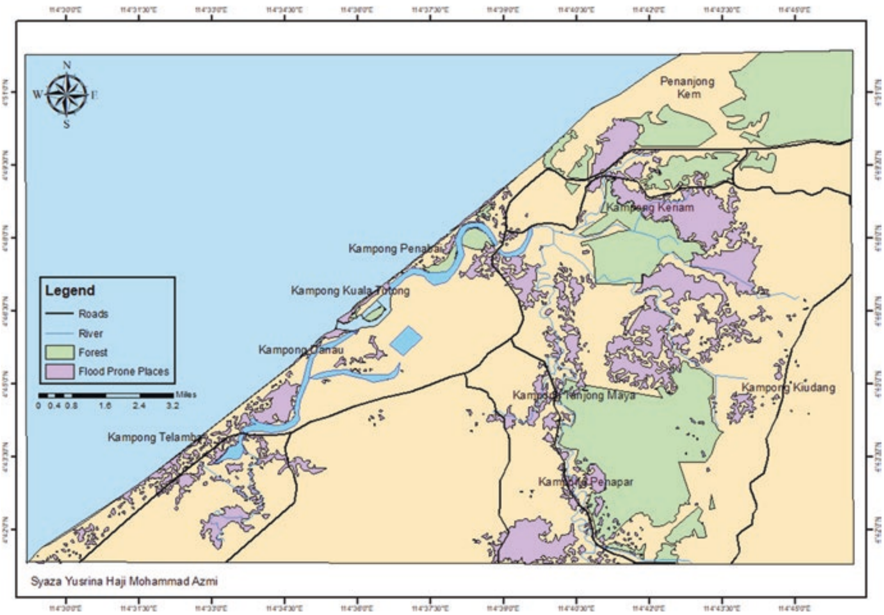

Fig. 8.8 Redrawn excerpt of the map for Tutong District with 6 m above sea level higher overall water level: inland lilac areas are water-inundating and therefore flood-prone places with a need for strong protection. (Source: FloodMaps, 2020; with further data sources of Leaflet, Esri, OpenStreetMap, Mapzen, TNM, SRTM, GMTED, ETOPO1)

partially disrupted in 2008 by landslides, floods, and strong winds, while in 2007, the country faced floods and strong winds (Gupta, 2010; NIDM, 2014; Saxena et al., 2012). The topographic area of the country of Brunei is not located in an earthquake hazard-prone area and therefore is a low seismic hazard region (GSHAP, 1998). Nevertheless, the region experiences reputedly high seismic hazards: The capital city Bandar Seri Begawan has experienced small earthquakes of a magnitude of 4–5. It caused the swaying of some high-rise buildings (5–6 stories) in 1992 (Waifong, 1993) and 2005. Further on, Brunei suffered from a forest fire disaster in 1998, which caused an economic loss of $two million with no reported casualties (Gupta, 2010).

So a general hazard-risk in Brunei is high with being impacted by global climate change as well as by the country's local geography and Brunei's relative location in the Asia–Pacific Region (in before Table 8.3) (comp. Gupta, 2010; NIDM, 2014; Saxena et al., 2012; Ndah & Odihi, 2017). Nevertheless, (1.) a limited reporting of localized disasters to international databases, however, prompts a misperception of low disaster risk in Brunei (Ndah & Odihi, 2017); (2.) limited knowledge, awareness, and motivation among the general population leads into high community vulnerability and disaster risk; to be activated knowledge, awareness, and motivation among the general population should be strengthened and would support effective mitigation and adaptation to lower magnitude but recurrent hazardous events (Ndah & Odihi, 2017); and (3.) only a partial, situated implementation of disaster risk reduction into development plans and governance structures contributes to

Table 8.4 The major disasters witnessed by Brunei Darussalam (since 1960) and flash floods were more consequently affecting, especially in Tutong District

S/N	Year	Name of Disasters	Impacts in society
1.	1962	Major floods	More than 2000 people were directly affected due to significant floods in Muara, Tutong, and Belait districts.
2.	1980s	Fire in Water Village	Over 200 incidents have occurred in Kampong Ayer (Water Village), and over 200 family and householders have lost their houses and properties due to a fire in Kampong Ayer.
3.	1987	Rasau Gas blow-out in Belait District	A gas blow-out in Belait District has severely damaged natural resources.
4.	1991	Poor air quality resulting from Mount Pinatubo eruption in the Philippines	The air quality of Brunei Darussalam was degraded during the mount Pinatubo eruption in the Philippines.
5.	1992	Small earthquakes in capital	The capital city Bandar Seri Begawan has experienced small earthquakes in a range of magnitude of 4–5, causing swaying of some high-rise buildings (5–6 stories) in 1992 and 2005.
6.	1998	Regional haze	Regional haze is a new threat for East Asian Countries as it is located in the southeast Asian region.
7.	1998	Forest fire disaster	The forest fire caused an economic loss of $ 2 million with no reported casualties.
8.	1998/1999	Flash flood during La Nina	Six flood-prone areas were affected by flash floods.
9.	2005	Small earthquakes in capital	The capital city Bandar Seri Begawan experienced small earthquakes (magnitude of 4–5) with swaying of some high-rise buildings (5–6 stories)
10	2007	Floods and strong winds	Bruneian people faced the impacts of strong floods and strong winds
11.	2008	Temburong flash floods, landslides, and strong winds	Community people are affected by flood damage and damage to agricultural crop fields.
12.	2009	Extensive flash flood in Brunei-Muara/Tutong and Belait Districts	Brunei faced floods, landslides, a pandemic, severe fire outbreaks, and haze.
13.	2010	Influenza A (H1N1)	Almost in every district (four districts), citizens were affected due to Influenza in Brunei Darussalam.
14.	2012	Heavy rainfall creates pluvial flash floods and thunderstorms in Tutong and Belait Districts.	Mukim Miudang and Mukim Lamunin of Tutang District are most affected by flashflood and thunderstorms during monsoon time.
15.	2019	Pluvial flash flood in Tutong Districts	Over 45 Tutong families were affected by floods during the monsoon season in early December 2019. (Source: The SCOOP, December 2019)

(continued)

Table 8.4 (continued)

S/N	Year	Name of Disasters	Impacts in society
16.	2020	COVID-19 Pandemic (1st wave)	141 were affected, and two died.
17.	2020	Pluvial flash flood in Tutong Districts	December 2020, January 2021, like Nr. 17 and flood cases 34 in Tutong District
18.	2021	COVID-19 Pandemic (2nd wave)	13,545 were affected, the number of deaths is 55, and 12,098 recovered from the case (until November 5th, 2021).
19.	2021/2022	Pluvial flash floods in Tutong and Belait Districts during the monsoon months of November until March 31st, 2022. COVID-19 Pandemic case until March 31st· 2022	Severe floods occurred in Tutong and Belait Districts, and almost ten sub-districts were affected in Tutong and Belait Districts in 2021. Three floods have occurred in Tutong in 2023 A flash flood occurred in Tutong on the 22nd and 23rd of March, 2022. 73,919 affected – total number of cases 127,970 and total death is 94 until March 2022
20.	2022	Pluvial flash flood in Tutong District and the COVID-19 Pandemic until November 2022	Until December new cases has been seen in last 7 days affected 484 total deaths –225 and total cases – 241 K (Source: https://www.worldometers.info/coronavirus/country/brunei-darussalam/ retrieved: 27th September 2023)
21	2023 until September	COVID-19 Pandemic cases detected in September 2023	The total number of cases detected by September 2023 and the affected case is 310,522 and total death in Brunei is 225. Data Source: Borneo Bulletin,tenth June / and September 2023.

Gupta (2010), NIDM (2014), Saxena et al. (2012), Borneo Bulletin daily News Paper with next to others Osman and Lim (2018) as well as MOH, Government of Brunei Darussalam in (2019, 2020, 2021) and (2022), (2023)

heightened disaster risks (Ndah & Odihi, 2017; comp. AHA and JICA, 2015; NIDM, 2014; Saxena et al., 2012; Gupta, 2010).

4.3 The Role of Tutong River for Flooding in the Catchment Area

The Tutong River and the surrounding landscape features and sloping patterns are the potential factors of frequent flooding in the Tutong region. The flow assessment is essential for developing flood prevention measures (comp. Shams, 2015). Therefore the characteristics of Tutong River and its basin had to be described as follows: The Tutong basin area or catchment area is vast and measures about 1300 km^2 (Fig. 8.9), for which Fig. 8.10a, b, c identified the flood affected areas visually on parts of the Tutong River catchment. The upper section of the river

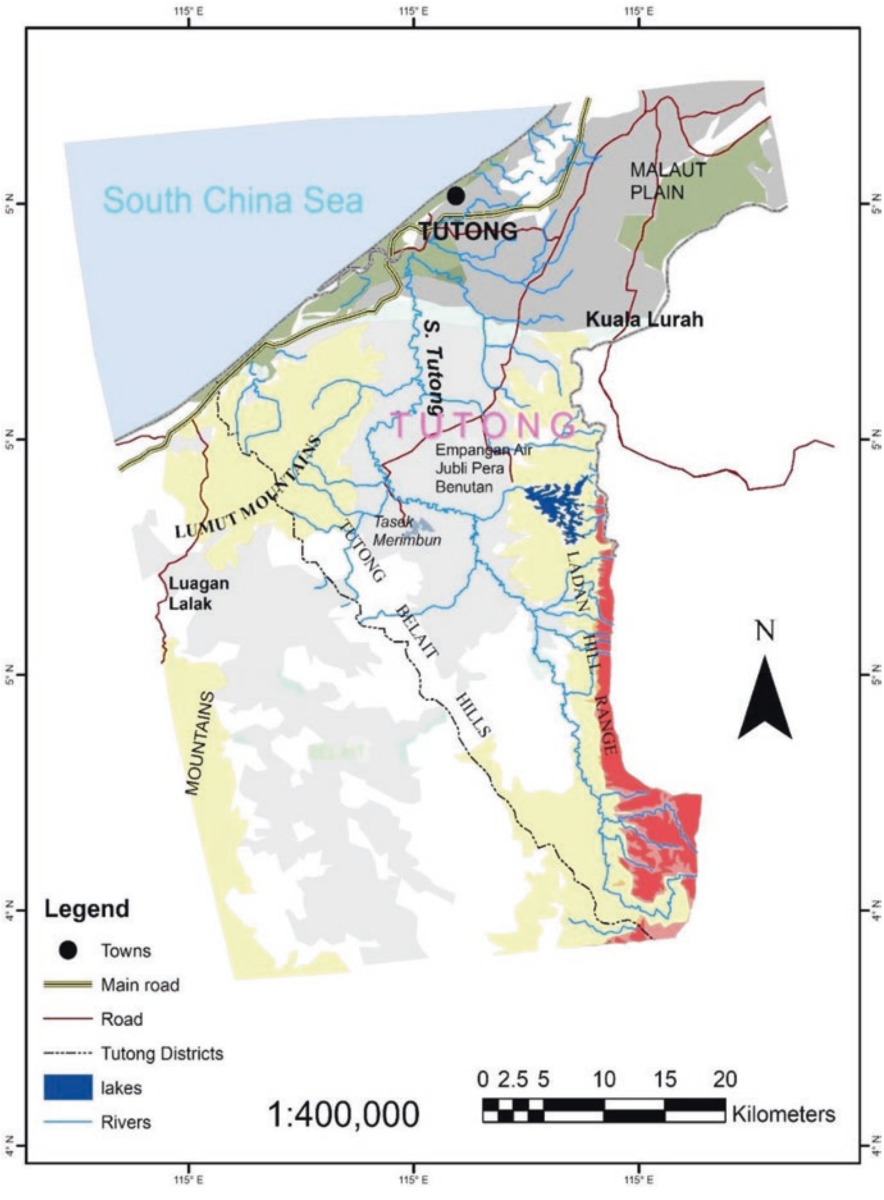

Fig. 8.9 The river system, landscapes, and flood-affected areas in Tutong. (Source: GIS Lab, Department of Geography & Environment, FASS, UBD at 18.06.2020 (GIS Lab UBD, 2020))

covers a mountainous and pristine forest. 70% of Brunei Darussalam's forest is pristine and untouched by humans. The settlements are located from the high-sloping to the low-sloping areas. Only the Pekan Tutong area is the high land area beside the Tutong Riverbank area as a shallow land area. The main roads are located in the

Fig. 8.10 (**a**–**h**) The eight different flood-prone areas are displayed (Locations Numbers **a**–**h**) (Locations of the flood-affected areas are **a** – Pekan Tutong, **b** – Lamunin, **c** – Kampong Rambai, **d**- Jalan Kuala Ungar, Tutong, **e** – Rambai area, Tutong, **f** – Rambai area, Tutong, **g**-Tutong River, Rambai, and **h** – Jalan Kuala Ungar, Rambai, Tutong)

lowland areas, but the highway is in higher altitude areas. The settlements in the lowland area have monsoonal floods every year, but some years the damage is more severe and crucial for the Tutong inhabitants.

Geographically, this river is also situated on alluvium, clay, and sand. The sampling area has a volume of approximately 500 m^3 with a maximum depth of about

3 m. The sampling points started from the Kelakas River tributary, surrounded by mangrove and Nipah swamps, straight into the Tutong District center, along the market and woodcutting industry areas. The sampling ended at the beach area, very close to the sea. The sampling locations can be seen in Fig. 8.10a–h. In the case of Tutong District, the river flows from the upper course, which is located in Ulu Tutong, then continue to flow toward the middle and lower course, where most of the settlement buildings and commercial sites, including all villages which are located in the flood-prone area (villages). The efforts and strategies put into both villages might have worked for a short time. However, during prolonged heavy rainfall, especially in the upper course of the river will reach its maximum capacity, which eventually will flow out of the river channel and flood the areas nearby (Muizz, 2021).

Figure 8.10b shows one of these rural areas in the Tutong District. This depicted place is part of the middle basin of the Tutong catchment (TRB). In theory, the meandering river, where erosion activities are dominant, would create erosion activities while initiating the river to meander deeper, and the surrounding floodplain, therefore, would change its appearance and river bed placement. Moreover, these areas are low-lying areas and prone to flooding. Houses and buildings are seen in Fig. 8.10b, c, showing that they are at risk. A more vulnerable environment can be predicted for the future in the surrounding areas. Humans populate the middle section of the river channels, which consist of rural areas such as Kampong Rambai, Kampong Lamunin, and Kampong Layong. The main income for these villagers is primarily through agriculture, living in the alluvial plain area, where the soil is fertile, rich in nutrients, and has a high chance for a successful crop outcome. As can be seen through Figs. 8.9 and 8.10b, c, in these areas population lived historically in a linear pattern along the river floodplain.

These land patterns are due to their fertile soils and transportation purposes, as in the early days, transportation services were handled through waterways. However, due to the floodplain area combined with the low-lying area, the vulnerability of these individuals is fatal, especially in correlation to natural hazards, such as floods. These locations are severely flooded and affected by flooding in Tutong District (comp. in before Figs. 8.6, 8.7 and Figs. 8.8, 8.9).

The after the La Nina flooding from October 1998 to 1999, the Integrated Environmental Consultants (IEC) Brunei for Tutong River (Figs. 8.7 and 8.8) developed Sungai Tutong Early Flood Warning System gives a further spatial overview of necessary floodplain management and capital work to reduce flooding impact (IEC, n.d.; comp. Saxena et al., 2012): The historical floodings scenario displays that the majority of Tutong District's subdivisions are affected by annual monsoonal rainfalls and annual flooding (IEC, n.d.); the following areas are mostly the common areas where the annual floods destroy and damage house property construction, housing structure, road construction, and networking system; the areas are as follows: Keriam, Pekan Tutong (A), Tanjung Maya (D), Ukong, Kiudang, Lamnin, Kampong Panchong, Kampong Pangan, and Rambai areas being located in the downstream of the TRB areas (Fig. 8.10a–h) (IEC, n.d.).

Coordinating instances in case of Tutong River catchments' floods is the National Disaster Management Centre (NDMC), along with various other agencies such as the Operation Branch 'B' of the Fire and Rescue Department, the Third Battalion, the Belait District Branch of the Community Development Department (JAPEM) as well as the Belait and Tutong PWD are currently making efforts to control the situation and provide assistance to those affected in the flash floods (Ummu, 2021; Nurhamizah, 2021).

4.4 The Impact of Floods in Flood-Prone Areas on the Socio-economy

Brunei, as part of the Asia–Pacific Region (APR), is a natural hazard-prone area. The APR's socio-economy has a combined population of 622 million (UNISDR, 2016; Ndah & Odihi, 2017)—of which Brunei has a population size of 0.42 million and an urban population rate of 76.7% (NIDM, 2014)—with an average direct economic loss from disasters worth US$ 4.4 billion annually (UNISDR, 2016; Ndah & Odihi, 2017). Therefore, enormous socioeconomic costs threaten sustainable development and livelihood in the APR (UNISDR, 2016; Ndah & Odihi, 2017). As for Brunei, due to a lack of disaster data, the disaster risk analysis for economic loss potential has not been carried out (Gupta, 2010).

In Brunei, natural gas and crude oil production accounts for 60% of the gross domestic product (GDP) and more than 90% of exports (NIDM, 2014). Substantial income from overseas investment complements revenue from domestic production (NIDM, 2014). The Brunei Government has strong intentions to diversify the economy both within the oil and gas sector. However, new sectors should be introduced through policies and resource investments (NIDM, 2014). Brunei, particularly the inner parts of Tutong, has a small, prosperous economy that depends on revenue from natural resources. However, it comprises a mixture of domestic and foreign entrepreneurship, welfare measures, government regulation, and village traditions (NIDM, 2014).

Village traditions and other social activities and economies are predestined for negative impact due to floods. In December 2019, 47 Tutong families were affected by floods during the early monsoon season (Bakar, 2019). And since 97% of the population lives in the lowland western region of Brunei (NIDM, 2014), the prolonged risk of natural disaster is increasing.

In 2020, stronger and more severe floods have damaged and affected families and have continuously increased. The severity of the floods in Tutong in 2020 could be seen when citizens stayed at home for long durations as the main road was flooded and land vehicles could not move anywhere. The water taxi was the only possible vehicle used for transportation and mobility.

Throughout 2020, some 500 families faced problems with their homes during the massive floods in Tutong, and students also faced irreparable damages to books, computers, and other educational materials. In 2021, the Brunei Darussalam Meteorological Department (BDMD) warned of the occurrence of wind speeds of up to 50 km/h (Ummu, 2021; Nurhamizah, 2021), and the public and motorists were urged to be on alert and to take necessary precautions to ensure their own safety (Ummu, 2021; Nurhamizah, 2021). However, 17 houses in Kg Sungai Liang, Kg Tunggulian, Kg Sungai Bakong, Kg Sungai Lalit, Kg Sungai Kuru, the Government Barrack Housing area located near Brunei LNG, as well as the Barrack Housing Area in Lorong Tiga Selatan, Seria were all affected by flash floods. It was so severe that the roof of one of the houses was blown away by heavy wind that accompanied the torrential downpour.

4.5 Flood Mitigation Measures and Solutions

In light of the aforementioned events, it is undeniable that the floods need to be mitigated. Measures are already being taken into account to lower the chance or risk of each occurrence. In the case of Brunei, the government has contributed with evaluative, coordinative, administrative, communicative, informative, and directive actions to help reduce the risks during these hazardous events. The National Disaster Management Centre (NDMC) plays a vital role in monitoring and allocating vulnerable areas, analyzing anthropogenic structures to lessen society's impact, building artificial levees, and widening the river channel (NDMC, 2021), while BDMD is responsible for providing meteorological and climate services, monitoring, and analyzing weather conditions. BDMC continues to issue weather warnings, for instance in the cases of heavy thunderstorms and flash floods in low-lying areas (Islam et al., 2018, 2019).

In the case of TRB floods, NDMC, along with agencies such as the Fire and Rescue Department, the Third Battalion of the Royal Brunei Land Force (RBLF), the Belait Branch of the Department of Community Development (JAPEM), as well as the Belait and Tutong Public Works Department (PWD) are responsible for controlling the situation and providing assistance to those affected, especially during flash floods (Ummu, 2021; Nurhamizah, 2021; Islam et al., 2014b, 2017). During the 2019 floods in Tutong, the Second Battalion of the RBLF was responsible for transporting residents from their affected homes in trucks (Bakar, 2019), while other uniformed officers were delegated to help and assist the vulnerable population. On a district level, the Tutong District Disaster Management Council (Tutong DDMC) provides fiberglass boats as transportation to affected residents (Islam et al., 2014b, 2017).

On a practical level, active flood prevention and planning are needed, such as administrative, coordinative, or communicative spheres and governance (Reinstädtler, 2022a, b, c, 2021a, b) and need to be communicated so that the relevant authorities can take responsibility. In Brunei, practical measures for active flood prevention have resulted in the development of the Early Warning System

(EWS), proposed by the Brunei Integrated Environmental Consultants (IEC) after the La Nina floods that occurred from October 1998 to 1999 (IEC, n.d.; Saxena et al., 2012); it should have been instigated for the country starting from the Tutong River. An overview of a flood study was undertaken using the Storm Water Management Modelling (XP-UDD), field investigations, and a history of the river from the residents' perspectives (IEC, n.d.). This overview on flood study provided the basis for hazard assessment and floodplain management while incorporating EWS, hazard control, and capital works improvements (Fig. 8.7).

EWS uses electronic sensors for upstream river levels, which telemetry conveys to control rooms at Bukit Barun and the Department of Drainage and Sewerage (DDS) at the PWD headquarter (IEC, n.d.). For downstream villages, the system provides lead times of 12–15 h, and up to 25 h for Tutong Town at the bottom of the catchment. DDS can produce daily reports predicting flood levels for 13 locations. The integrated flood hazard control provides a mapping of flood-sensitive areas, identifies danger levels for vehicles and pedestrians, and suggests flood response strategies (IEC, n.d.).

Further to the described advantageous flood forewarning system as a mode of emergency preparedness, reports such as NIDM (2014), AHA, and JICA (2015) provide further details on the roles, achievements, legislative and operational aspects of disaster management in Brunei (NIDM, 2014; AHA & JICA, 2015; Ndah & Odihi, 2017) and should be implemented in the approach for flood mitigation measures.

Meanwhile, some flood mitigation projects are also being implemented on a stand-alone basis (Shafiuddin, 2014). The relevant government departments had introduced projects that had been processed without considering and integrating the essential aspects of water issues, such as over-drainage, storage of residual flood flows on streams for agricultural irrigation requirements, and agro-land reclamation by leaching whole saline-damaged agri-fields (Shafiuddin, 2014). With follow-up projects, these parts have to be acknowledged for the countries' best interest in general and for TRB in particular. Therefore, an infrastructure for the development of irrigated agriculture is required which would utilize residual flood flows that have been stored in the streams (Shafiuddin, 2014).

Another essential approach for the development of flood mitigation measures and solutions is the availability of disaster data in order to analyses diverse coherences. However, due to the unavailability of any existing disaster data (except for one forest fire event), a disaster risk analysis economic loss potential (AAL) and economic losses for different probabilities of exceedance could not be carried out (Gupta, 2010). While these deficits have been bettered today, the consequences had been taken into account in 2006: the country established the NDMC to take on disaster risk reduction (DRR) initiatives. Furthermore, a National Progress Report on the Implementation of the Hyogo Framework for Action (2009–2011) was also developed (GBD, 2011).

An elevation flood map such as the existing one (Figs. 8.5, 8.6, 8.7, 8.8, and 8.9) should always be carried out in all planning processes and to strengthen the understanding and necessity for the implementation of mitigation measures on the ground. Elevation flood maps on their own are not sufficient for the analysis of flood risks. The awareness for preventive organization in spatially localized areas is a greater step forward. Many other factors are involved and have to be acknowledged in planning activities: surface run-off, flow diversion, land type, soil type, etc. For natural hazards, calamities, and flood mitigation in particular, measures and remediations should be taken into consideration:

- Lowering risk factors through.
  - Establishing a risk profile due to historical disaster data.
  - Minimizing urbanization and in general minimizing sealing against higher water run-off.
  - Accepting the floodplain area as retention space in case of floods.
  - Planning measures for new retention areas in the floodplain area of the Tutong River such as a renewed NBD Master Plan (NBD, 1987) and a renewed National Land Use Master Plan (NBD, 2008) for any national and up to local informal processing.
  - Sustainable floodplain management plan that could be implemented properly.
  - Protection of forests, natural resources, and environmentally sensitive areas through land-use zoning (MIPR, 2008), and strenthening rural livelihoods in line with nature.
  - Mitigation approach and nature-based solution development on the basis of the entire watershed perspective.
  - Engineering measures and involvement as well as non-engineering measures.
  - Structural measures and non-structural measures.
- Improving flood disaster data through databases on a regional and national level: Solving a lack of information on the intensity and duration of floods while bettering the identification of different classes of flood hazards.
- Enhancing, developing, and implementing the disaster risk reduction indicator in correlation to flash floods and monsoon floods on a national level.
- Enhancing, developing, and implementing the flood risk reduction modeling.
- Natural mitigation and indigenous engineering knowledge application.
- Improving flood disaster risk reduction in planning spheres (GBD, 2011).
  - A national development plan, and Sector Strategies and plans.
  - A climate change policy and strategy.
  - Poverty reduction strategy papers (the less financial resources that exist, the more prone to disasters in general).
  - Common Country Assessments (CCA)/United Nations Development Assistance Framework (UNDAF).
- Natural resource protection, throughly,
- Stabilizing vegetation cover near the riverine system (Huang & Nanson, 1997).

- River catchment management and drainage system development in consent with sustainable land use.
- Water storage, drainage, and supply system development.
- People's awareness on development, participation, and engagement and
- Infrastructure and security functions:

Specific flood mitigation and adaptation measures might be of highest interest, such as re-building the highway as a main transport way and access point to the district in the form of a combined highway and dam (German examples of railway dams) or by building the road(s) higher by topsoiling them.

5 Discussions

The natural disaster rate in Brunei is comparatively low, but the recent trend of flooding in Tutong is actually rated higher. However, natural disasters that Brunei has encountered so far are mainly floods and landslides. This is supported by the Brunei Disaster Management Reference Book (CFE-DMHA, 2022), which said that floods in Brunei are the highest natural threat to the country, brought on by disasters from neighboring countries, such as typhoons in the Philippines, although Brunei is not located along the typhoon path. In January 2009, flooding in Brunei caused significant damages to the infrastructure and economy, and has also caused the loss of many lives. More than 200 houses were damaged and some 420 residents in Brunei-Muara were flood victims, while power failures and disruption of phone services and traffic also occurred (Ndah & Odihi, 2017). Disasters or hazards that occurred in Brunei in the past compared to the current scenario have shown a significant increase and change in statistics. As a result, they have become a source of worry and anxiety within the Bruneian community (Ummu, 2021).

Human disturbances in the river floodplain might be minimized to better the river's geomorphological condition and decrease the risk and vulnerabilities of the alluvial plains against floods (Smith, 2013; Ali et al., 2019). The existence of the Tutong River basin is the first agent or the main factor that contributes to the hazard of flooding, next to aspects of land use activities by the river. Moreover, the importance of vegetation cover along the river channel should be acknowledged; the thickness of vegetation cover reduces erosion because the roots decrease lateral erosion, reduce the risk of flooding (Smith, 2013; Ali et al., 2019), and absorb parts of the water runoff. However, in the case of Tutong, drainage basins are pressured by human development, which explains the high vulnerability and risk of catastrophic flooding in several areas. The catchment area of the Tutong basin is distributed into canals, tributaries, and distributaries due to human interruption to the river's natural flow, which should be reassessed.

Human intervention on the Earth's ecosystem, such as the drainage basin, contributes to another overwhelming phenomenon: climate change. About 75% of the

Earth consists of water and this natural resource creates life, but it is also crucial for life and dwellings. Climate change and the excessive production of greenhouse gases into the atmosphere causes a change in the pattern of the Earth's ecosystem. Global warming is one of the inducing factors that increases the Earth's temperature, which causes sea levels to rise in the coastal regions and thus contributes to vigorous coastal erosion. The intrusion of coastal water in estuaries strains the river's capacity to hold water and eventually causes floods (Shams, 2015).

Development such as housing communities and business centers along the floodplains also creates strain on the geomorphology. Furthermore, human development on the floodplain surface creates impermeable surface rainwater that cannot penetrate the surface, which causes high surface run-off. As a result, vegetated land surrounding the floodplain could result in the slightest, though less chaotic, floods. However, this is due to little or no surface run-off as the canopy prevents 15–30% of rainwater from trickling into the ground, and the vegetation soaks up the existing moisture during photosynthesis.

The 1987–2005 NBD Master Plan (NBD, 1987) and the 2006–2025 National Land Use Master Plan (NBD, 2008) regulate and require the protection of forests, natural resources, and environmentally sensitive areas through land-use zoning (MIPR, 2008). In any national and local processing, these rules should be incrementally adapted.

6 Conclusions

In conclusion, the Tutong River is a natural ecosystem that is characterized by the event of flooding. Therefore, flooding events are regular, and it is a natural phenomenon that occurs along the drainage basin. However, the strain and pressure of human development has increased the severity of flooding in recent years. In the case of the Tutong basin, the flood-prone area is pressured by human development such as agricultural activities and heavy infrastructure. A report by NDMC, supported by the author's own evaluations, has verified that flood-prone areas include Kg Telanai and Kg Bebuloh in Brunei-Muara and Kg Kiudang in Tutong. They generally show the high flood rate of the Tutong River, as well as other areas in Brunei. Meanwhile, a higher rainfall rate that occurs from November to February during the monsoon months also results in a higher tendency of flood to occur in these areas.

In recent years, Brunei has faced disasters, as seen in Table 8.4. For instance, in 1998, Brunei faced a forest fire disaster, while in 2007, the country experienced floods and strong winds. In 2008, Brunei experienced landslides, floods, and strong winds, while in 2009, the country was inundated with floods, landslides, a pandemic, a severe fire outbreak, and a haze. Further floods occurred in 2019, 2020, and 2020/2021, while in 2020 and 2021, the COVID-19 pandemic affected the Sultanate as well as the rest of the globe. Thus, the country is always at risk of natural hazards such as landslides, floods, forest fires, storms (winds), and haze. Based on evaluations in Table 8.4, the number of flood-prone areas in Brunei could increase in the future, through an increase in heavy monsoon rainfall, rising sea level, and devastating floods in Tutong, as well as in the rest of Brunei.

Therefore, the country has created DRR initiatives, such as the establishment of NDMC, to coordinate and communicate responsibilities to all governmental administrative levels, from the country level to the district level, and to eventually to the local level.

Flood prevention and mitigation can be better optimized by: (1) Creating a limited reporting of localized disasters to international databases to avoid misperceptions; (2) Activating and strengthening limited knowledge, awareness, and motivation among the general population, while supporting effective mitigation and adaptation; and (3) Implementing a partial DRR into development plans and governance structures contribute to heightened disaster risks.

Recommendations for Mitigation.

Brunei has hosted different initiatives related to flood mitigation that should be further fostered to create awareness on landslides and flood risks in Tutong. This would thus mitigate and prevent while at the same time increase public awareness. People within the community could also actively participate in sharing indigenous knowledge on the mitigation of natural hazards.

- The Tutong and Brunei Flood Map may help provide flood alerts/flood warnings, in the event that the floodwater level rises to a certain point. A flood map could help locate places at higher levels where people could escape from floods or where flood rescue/flood relief operations could be conducted as preventive measures.
- Global warming and rising sea levels are effects of climate change. Date related to these events could also be incorporated into a floodplain map and flood line map for streams and rivers; and, as a result, the effect of rises and changes in sea-levels could be seen. It could be helpful in coastal areas for the purpose of monitoring and management, and could help perform elevation analysis of an area for purposes such as city or town planning, new construction, etc.
- The Brunei Government, non-government organizations, and social organizations need to make an effort to develop methodologies and policies, validate tools, and create impact assessment indicators and instruments for flood and riverbank erosion protection and management on a micro level in Tutong (Islam, 2016).
- Geographical Information Systems (GIS) and remote sensing techniques should be introduced in the data analysis, visualization, mapping, planning, and modeling of flood-prone areas for future flood forecasting, erosion control, general floodplain control, and effective management measures.

- Flood monitoring, forecasting, and warning systems should be developed and communicated in a more transparent manner to the locals. Disaster risk and disaster behavior education with exercises for locals, as well as for the disaster management operators responsible, should also be prepared in a better way to create awareness.

Additionally, the community's participation, mitigation and adaptation strategy, awareness education, and applied research on floods, floodplain management, and agricultural cropping systems should be incorporated into the national development plan agenda. Local residents should be equal partners in decimating the knowledge about river systems and flooding pattern in the floodplains as well as in catchment development. Together, all relevant parties could create a safer and more sustainable settlement and livelihoods. Therefore, indigenous knowledge, skills, and capacities should be incorporated to the ecological management of the Tutong River floodplain and basin area. These mitigation approaches could then positively influence the riverine floodplains, and landscapes of Tutong District in Brunei Darussalam.

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Chapter 9
Adaptation and Resilience Measures in the Face of Extreme Events in Algeria

Faiza Hallouz and Mohamed Meddi

Abstract When designing policies and programs, it is important to consider the limitations of adaptive capacity, of the population in certain contexts of extreme events. This may require a transformation of the systems themselves, so as to build resilience. Building resilience to climate change will require the incorporation of climate change adaptation and disaster risk reduction measures into short, medium, and long-term policies, programs, and practices. This chapter aims to propose a conceptual framework for assessing resilience in a socio-hydrological context and provide insights into how resilience can be understood and managed in Algeria in this case. The two most important extreme events are droughts and floods. Thus, the search for resilience goes through actions that act on the population's response to the effects of climate change. Acting and responding effectively to a disaster before, during, and after depends on the right attitudes and skills of individuals acquired through education, training, and awareness-raising to the effects of climate change. Analysis of the results shows that adequate resilience in any society depends largely on water resources sector planning and water supply infrastructure. Overall, the results of this chapter suggest that several disciplines, such as eco-social management, engineering systems, and institutional management, should play a role in planning disaster resilience strategies.

Keywords Resilience · Climate change · Extreme events · Water supply · Algeria

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1 Introduction

A fashionable concept, resilience, is now required both in academic research and in management practices. The polysemy of the term feeds many debates about its use and its heuristic and operational relevance.

Risk management often faces recurring challenges, and resilience is seen as a potential solution. However, it only addresses certain issues while creating new ones and also carries potential ethical and political risks. Furthermore, the push for resilience at the international level brings with it certain moral and ideological considerations, which are not always clearly stated but which are problematic (Igbatayo et al., 2022).

The idea of resilience, initially introduced decades ago, has evolved significantly. It has transformed from a simple descriptive term to a concept loaded with normative meanings and multiple interpretations (Brand & Jax, 2007; Olsson et al., 2015; Weichselgartner & Kelman, 2015; Mao et al., 2017). This lack of conceptual clarity has been noted by some authors and has led to difficulties in applying resilience thinking to socio-hydrological systems (Strunz, 2012). In the realm of human-water interactions, the term resilience is applied in various ways, including hydrological resilience, ecological resilience, community and urban resilience, and resilience of water cycles. However, these uses do not always fully encompass the complexities of socio-hydrological dynamics or facilitate interdisciplinary resilience research (Rockström et al., 2014). However, these applications do not always capture the essence of socio-hydrological dynamics or support interdisciplinary resilience research.

Despite the recognition of certain aspects of resilience such as flexibility, interconnectedness, and social learning, these elements are still not sufficiently examined in terms of design, planning, or authority practices in various contexts and regions (Javadinejad et al., 2019a). As a result, it is important to recognize the political and historical dimensions when developing resilience planning and strategy (Meerow et al., 2016). Currently, resilience planning involves the complex realities of environmental changes and resource governance in specific contexts. Water systems, in particular, are highly affected by global environmental changes (Francis & Bekera, 2014; Javadinejad et al., 2021). Despite being seemingly abundant, water is unevenly distributed globally. With industrial development and growing demand, many countries will experience water stress (less than 1700 m^3/year per capita) and water scarcity (less than 1000 m^3/year per inhabitant). The countries most at risk are those in North Africa, sub-Saharan Africa, and the Middle East (Hinrichsen et al., 1998; Ladjal, 2013).

The heating of the climate system is irrefutable, and since the 1950s, numerous changes have been observed that are unparalleled in recent decades or even centuries (Puget, 2010). The atmosphere and ocean have increased in temperature, snow and ice coverage has diminished, and sea levels have risen (Puget, 2010). All the world's experts agree that in the medium term, in 30 years' time, the climate will suffer serious and varied disorders. According to them, the rise in temperature will melt part of the sea ice and mountainous glaciers, and sea and ocean levels rise. Some parts of the world will be exposed to severe hurricanes, repetitive deluges, and severe, frequent, and prolonged droughts. The advances of the deserts will accelerate (Puget, 2010). Climate change could cause millions of people in Africa to fall into poverty by 2030 and undermine the progress made. Despite many African nations achieving significant development advancements in recent years, with an average annual growth rate of 4.5%, weather-related, hydrological, and climate hazards now pose a threat to these achievements (World Bank Group, 2020). Since 1970, Africa has seen more than 2000 natural disasters, with nearly half of them happening in the last decade. These types of events have impacted over 460 million individuals and resulted in the loss of 880,000 lives. With African countries facing increasing climate risks, it is essential for them to increase their adaptation and resilience measures promptly (World Bank Group, 2020).

In thirty years' time, if it has not already done so, a country like Algeria may face the advancement of the desert in the South and increased sea salinity in the North. Climate change is now widely regarded as one of the most significant threats to the environment and the future of the planet. Progressive climate change in the future presupposes that agriculture will continue to develop and that harvest periods will lengthen. Northern Europe, Russia, and North America will prosper agriculturally while Southern Europe, Africa, Central and South America will suffer from droughts, heat, water scarcity, and reduced production.

Water and its management are significant issues that will shape the future of the Maghreb region (Agoumi et al., 1999). Regardless of climate change, the sensitivity of watersheds to small changes in climate variables means that the amount of water that can be mobilized will be greatly affected by a decrease in runoff (PNUD-FEM, 1998). In Algeria, only 13% of the land has a Mediterranean climate, while the rest is dominated by a Sahelian climate. The majority of productive watersheds, accounting for about 75% of annual surface water flow, are located in the eastern part of the country along the Mediterranean coast. Much of the remaining land is subject to desert conditions, where water scarcity is severe and water management systems are deeply traditional (PNUD-FEM, 2003; Nouaceur et al., 2013; Belarbi et al., 2017). In addition to its unfavorable geographical position, the population explosion has exacerbated the situation. In fact, the ratio of water resources per person per year, which was 1500 m^3 in 1962, has dropped to 720 m3 in 1990, 630 m3 in 1998, and 500 m3 today, reflecting the gap in relation to population growth (Mozas & Ghosn, 2013). As a result, Algeria is already experiencing water scarcity (Benblidia & Thivet, 2010; Hallouz et al., 2021), a situation that could be amplified by the intensity and pace of climate change (Barnett et al., 2001; Frich et al., 2002; Belarbi et al., 2017). Furthermore, the current climate disruptions have resulted in irregular rainfall and a prolonged drought. This climate variability, characterized by a decrease in precipitation, has been the subject of numerous studies. In 1993, after analyzing data from 120 rainfall stations, Laborde was able to identify a succession of four rainfall phases, including a long deficit phase that began in late 1973. However, the results of the studies carried out by Djellouli and Daget (1993) showed that since 1881, Algeria has suffered two periods of drought: the shortage was felt from 1943 to 1948, which had a significant impact on crops and livestock, and the second is the one we have suffered since 1980. During the 1980s and 1990s, the rainfall deficit was estimated at 50% for the central and western regions of Algeria; in the East, it was 30%. And 1988–1989 was classified as a dry year for Algeria (Kettab & Ait, 2002). This drought was followed by numerous floods throughout Algeria (Hallouz et al., 2020). According to Meddi and Meddi (2009), while this reduction was of the order of 20% in central Algeria, it amounted to more than 36% in the far west of the country, thus causing a drastic decrease in surface runoff. Meddi and Hubert (2003) estimated this reduction at nearly 55% for the central basins, between 37% and 44% for the eastern region while it oscillates from 61% to 71% for the basins of the extreme west (Belarbi et al., 2017).

In the context of global politics, it is essential to establish resilience within the water governance systems of regions facing the effects of climate change. This resilience should help counter various impacts and prepare for future challenges (De Souza et al., 2015; Javadinejad et al., 2020).

Our goal is to develop a conceptual framework for evaluating resilience in a socio-hydrological context, and to provide an overview of how it can be understood, managed, and strengthened in Algeria in response to extreme events caused by climate change.

2 Population Water Demand, Extreme Events, Adaptation, and Resilience

The two most important extreme events are droughts and floods. Ranked first in the world of natural disaster, floods lead to the death of about 500,000 people per year (Bachi, 2011), the destruction of cities and villages, the freezing of all activities contributes to the development of different economic and social sectors. The risks of flooding are due to the complex interaction of several factors, it is the result of concordance of topographical, geological, hydraulic, and meteorological parameters. However, they are not always caused by exceptional events because they can take place following ordinary metrological episodes favored by the intervention of other parameters such as anarchic urbanization, poor planning of land development, lack of maintenance of rivers, etc. (Benserrai et al., 2019). Indeed, the fifth report of the Intergovernmental Panel on Climate Change updates the data on the impacts of climate change and highlights, on a regional scale, “Increased economic losses and impacts on populations due to flooding in watersheds and along coasts, compounded by urbanization, sea-level rise, coastal erosion, and increased river flows” (IPCC, 2014).

As for floods and well, resilience advocates forecasting – alert system for example – prevention, regulation, awareness raising, information to individuals, situational exercises to adopt good reflexes during the crisis and then rebuild, in order to return to normal functioning.

Thus, the search for resilience goes through actions that act on the behaviors of individuals. Acting and responding effectively to a disaster before, during, and after depends on the right attitudes and skills of individuals acquired through education, training, and awareness-raising (Dauphiné & Provitolo, 2007). Drought expresses a major risk through a water deficit in all its forms (climatic, hydrological, and edaphic) whose consequences are always harmful and sometimes dramatic (conflicts over water, livestock mortality, desertification, fire, destruction of crops, insalubrity, famines, migrations, etc.). For example, the drought in the Sahel, which raised the most awareness of world opinion, caused the death of 1,200,000 people between 1972 and 1973 and between 1984 and 1985 (PNUE, 2011). In addition, urban and agricultural developments, the water needs of populations, and regional development plans induce an increasingly strong pressure on water resources. In regions where drought is rife, it is necessary to develop a strategy based on the analysis of this climatic phenomenon and its magnitude on the one hand and to develop an approach to adaptation to this scourge on the other hand. This major climate risk, which will probably tend to increase in the future, particularly in Mediterranean regions with climate change, requires support through international solidarity and at the national level through ecosystem-preserving development program and coherent and patrimonial management of water resources.

Drought is probably one of the major risks that require the involvement of everyone (politicians, scientists, different sectors, civil society, the population) to face it.

For drought, resilience depends on the following factors:

- To ensure long-term water recovery, we must: make the population more flexible to preserve water.
- Support communities to undertake innovative adaptation actions that build their resilience to drought.
- Improve irrigation techniques (drip irrigation, sprinklers, and pivots).
- Reduce the leakage rate in our distribution networks through good quality of realization and maintenance.
- The increase in the exploited fraction of water resources and this through the realization of hill reservoirs and the reuse of purified water for irrigation as well as the realization of boreholes for the supply of portable water to scattered areas.
- Additionally, in pastoral areas, water demand is primarily related to irrigation on spreads, thus resilience can be improved by adjusting the planting time, crop types, or cultivation location. These socioeconomic factors play a crucial role in building resilience and in the decision-making process.

3 Descriptions of Resilience

Resilience can be defined as the capacity of individuals and systems to anticipate, adapt to, and recover from negative impacts such as natural disasters and climate change, in a way that minimizes their vulnerability, safeguards their livelihoods, and promotes economic and social development while maintaining their cultural identity (Hume, 2019). Climate-resilient development encompasses measures and actions that will have a beneficial impact regardless of future climate conditions and are able to cope with climate uncertainty. Under the lens of the fight against climate change, the IPCC uses a more nuanced definition of resilience: Resilience can be described as the ability of social, economic, and environmental systems to manage and withstand a hazardous event, trend, or disturbance, by adjusting or reorganizing in ways that preserve their core functions, identity, and structure, while also preserving the ability to adapt, learn, and evolve (IPCC, 2014; Hume, 2019). Resilience is "in vogue" among scientists, managers, and international bodies in charge of disaster reduction. Comfort et al. (Comfort et al., 2010) speak of "buzzword" and date the consecration of the term September 11 and Katrina. Klein et al. (2003) rather show its link to climate work and concerns. Be that as it may, the omnipresence of resilience questions its relevance. Indeed, the abundant use of the concept, especially in the social sciences, is not always accompanied, far from it, by a solid theoretical foundation. The term then becomes a kind of portmanteau word solicited for very diverse purposes, like other notions in vogue (sustainability, governance, etc.) which are often attached to it (Aschan-Leygonie, 2000; Gallopin, 2006). The concept of resilience has been extensively examined, but its origin remains a subject of debate. The meaning of the word is often used to infer its scientific definition (Tisseron, 2009; Klein et al., 2003; Godschalk, 2003); however, there is no agreement on where the concept originated from. According to various sources, resilience may have originated in the fields of engineering, ecology, or psychology. However, there is general agreement that the concept is multidisciplinary (Cutter, 2008; Hernandez, 2009; De Bruijne et al., 2010, etc.) and that it has spread widely outside its original disciplinary fields (Fig. 9.1).

Describing resilience from the perspective of hydraulic engineering depends on some quantifiable properties of the technical infrastructure system, e.g., reliability and resilience. However, the description of the resilience of an ecohydrological system depends on its responses to water and socio-ecological systems. However, descriptions of resilience vary, they can help identify important trends in resilience concepts. There is an accretive graph of the different types of delineations and conduct of resilience linked by different aspects during 2006–2017 (Fig. 9.2) (Javadinejad et al., 2021).

The Framework Convention and the Kyoto Protocol address the urgent need to implement climate change adaptation and risk reduction strategies, and to strengthen 3 capacities and resilience at the local level. Vulnerability to disasters is a complex phenomenon with social, economic, health, environmental, and cultural dimensions. It has two facets: (i) the degree of exposure to disasters (sensitivity) and (ii) the ability of a society or community to cope with or recover from the consequences of the disaster (resilience). Risk reduction programs aim to reduce sensitivity and increase resilience. In addition, the resilience of a society or community can be understood as: (i) its ability to absorb the shock through resistance or adaptation (Ballet et al., 2003), (ii) the ability to manage or maintain certain basic functions or structures (Randrianalijaona, 2008), and finally (iii) the ability to recover or "bounce back" after a shock. By this third definition, resilience has a temporal dimension. It assumes that resilience can only be assessed after a disaster or shock. There is

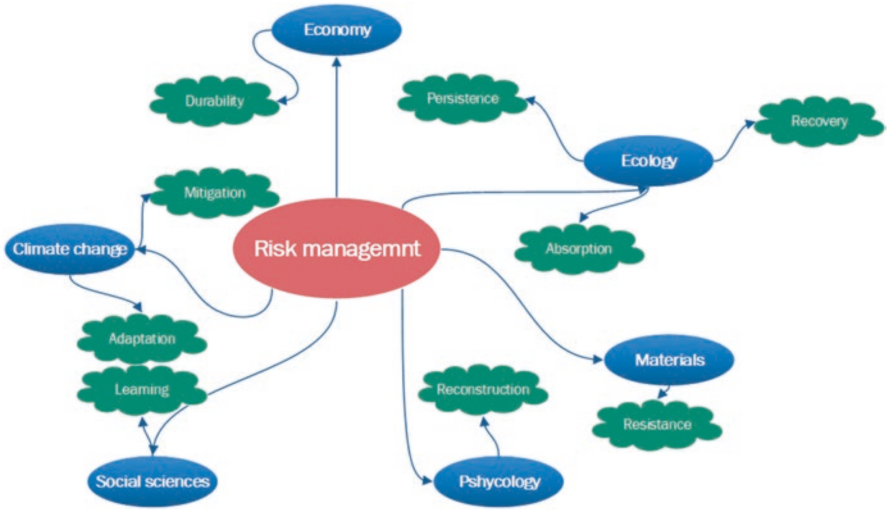

Fig. 9.1 Interdisciplinary nature of resilience. (Djament-Tran et al., 2011 modified by Hallouz)

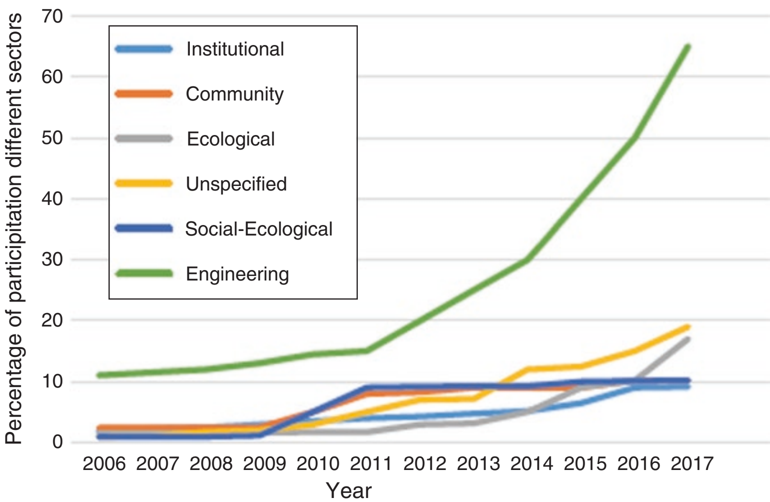

Fig. 9.2 A comprehensive understanding of the concept of resilience can be gained by grouping and representing the various definitions and actions identified in literature reviews from 2006 to 2017. (Javadinejad et al., 2021)

therefore a panoply of methods for calculating the resilience or recovery time. The latter definition nevertheless shares the scientific community, with on the one hand those who consider that resilience can be assessed even before a disaster (D'Ercole & Metzger, 2009). For them, resilience is the ability of a community to prepare "before" the shock and to recover "after". On the other hand, researchers believe that it takes a shock first to determine a community's resilience to that shock (Randrianalijaona, 2008; Razafindrakoto, 2011; Reghezza-Zitt & Rufat, 2015; Cyrulnik, 2015). UN-Water describes water resilience on a global scale, OECD, UNDP, World Bank, IPCC report, Global Water Partnership and European Commission. These Organizations play an important role in global water governance, and resilience at local scales such as cities and hydrology system should increase (Javadinejad et al., 2019b).

4 Main Problems of Water Resources in Algeria

4.1 Climate of the Mediterranean Region

The Mediterranean climate is characterized by a dry summer and a temperate winter. Rainfall varies widely (between 100 and 2500 mm) (Tassin, 2012). This climate is found in the territories bordering the Mediterranean but also in other regions of the globe such as those located in California, Chile, Australia, and South Africa (Médail & Quézel, 1997; Meddi et al., 2003). It is now widely recognized that the Mediterranean region is a "hot spot" for climate change. According to the IPCC, temperatures will rise by 2–3 °C in the Mediterranean region by 2050, and by 3–5 °C by 2100. Summer precipitation could decrease by 35% on the south shore and by 25% on the north shore by the end of the century (Nabi, 2016). Mediterranean countries are already facing significant problems of water stress, desertification, biodiversity loss, and extreme weather events such as floods and droughts. Climate change will most likely result in a worsening of these problems, resulting in considerable human and economic losses (Médail & Quézel, 1997; IPCC, 2001).

4.2 Climate in Algeria

The climatic areas are very diverse and the climate varies from the Mediterranean type to the Saharan type. In the north, winters are rainy and cold, and summers are hot and dry. The climate, along the coast, is softened by the presence of the sea (Meddi et al., 2003). The Algerian East is a rainier region than the West, with its 2 meters of rain per year and snow-capped peaks from October to July (Meddi et al., 2003). The North of Algeria is essentially Mediterranean with a continental counterweight, due to the barrier put up by coastal links to maritime influences. The combination of Mediterranean features with continental characteristics develops more as one advances inland. The winter is then harsh and the summer is hot and dry. Insufficient and irregularly distributed rains are absent in summer and quite frequent in winter in the Tell, and in spring in the highlands. They are abundant in the Eastern Tell and in the high plains of Constantine, while it is rarer in south of the

Aurès, and in the High Plains of Oran (Meddi et al., 2003; Grimes, 2008). To the south, the foot of the Tellien Atlas marks the limit of the arid climate: dry and tropical, with large temperature differences in winter: the average temperature is 36 °C during the day and 5 °C at night. The deserts (Sahara) are located globally in the intertropical region. The nature of the desert is first linked to the notion of aridity. The first works on rainfall indicate that the heart of the Sahara is experiencing extreme aridity and that the northern and southern limits receive 100–150 mm of rain per year. The rainy seasons show a Mediterranean influence in the north (winter and autumn) and tropical influence in the south (summer rains). A corridor stretching from the Hoggar to the Red Sea records spring rains. During the winter, the altitude anticyclone can be pushed southwards and disturbances of polar origin reach the northern Sahara. In summer, the altitude divergence is more marked north of the Sahara, while Saharan depressions can be triggered. At this season there is an interaction with the African monsoon regime whose impact can reach the Hoggar (Grimes, 2008; Dubief, 1959).

- The coastal and mountainous regions of the country make up a small portion of the total area, yet they are home to a significant portion of the country's cultivated land. These areas are highly susceptible to erosion due to the concentration of population and activities, as well as unchecked urbanization. The Mediterranean climate, with heavy winter rains and strong erosion, combined with infrequent and intense summer heat, creates a challenging environment for these fragile regions. The rainfall, which can reach up to 1600 mm per year on the mountainous areas, is unpredictable and unevenly distributed.
- The highlands, which occupy about 9 percent of the total area, are characterized by a semi-arid climate (rainfall between 100 and 400 mm/year). Almost two-thirds of the cultivated areas are concentrated there. The land in the area is known for its high salt content, which exacerbates the desertification process. The drought, coupled with wind erosion, weak water resources, and intensive agro-pastoral practices, weaken the soil and make it less resilient to desertification.
- The Sahara Desert, which receives minimal rainfall at an average of less than 100 mm per year, encompasses 87% of Algeria‘s territory. The amount of land used for cultivation in this region is extremely limited, with only about 100,000 hectares being utilized. The land here is poor in quality and the climate is harsh, with extreme temperatures and large temperature fluctuations.

Across the country, average rainfall is 89 mm/year and potential evapotranspiration ranges from 800 mm in the north-east of the country to more than 2200 mm in the south.

Five to six years of droughts in ten years currently. The prolonged and severe drought experienced in Algeria over the past three decades, marked by a 30% deficiency in rainfall, has greatly affected the patterns of river flow, the filling capacity of dams, and the availability of groundwater. This has had a detrimental impact on all aspects of society and the economy. Taking into account the drought of the last 30 years, estimates of water potential are being revised downwards. Agricultural and rural development strategies also take these changes into account and consider adaptation measures (Kerrouche, 1998; Safar-Zitoun, 2019). Much of northern Algeria is extremely vulnerable to climatic variations and extremes, with recurrent drought becoming a particularly serious problem. The early 1990s were, for example, characterized by extreme drought that caused water shortages and crop failures in the region (Safar-Zitoun, 2019).

5 The World's Water Reserves

It is estimated that there is about 1.4 billion m^3 of water on the planet (Nabi, 2016). However, most (97%) of this water is present in the form of salt water in the seas and oceans. It is difficult to value for human activities. Of the remaining 3% (36 million km^3) more than 3/4 constitute the glaciers that are very inaccessible. The remaining 1/4 km^3 consists mainly of groundwater (less than 1% of the total water of the globe) and a small part in the form of surface water contained in lakes and rivers (or 0.01% of the world's water) (Meddi & Humbert, 2002).

5.1 Water Resources in Algeria

Algeria is divided into five hydrographic basins grouping the country's 19 watersheds (Table 9.1, Fig. 9.3).

Until 2000, Algeria had 44 dams in operation. The theoretical capacity of this surface water mobilization was around 4.5 billion m^3. The capacity actually mobilized hardly exceeded 2.5 billion m^3 for reasons mainly related to an increased drought and a spatial and temporal irregularity of rainfall (Kettab, 2001; MATE, 2008). The sediments deposited are estimated at 20,106 m^3/year of lost volume. It is a semi-arid country, even arid (200–400 mm) and water resources are low, irregular, and localized in the coastal strip. If we consider a capacity of 3.4 billion m^3 mobilized by groundwater, the total mobilization potential of the country reached 5.9 billion m^3, while the real needs were 6.85 billion m^3 (Kettab, 2001; MATE, 2008; Bellal et al., 2015). In Algeria, the population was 23 million in 1987, and will be

Table 9.1 Watersheds (FAO, 2016)

Basins	Area (km^2)	Watershed
Cheliff-Zahrez	56,230	Coastal Dahra, Cheliff, Zahrez
Algeries-Hodna-Soummam	47,430	Coastal Algeries, Sebaou, Isser, Soummam, Chott Hodna
Constantine-Seybouse-Mellegue	44,350	Coastal Constantine, Kebir-Rhumel, Medjerda-Mellegue, Seybousse, Highland Constantinois
Oranie-Chott Chergui	77,170	Coastal Oranais, Macta, Tafna, Chott Chergui
Sahara	2,018,050	Sahara, Chott Mekghir

Fig. 9.3 Map of the 5 watersheds. (AHS, 2012)

46 million in 2025, which means a consumption of drinking and industrial water of the order of 6 billion m^3/year, while the real mobilization, at the time, was barely 3 billion m^3 (Kettab, 2001; MATE, 2008). This means that it was necessary to mobilize, for these two sectors alone, an additional 3 billion m^3, without including irrigation water or leaks in the pipes, i.e., a total of 10 billion m^3 of water, a real challenge to be met but above all a strategy and a policy to be defined (Kettab, 2001; MATE, 2008).

5.2 The Natural Characteristics of the Algerian Territory

It covers 2.4 million km^2. From North to South, there are three very contrasting ensembles, different in their relief and morphology. First of all, the Tell range and the coastline, then the Atlas range that runs along the High Plains further south, and finally, the Saharan desert that extends beyond the Atlas Mountains. It is this arrangement of the relief that, together with climatic conditions, determines the agricultural potential and water resources of the country (Perrodon, 1957). Most of the country (87%) is a desert where rainfall is almost zero, but which contains significant fossil resources of groundwater. The northern part of the country is characterized by its Mediterranean climate; it has renewable water resources, both for surface water and for groundwater. The 90% of the surface water is located in the Tell region which covers about 7% of the territory. The country is also characterized by a strong disparity between East and West. The western region is well endowed with plains but is little watered. The eastern part of the country is mountainous where major rivers flow (Perrodon, 1957; Agoumi, 2003; Meddi et al., 2016; Hallouz et al., 2021).

5.3 Global Water Potential

The total water availability in the country is calculated to be 19.4 billion cubic meters per year. The northern region of the country boasts significant groundwater reserves, estimated to be 2 billion cubic meters per year, while surface water resources are estimated to be 12 billion cubic meters per year. The southern part of the country is home to substantial groundwater resources located in the Continental Intercalaire and Terminal Complex aquifers (Nabi, 2016; IPCC, 2018). The water reserves are very important and are of the order of 60,000 billion m^3, of which 40,000 billion are located in Algeria. The peculiarity of this resource is that it is not renewable (Servat et al., 1998; Nabi, 2016).

5.4 Water Situation in Algeria

The challenges facing water management in the Maghreb region are significant and multifaceted. Ensuring access to clean drinking water for the population, managing and protecting water resources, and controlling the agricultural and industrial use of water are all critical issues. Additionally, factors such as the impact of human activity on natural environments, the management of natural risks like floods and droughts, and the potential for global warming all add to the complexity of the situation. Overall, addressing these challenges will require a comprehensive and integrated approach that takes into account the interrelated socio-economic, political, and environmental factors at play (Vervier et al., 2004). For all these reasons, the quantification of water resources has been of particular importance to scientists and water managers around the world over the past 20 years (Milano et al., 2013). The significance of this research is rooted in the crucial challenges posed by weather fluctuations and their effect on water resources and the hydrological cycle, which vary depending on the region (Goula et al., 2006). The depletion of water resources due to human, industrial, and agricultural activities, as well as global warming, is a pressing concern that the Algerian government is giving high priority to address. However, it must be recognized that water resources in Algeria are limited, vulnerable, and unevenly distributed. The country's natural water potential is globally estimated at 18 billion m^3/year distributed as follows: 12.5 billion m^3/year in the northern regions, including 10 billion in surface runoff and 2.5 billion in underground (renewable) resources. 5.5 billion m^3/year in the Saharan regions, including 0.5 billion in surface flows and 5 billion in underground resources (fossil aquifers) (Mozas & Ghosn, 2013). The uneven distribution of precipitation means that surface waters are equally poorly distributed (Nouaceur et al., 2013). Coastal areas are more water-rich than semi-arid and arid areas. This leads us to say that Algeria, by the force of nature and the human beings, is today confronted with a problem of availability in sufficient quantity and quality (Hallouz et al., 2021). It is particularly important to note here that, the World Bank ranks Algeria in the category of the poorest countries in terms of water potential, with only 11.5 billion cubic meters of renewable water per year, or 292 m^3 per person, while the world average is 6000 m^3 per person (Belarbi et al., 2017) (Table 9.2).

It should be noted that more than two-thirds of the volume of surface water that can be mobilized is located in 4 of the 17 watersheds (Chlef, Algiers, Soummam, and Constantine), which occupy an area of 75,000 km^2, or 3% of the area of the national territory (Agoumi, 2003; Guergueb & Ferhat, 2021). These resources have also suffered the adverse effects of drought, pollution, and mismanagement over the past three decades. The equations to be solved are not simple in view of the strategic and vital dimension of this precious resource (water) characterized by scarcity and shortage (Guergueb & Ferhat, 2021). In fact, Algeria has chronic water stress in some regions. This vulnerability represents a challenge that Algeria has undertaken to address, adopting a multisectoral approach. The construction of new dams, the realization of large regional transfers and large urban and agricultural supplies, desalination plants have made it possible to significantly increase the volume of water resources mobilized and to improve the supply conditions of regions and agglomerations in deficit. It is true that since the early eighties, significant efforts have been made in the field of hydraulics. But they fall short of real needs and opportunities to mobilize existing potential. The construction of new storage facilities is not yet ahead. Rainwater is not captured in full, and Algeria‘s water policy is failing to catch up with the needs in some regions (especially grey areas) (Guergueb & Ferhat, 2021). To the state's credit, remember that in 1962, Algeria had 14 dams in operation, in 2015 there were 75 dams, and today there are 78 dams, with projections that count on 124 dams by 2030. Between 2000 and 2015, the volume of water regulated by these dams increased from 1.6 to 5 billion m^3 and will reach 5.6 billion m^3 in 2025. As for small dams and hillside reservoirs, their adjustable volume has increased from 0.2 to 0.5 billion m^3 (Chehat et al., 2018). The infrastructure potential for groundwater exploitation consists of 23,000 boreholes and 60,000 wells (2012). Indeed, underground water resources contribute significantly to meeting the needs for drinking water and agricultural and industrial water. In many urban and rural areas, they are the only source of water supply because of the scarcity or non-existence of surface water resources. However, this heritage is threatened daily in terms of its quality and quantity (several groundwater have a high salinity rate, 25 g. l^{-1}, dissolved salts). It should be noted that the exploitation of these resources is very intense with the ever-increasing needs of the population and economic activities. In Algeria, the rains decrease from East to West and from North to South. Eastern Algeria is the wettest part with an average rainfall of 530 mm per year. The Centre is in second place with 480 mm. Finally, the West is drier with an annual average of 260 mm. Across the country, average rainfall is 89 mm/year (FAO, 2015).

Table 9.2 Water requirements (CNES, 2000)

Water requirements (Million m^3/year)	2005	2020	2050
Total population	319,859	475,229	1134,196
Industry	12,401,052	14,197,964	20,587,048

Table 9.3 Annual water supply per capita in Algeria (CNES, 2000)

Years	1962	1990	1995	1998	2000	2020	2030
m^3/inhabitant/year	1500	720	680	630	500	430	–

The water that falls is not captured in full. Droughts mark the country's history and aridity is a constant threat. It is important to emphasize here, it is that the climate in Algeria is characterized by a very marked aridity and by the irregularity of the rainfall. This irregularity affects the different agro-climatic zones very unevenly: what is a bad year in one region is not necessarily bad elsewhere. It is therefore rare that the year is everywhere good or everywhere bad. According to specialists, by 2025 Algeria will experience a decrease in rainfall of around 5–13% and a rise in temperatures of 0.6–1.1 °C (Guergueb & Ferhat, 2021). Similarly, in the space of 40 years, between 1962 and 2000, the annual water supply per capita was divided by 3, from 1500 to 500 m^3/inhabitant/year, as shown in Table 9.3.

5.5 *Underground Reserves*

The first reserve, the water table located at a depth close to the surface, less than 100 meters generally and recharges with surface, rain, or wastewater. Nevertheless, this slick is of less use because of its high salinity rate. Water from the water table is even discouraged in agriculture given the salts it drains to the surface by destroying the fertility of the land (Nabi, 2016). The second reserve, the Albian aquifer, is largely in the Algerian Sahara, it is the largest freshwater reserve in the world. According to Fabienne Lemarchand, Doctor of Earth Sciences and having conducted during her career multiple studies on the potentialities of the African subsoil, this reserve extends over more than a million km^2 under Algeria, Tunisia, and Libya. It contains about 31,000 billion m^3 of water (Perrodon, 1957).

5.6 *Surface Waters*

Hydrometric data collected through observation networks are the main basis for any surface water assessment. The quality of this evaluation depends on the availability of these data, their density in time and space, and their accuracy. For this purpose, National Hydraulic Resources Agency (ANRH) has 220 hydrometric stations, 800 rainfall stations, and 60 complete stations. The first stations of the Algerian hydrometric network were installed in 1924; then this network developed gradually to reach their current level. Table 9.4 shows the distribution of rainfall and the annual supply in northern Algeria.

Table 9.4 Precipitation in the four hydrographic regions of northern Algeria (ANRH, 2014)

Regions designations	Oran Chott Chergui	Cheliff Zahrez	Algiers Soummam Hodna	Constantine Seybouse Mellègue	Total Northern Algeria
Area in (km^2)	76,000	56,200	50,000	43,000	225,200
Rainfall (billion m^3/year)	24,5	23,5	21	26	95
Average annual supply (million m^3/year)	958	1974	4300	5595	12,827

6 Vulnerability of Water Resources to Climate Change in Algeria

In Algeria, vulnerability to climate change is expressed through several aspects:

6.1 Scarcity of Water Resources

Algeria is among the 17 African countries facing water stress and is considered one of the poorest countries in terms of water availability. According to the World Bank, the theoretical scarcity threshold for water is set at 1000 m^3 per capita per year (Agoumi, 2003). However, data shows that the water availability per capita in Algeria has been decreasing over time. In 1962, the theoretical water availability per capita was 1500 m^3, but by 1990, it had decreased to 720 m^3. By 1995, it was 680 m3, and by 1998, it was 630 m^3. This trend is expected to continue, with water availability per capita projected to be only 430 m^3 by 2025.

6.2 Disruption of Water Flow

Since then, the highlands and the Saharan regions that occupy a large part of the national territory (93%) receive only 10% of the total flow in Algeria, estimated at 12.4 billion m^3 (Agoumi, 2003).

6.3 Evaporation of Surface Water

The vulnerability of surface waters can also lead to their warming in the event of an increase in temperature, hence the reduction in their ability to biodegrade certain pollutants leading to a decrease in water quality (Agoumi, 2003).

6.4 Floods

Floods are as devastating as droughts. Among the most important that the countries have suffered, we can mention:

- On 10 November 2001, floods of unprecedented magnitude hit the Algiers region, in particular the commune of Bab El Oued. The recorded rainfall was 290 mm in less than 17 hours. The damage was catastrophic (40% of the interannual average) (Meddi et al., 2003).
- In October 2002, heavy rains (28.5 mm in 45 min) fell on the Tamanrasset region and in particular the Arak region (Meddi et al., 2003).
- In October 2008, heavy rains caused severe flooding in Ghardaïa (Dechemi et al., 2000). The death toll was 43 dead, 86 wounded and 4 missing.

These examples, relatively recent, in very different areas, illustrate the highly irregular regime of rainfall and runoff and encourage anticipation of the devastating effects of floods by preventive management of watershed management, and control of runoff water management (Meddi et al., 2003).

6.5 Drought

The heat wave of the summer of 2003 will remain in the climatic annals of Algeria as being an exceptional weather event by its duration (nearly 4 weeks). Never the previous heat waves had not been so long, and intense (more than 40 °C during 20 consecutive days), as well as by its geographical extent. Both maximum and minimum temperatures were marked by significant positive anomalies (Rognon, 1996).

7 Climate Change Impacts on Surface Runoff

The intense and persistent drought, observed in Algeria during the last 30 years and characterized by a rainfall deficit estimated at 30% (50% during the year 2001–2002) (Elouissi, 2004). The latter has had a negative impact on the flow regimes of the rivers, with serious consequences on all socio-economic activities in the country (Puget, 2010).

7.1 Changes Affecting Dam Waters

The changes affecting surface water retention are due to siltation and decreased runoff, the nature and morphology of sloping land, the fragility of the vegetation cover, the lack of afforestation, and urbanization upstream of dams cause severe erosion that reduces the storage capacity of dams by 2–3% each year, due to siltation due to the transport and deposition of sediment by rainwater. Currently, 14 dams out of the existing 60 are silted (Nabi, 2016).

Decreased in runoff: The contribution of runoff to surface water has consistently decreased. Too low flows do not allow the existing dams to be sufficiently filled (MATE, 2008).

Algeria has developed the adaptation strategy in the water resources sector to ensure the feeding of the population and avoid hindering the country's development, particularly in the agricultural and industrial sectors. This strategy is based on the protection of resources, the rationalization of consumption, and the use of non-conventional water resources such as seawater desalination and the reuse of urban and industrial wastewater, particularly for agriculture and the introduction of water-saving irrigation techniques (Hallouz et al., 2020). In addition to its domestic use, it should also be remembered that water is used massively by irrigated agriculture, which produces more than half of the world's food, and by industry, especially for energy production (and not only to cool thermal power plants) (Meddi & Humbert, 2002). The future of Algeria is closely linked to the management and availability of water resources. Climate change poses a significant threat to these resources, with predictions that the country could experience a water deficit as early as 2025. The vulnerability of water resources to climate variability highlights the need for effective management and conservation efforts (Meddi et al., 2009).

8 Sustainable Development and Sustainability of Water Resources

Sustainable development, as outlined by the Brundtland Commission in their report presented at the 1992 Earth Summit, prioritizes meeting current needs while ensuring future generations have the ability to meet their own needs. This definition has become an internationally recognized reference, widely accepted by all stakeholders (Guergueb & Ferhat, 2021). The goal of universal and equitable access to safe drinking water, hygiene, and sanitation by 2030, particularly for vulnerable populations, is emphasized in the sixth goal of sustainable development. This goal also includes the need for sustainable management of water resources and reducing the number of people experiencing water scarcity. This objective incorporates the notion of cross-border management of this resource, which is essential for sustainable management but also conducive to peace and cooperation (ODD6, 2018). It is clear and undeniable that there can be no sustainable development without control of water resources, especially for arid and semi-arid countries. This objective remains difficult to achieve, particularly for developing countries such as Algeria (Mediterranean country on the southern shore). In Algeria, the water sector is the subject of special attention by the public authorities, which devote increasingly important resources to it. For sustainable development, it is essential that there be strategic approaches to the sustainable management of water resources, and this can only be done through an integrated, intersectoral, multi-sectoral, and multidisciplinary approach. Agriculture, industrial activities, tourism, energy production, and sustainable development are intimately linked to the presence of water. The proposed approach for the country's 17 watersheds aims to develop an integrated model that takes into account socio-economic factors, water quality, pollution pressures, impacts on human health and on ecology and institutional approaches. Aware of the challenges of the Millennium, Algeria acceded in 2000 to the #Objectifs Millennium Declaration; the essential objective that the Algerian State seeks to achieve in the field of Water is to improve access to Water and Sanitation services for the populations according to conventionally accepted standards. According to figures put forward by the MRE (www.mre.dz), the volume of annual needs forecast for 2030 consists of 4 billion m^3 for household consumption (against 3.3 billion m^3 in 2018), 8.3 billion m^3 for agriculture (against 6.8 billion m^3 in 2018), and 0.6 billion m^3 for industry (against 0.3 billion m^3 in 2018). The effort already made in terms of mobilization and management of the water resource allocated to agriculture – mainly through small and medium-sized hydraulics – has made it possible to increase from 350,000 hectares irrigated in 2000 to 1,330,000 hectares at the end of 2018, or 16% of the useful agricultural area (UAA) of the order of 8.5 million ha. This quantitative evolution has been accompanied by a qualitative evolution due to the development of water-saving irrigation systems. The irrigated area equipped with water-saving systems (sprinkler and drip) has indeed increased from 75,000 hectares in 2000 to 977,000 hectares in 2018, which practically corresponds to a generalization of the use of water-saving irrigation systems (3/4 of the irrigated area). However, the effectiveness of these efforts remains limited because water service is still imperfect in most cities, irrigation in large areas is not progressing sufficiently and pollution threatens groundwater in several regions. In addition, large volumes are lost in urban water distribution networks and irrigation networks are dilapidated or poorly maintained. For many observers, the water crisis in Algeria does not come from the shortage but from its management with losses sometimes reaching 50% on the volumes distributed (Hallouz et al., 2021).

9 Developing Socio-hydrological Resilience Planning

The urbanization rate is expected to be above 87% in 2030 for a population of around 50 million people. According to the figures put forward by the Ministry of Water Resources, the volume of annual needs forecast for 2030 consists of 4 billion m^3 for household consumption (against 3.3 billion m^3 currently), 8.3 billion m^3 for agriculture (against 6.8 billion m^3 currently), and 0.6 billion m^3 for industry (against 0.3 billion m^3 currently) (Fig. 9.4). Thus, the strengthening of infrastructure planned under the National Water Plan will be accompanied by the intensification of efforts to reduce water leakage to 18% in 2030 from 35% currently. This has allowed the supply of drinking water to 98% of the Algerian population, 80% of whom benefit from a regular supply, with a daily intake of 180 l/day per citizen (APS, 2019).

Fig. 9.4 Different types of water resources in Algeria. (APS, 2019)

10 Increasing Practices to Achieve Socio-hydrological Resilience

This strategy has been based on development programs, including the construction of numerous dams in the main river basins, whose interconnection, through water transfer systems, has made it possible to weave a real web at the level of all regions of the country to serve landlocked areas through:

- The development of unconventional water production capacities using seawater desalination techniques (e.g., Algiers pilot station).
- The carrying out of inter-regional water transfers to cope with local or regional droughts.
- The recovery of treated waste water for the needs of agriculture and industry.
- The mobilization of surface and groundwater resources..
- The construction of water supply and distribution networks.
- The extension of irrigated areas to support the country's food security.
- The fight against the loss of resources through, in particular, rational management of these resources.
- The reform of the legal and institutional organizational framework to ensure good water governance and improved management indicators.

11 The Adaptation Strategy in the Water Resources Sector

The main steps in the adaptive management process are:

- Monitoring programs, to understand the changes that are occurring.
- Risk assessment and hazard mapping, to understand the consequences of climate change and the risks they pose to species, ecosystems, infrastructure, and people.
- Planning and decision-making, to manage land, natural resources, and infrastructure in the face of great uncertainties and potential changes.
  - Resilience and adaptation, to increase our ability to withstand climate impacts, adapt to unavoidable effects, and take advantage of new perspectives.

Priority areas to be discussed and included in the Climate Change Strategic Framework could include:

- Ecosystems – the evolution of the natural environment and how natural resources are Managed.
- Infrastructure – the maintenance and construction of buildings, infrastructure and networks capable of withstanding future climate change impacts.
- Health and well-being – identifying and addressing current and emerging health risks, including food security, air quality, vector-borne diseases, and mental health.

12 Improved Socio-hydrological Resilience Planning Taking into Account the Education of Future Generations of Specialists

Algeria, as an arid and semi-arid country, is particularly vulnerable to the effects of climate change. This is why great importance must be given to adaptation measures, mainly in the strategic sectors: water resources and agriculture (Projet National ALG/98/g31, 2001).

12.1 Mitigation Measures that Will Be Undertaken in Wach Sector of Activity to Ensure Economic Growth, Protection, and Safeguarding of the Environment and Resources

12.1.1 Water Sector

Studies will have to be carried out for the preparation of "demands–resources" balances at the regional level, taking into account factors such as siltation of dams, pollution, salinity of water, cost of works, and cost price of water. These studies, by region, will make it possible to project. Due to the high potential of conventional water resources, for many years to come, water policy will remain based on the development of conventional mobilization structures (dams, hill reservoirs, boreholes, etc.). The water action program must integrate soil conservation, protection, forest conservation and extension, and watershed management. Two types of action will have to be carried out simultaneously: optimal management and the saving of water resources. The measures will focus on:

- Control of the holding at the level of the dams: the volumes of water supplied must correspond to real needs downstream, particularly for agricultural needs.
- The intensification and prospection of the country's water resources, particularly underground resources.
- Monitoring the evolution of water quality.
- Improving the conditions for collecting and storing rainwater in catchment areas through intensive revegetation techniques and soil defense and restoration.
- The modernization of distribution networks in large urban centers of the coast to measure consumption and reduce losses due to water leaks estimated at more than 40%.
- The use of industrial manufacturing processes with low water consumption – the recycling of industrial wastewater.
- The installation of economic devices that reduce throughput at the level of major consumption centers (hotels, administrations, schools, public bodies, local authorities, etc.).
- Raising users' awareness of the vital role of water by relying on the media, schools, Non-Governmental Organizations (NGOs), and itinerant information campaigns.

12.1.2 Agriculture Sector

In the field of agriculture, in particular, the use of improved seeds or agroforestry techniques are "climate-smart" practices that strengthen the resilience of small producers to extreme weather events. Rural populations can reduce their vulnerability to shocks by diversifying their food production and implementing social protection measures, thereby increasing their socio-economic resilience (Projet National ALG/98/g31, 2001).

The use of technology can also help farmers to better contribute to climate change mitigation and adaptation. Indeed, it is possible to develop integrated weather and market warning systems that will allow farmers to make more informed decisions on many aspects: what and when to plant? when to harvest? how to manage your workforce? where to sell your production? This results in higher returns and incomes in a context of climate instability. The agricultural action plan is based on a conversion program covering arid and semi-arid areas and those subject to aridity, currently reserved for cereals or left fallow and threatened with irreversible degradation. The conversion will be for the benefit of arboriculture, viticulture, livestock, and other adapted activities. The aim is to concentrate cereal production in areas recognized as favorable. The plan also aims to improve the farmer's income and achieve sustainable development through the optimal use of natural resources. This plan is based on the support of the populations to the recommended adaptation actions of the cropping systems. It inaugurates a specific approach to drought and the reduction of fallow land in the northern areas of the country. The action program mainly concerns the distribution of crops by area:

- Fodder crops: at coastal level for intensive species and at sub-coastal areas and highlands for crops with less water demands.
- Pulses: in the potential areas of the regions of Tiaret, Ain Témouchent, Relizane, Mila, Skikda, etc.
- Oilseeds: at the level of the highlands for safflower (Tiaret, Sétif ...) and at the level of coastal and sublittoral areas (Guelma, Ain-Defla, Chlef) for sunflower.
- Sugar beet at its former cultivation area (Haut Cheliff, and Guelma).
- Viticulture in its area of cultivation, particularly in the west of the country.
- Olive and hardy fruit arboriculture (almond, pistachio) in arid areas and foothills and mountain areas.
- Citrus fruits: rejuvenation of orchards, their constitution, and realization of new plantations in the Central and Eastern areas where water resources allow it.

13 Conclusions

Climate change poses a significant threat to water resources in Algeria. The recurring droughts in the country have had a significant impact on available water and pasture. The dry climate causes water stress that greatly affects the livelihoods of the population, livestock, and natural resources. Rural communities, particularly, are highly vulnerable to the negative effects of drought and floods and are forced to rely on minimal means of survival. Resilience cannot be an absolute horizon of expectation and it does not necessarily have to be sought in the fabrics, in the landscapes, in the material structures of the city: it implies a part of forgetfulness, which allows reconstruction, even identically, and a part of adaptation, which imposes a change in the structures and in urban functioning. Resilience, when viewed as a political discourse, aims to make choices that should be publicly discussed and debated. However, its use can often divert attention away from underlying political and social processes and focus on technological solutions. In this perspective, resilience provides several opportunities such as a heuristic approach which has been proven to be effective. For example, it forces us to think about the different temporalities before and after the crisis, to combine cyclical and linear time. It pushes to take into account the memory of the disaster by developing diachronic comparisons or to combine, interlock, and confront temporal and spatial scales. The strategic use of the concept of resilience allows for a comparison of the different responses and discourses of societies facing disasters, and can provide insight into how thinking about resilience shapes their management approach. From an operational perspective, resilience offers new opportunities to break through situations that have become stuck due to the buildup of negative feedback. It provides hope that alternative solutions can be found and pursued, and as a result, creates high expectations for researchers from managers. From a political perspective, resilience is primarily a discourse that allows for a shift in practices and perceptions by revitalizing outdated or overlooked ideas and analyses. This decentralization can lead to new solutions and approaches to overcoming obstacles. In particular, it makes audible the need to finally go beyond the logic of "zero risk". Resilience could therefore have led to a debate on the risk acceptable to each society. But as the concept remains vague and elastic, it has been invested by a profusion of actors with conflicting interests, so that for the moment, the discourse of resilience leads more often to impose its views than to actually open the debate. Governance levels, stakeholder engagement, and contributions can play an important role in ensuring social acceptance; however, the responsibility for building resilience rests primarily with governments and water managers.

Finally, as there is some work on adaptation and polycentric governance, and little work on applying water-sensitive values in water resources planning, there is still no evidence that the water sector is contributing to climate-sensitive and equitable water governance. Overall, the results of this chapter suggest that multiple disciplines such as eco-social management, engineering systems, and institutional management should play a role in planning resilience strategies in disaster phenomena.

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Chapter 10
Socio-Hydrological Role of North Africa's Traditional Water Management Systems Under Extreme Climatic Events

Ines Gasmi

Abstract Traditional methods of managing water are decreasing with time, mostly due to government incompetence, followed by groundwater availability and inadequate maintenance. The social, cultural, and economic effects of this change in water management technique are poorly understood. However, there aren't many financial incentives for using these tactics, especially for young business owners. Although the field of disaster management has been slow to include indigenous knowledge, there has been a noticeable increase in research on the topic since the middle of the 2000s. In addition, it is increasingly common to incorporate indigenous knowledge into scientific study, public policy, and planning. This knowledge includes methods for disaster risk reduction and adaptation. However, incorporating local and indigenous knowledge and traditions to boost communities' resilience against the impacts of climate change and disasters has only recently caught the serious attention of scientists and practitioners. In this context, this chapter will highlight, based on a critical evaluation of Traditional Water Management Systems (TWMS) in North Africa and their socio-hydrological role under extreme climate events. The study outlines the history of Traditional Water Management Systems, and how to promote and revive these systems. Meanwhile, the comprehensive analysis targeting the North African decision-makers and water managers might serve as a baseline indicator for further investigations to integrate Indigenous knowledge for TWMS in the future management strategies and new policies to ensure a water-resilient system.

Keywords North Africa · Traditional water management systems · Indigenous knowledge · Socio-hydrology · Extreme climatic events

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1 Introduction

The first great civilizations in the Nile, Tigris and Euphrates, Indus, and Hoang-ho River Basins could only emerge and prosper based on sophisticated and advanced water-management systems. The topographical, climatological, and hydrological circumstances in these areas only allowed for permanent settlements and the production of enough food based on irrigation, drainage, and flood control. The "hydrology chaos" of the valleys was changed into thriving gardens, fields, and meadows through intricately coordinated systems of dikes, canals, reservoirs, and lining systems. The term "hydraulic civilizations" has been applied to these empires due to the tight relationship and dependency between the management of water resources and political-social situations. Many of the strong and long-lasting civilizations of antiquity emerged in regions with scarce water resources. The engineers of ancient times had to find enough water that was of good quality, transport it to the cities, store the water, if necessary, by building dams, distribute the water, and then dispose of the sewage. As a result, sophisticated hydro-technical installations for the provision of water were designed and built even in those earlier historical periods, their audacity in design and the superior quality of their execution undoubtedly matching the smart architectural achievements of their times. The primary source of revenue for these civilizations was agriculture, which they produced via irrigation systems. People created methods for gathering and storing rainwater for residential purposes, the irrigation of crops, and the watering of cattle in dry locations when droughts were more likely, and water was limited. Such water collection ensured people's well-being in addition to assisting them in surviving drought (Oweis et al., 2001).

In the Roman era, North Africa was a major producer of grain and olive oil. Other than along the coast, North Africa lacked abundant water resources. Diverse water exploitation systems were created, particularly in arid or semi-arid regions, to overcome excessive drought. Solutions for water management were equally intricate and sophisticated, fusing different technology and customs (Leone, 2012). Since the 1970s, there has been growing evidence in the field of disaster risk reduction that local knowledge and practices can enhance preparedness. Even though it has been said that indigenous knowledge has been reluctant to infiltrate the area of disaster management, a notable growth in studies on the subject can be seen specifically around the mid-2000s. According to Hiwasaki et al. (2014), incorporating indigenous knowledge into scientific research, public policy, and planning is becoming more common. This knowledge includes solutions for disaster risk reduction and adaptation. However, integrating local and indigenous knowledge and practices to strengthen communities' resilience against the effects of climate change and disasters has only recently attracted the serious attention of scientists and practitioners (Reij, 1991).

Vulnerability is frequently a result or symptom of state-approved oppression and marginalization for Indigenous groups. Indigenous Knowledge (IK) was categorized by three socio-ecological systems and their risks by Hsu (2016) and Shaw et al. (2009), including mountains (geological and hydro-meteorological hazards), coastal (tsunamis, storm surges, erosion), and water management (drought risk). The authors also pointed out the disconnect between what Indigenous groups know about a risk and what state officials did in response to ensuing disasters. Contributors underlined the significance of "bottom-up" organizing and the necessity of community-led methods. Water managers, however, strive to develop more effective tools to preserve resources while ensuring social equity in water access. Hence, to assist decision-makers in making the right choices, it is vital to address the different issues related to this scarce resource. In keeping with this, the current chapter explores the development and persistence of several traditional water management practices in the North African region as well as their possible use in a changing socio-economic and political situation. Our focus in this chapter is on how these Traditional Water Management Systems (TWMS) were used historically to recover the groundwater table and manage marginal water. As a result, a new socio-economic and well-educated policymakers' framework, according to our argument, is required to repair these systems by enhancing their viability.

2 Definition of Indigenous Knowledge (IK)

The UNESCO refers to local and indigenous knowledge (LIK) as the comprehensions, skills, and philosophies developed by societies with a long history of interacting with their natural environment. Thus, local expertise helps rural and indigenous people make decisions regarding crucial elements of daily living. This information is crucial to a complex cultural system that also includes language, classification schemes, resource-use customs, social interactions, rituals, and spirituality.

Indigenous knowledge (IK), as described by Mistry (2009), is the knowledge that is collective, holistic, and adaptive within a given spatial and/or cultural context. Indigenous knowledge is currently experiencing a renaissance, and it is viewed as crucial to include it in development efforts, even though it was previously completely overlooked in the domains of development and conservation. The recording of indigenous knowledge and its dissemination to different locations and settings, however, is fraught with difficulties. There are disagreements over the extent to which and for whom indigenous knowledge is beneficial outside of the context in which it was created. Although it is commonly acknowledged that there are numerous lessons to be learned from indigenous knowledge systems, these systems get minimal protection under international law, making them vulnerable to exploitation.

3 History of Water Management in North Africa (NA)

Shaw (1984) stressed that there is circumstantial evidence that rural hydraulic systems existed before the Roman era. This perspective is supported by the dispersion of water control plans, which indicates that village settlements depending on irrigation systems existed far outside the areas under the direct administration of the

Roman state. Even in the Roman era, it is very difficult to find hard facts. Inadequate data exist from both the literary and archaeological perspectives to draw firm conclusions. Analysis of the runoff control walls located in the Tazbent region west of Tébessa's quadrille network. The wall patterns that Baradez and others identified as "Roman" on aerial pictures are the same as the net-like wall patterns. However, the region is remarkably absent of any ruins that may be classified as Roman. The Mistiri dolmen tombs' calcareous stone-like slabs were used in the dry-stone walls' construction. All that can be said with any degree of confidence is that many of the latter types of constructions are linked to neolithic settlements that persisted uninterrupted until the Roman era. Camps asserted that the creators of the Mistiri dolmens and the small-scale farmers who set up the quadrille systems near Tazbent were responsible for these systems (ibid).

Pre-Roman Africans who lived in the Tripolitanian hinterland undoubtedly already had the fundamental farming methods needed to cultivate wadi valleys as a response to their arid climate, much like the Negev farmers had. According to Strabo,[1] the Carthaginians constructed a "kind of cross-wall" to "bridge" certain wadi valleys flowing into the interior. There is no question that the Italians helped to build this hinterland, as did the Romans and the Phoenicians who came before them.

The importance of Roman influence in the agrarian development of North Africa is widely acknowledged. Where the two overlapped, it was discovered that there was a conflict between the patterns of nucleated communities and the individual units of agricultural exploitation. The rural hydrological systems and cadastral patterns were visible in aerial photographs and satellite images. However, Shaw (1984) showed that certain building methods, such as the use of dressed stone or ashlar fronting, as well as the size of the construction, are seen to be signs of Roman craftsmanship. The intimate connection between ancient hydraulic systems and settlement patterns is considered a component of a deliberate development strategy or overarching plan and is hence Roman. Shaw (1984) claimed also that the waterworks are at least "Roman" in that they are uniform and show evidence of a larger scheme and control. Uniformity is said to be a sign of an overarching administrative power that issued directives or the outcome of the entrance of Roman colonists who brought the necessary organizational and technical abilities to a particular territory. The waterworks are at least 'Roman' in the sense that their stunning uniformity in the plan, style, and distribution is thought to imply an overall plan and control, which is still held by those who disagree with Baradez's theory[2] of an economic miracle created by the Romans. These criteria for designating this or that water system as Roman are rather arbitrary because, aside from consistency of plan or technique, they leave the specific components that defined a particular scheme as "Roman" ambiguous and imprecise (Shaw, 1984; Leone, 2012). It is also likely that

[1] Strabo. Geography, Volume I: Books 1–2. Translated by Horace Leonard Jones. Loeb Classical Library 49. Cambridge, MA: Harvard University Press, 1917.

[2] Jean Barader, Vue-Aerienne de l'organisation romaine dans le sud Algerien, Fossatum Africae (Paris, 1949): cf. now E. W. B. Fentress. 'Numidia and the Roman Army', ap. B.A.R. Supp. Series, 53 (1979), with up-to-date bibliography.

these hydraulic systems were a part of an earlier tradition that persisted in the area even after the Romans left.

According to Shaw (1984), before and after any act of political incorporation in the region, the absolute conditions of the former had to spur economic growth. Pre-Roman water control technology existed and was destined to go through its cycle of evolution. Many historic Tunisian water projects that were long credited to the Romans were the labor of peasants during the Hafsid era of control in Tunis (i.e., of the thirteenth to the fifteenth centuries A.D.). It is now known that the enormous terrace schemes that still survive in northeastern Tunisia are of more recent construction. The gigantic engineering accomplishments that stand out the most—the enormous aqueducts that feed water to key cities and towns like Carthage and Iol-Caesarea—are directly connected to urbanization.

Ibn Khaldun[3] linked the enormous reception hall at Khosraw (Iwan Kisra) and the Egyptian pyramids to the aqueducts of Carthage and Iol-Caesarea. But that is exactly the purpose; the main goal of these kinds of waterworks was to serve huge urban areas with a steady supply of water. The most expensive of these may have suited the city's philosophy and status more than its practical need. These mechanisms were mostly consumptive and were only indirectly to blame for the rural areas' ability to produce. The establishment of increasingly densely populated communities, which in turn supported more intense exploitation of the surrounding land, was likely greatly aided by the concentration of alimentary waters at collective center points. The issue was the efficient distribution of limited water supplies across large tracts of the countryside. The main barrier to the use of hydraulic systems (such as wells, aqueducts, and cisterns) for agricultural purposes was their extremely restricted ability to adapt to the changing demands of agrarian exploitation. Ibn Khaldun further emphasized that while other hydraulic techniques were needed for agricultural output, aqueducts and reservoirs were necessary for the urban population to reside in any rural area. For instance, an aqueduct and reservoir system that tapped Ain ad-Delfa hydrated the town center (the fort of Guérira) on the Numidian frontier, about 50 kilometers southeast of Thubunae (Tobna-Algeria). The agricultural productivity of this same area depended heavily on the control of runoff streams maintained by stone-walled fields and terrace dams in the wadi valleys. Short garden plots connected to residential units might use wells and cisterns to supply water within a relatively small area around their location. The early agronomists understood the wells' marginal utility, clearly, not meant for agricultural output, these water systems were instead used to support people (domestic use) and animals watering on farmsteads.[4]

Indigenous people used specialized "dry-farming" techniques to treat soil and plants to make the most of existing levels of precipitation and ground humidity to

[3] Ibn Khaldun, The Muqaddimah: An Introduction to History, transi. F. Rosenthal, Princeton, 1958 I. 357 (318); II. 239 (205–06) and 243 (209).

[4] A. Audollent, a romane from Carthage. Extract from a note on the restoration of the old aqueduct in Carthage is found in Paris, 1901, pages 183–185, C., and Caillât (P.). R.A., t. 26, 1873, p. 292–301.

grow crops under extremely arid circumstances.[5] Since these activities mostly included unique methodologies rather than unique ways of creating systems, it is practically impossible to prove their presence at any given time in history (given the absence of any written records). The likelihood of the employment of such tactics would be high given the scope of farming operations in pre-Roman periods (e.g., based only on the testimony of Herodotus).

Flood zone agriculture is the most productive and widely used sort of "technology" used to farm desert terrain, aside from dry farming methods. The method involves building artificial barriers out of materials that are easily accessible to direct flood or runoff waters onto surrounding fields. It can be assumed that this method was widely used in the first century AD based on Agennius Urbicus'.[6] On the same subject, the Roman agrimensor (land surveyor)—Julius Frontinus—observed that the technology required for the operation of even large-scale flood-zone systems was straightforward. Besides, to redirect runoff streams and keep them inside the small plots composing the field, earthen embankments were established, to concentrate water where it was needed and making use of any natural slope. The Po′s[7] recurring flooding prompted a similar use of aggeres to divert floodwaters away from farmers' fields and towards the riverbed instead. The dams or dikes constructed in the African example to divert the flood waters must go by a few fundamental guidelines. The dams had to be submersible, or the runoff water's sheer force would have destroyed them. The dams had to be submersible, otherwise, the runoff water's sheer force would tend to turn the dam's edge or break through it.[8] Flood waters flowing through the substantial drainage basins of Wadis Zerud and

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[5] These procedures were undoubtedly known to Carthaginian agronomist Mago (see Pliny, NH, 17.19 (93), 17.20 (128) and 17.30). (130–31). It's conceivable that most of his work was included in the three-volume Kitâb al-Falâhah, Livre de l'agriculture by Andalousian agronomic Ibn al-Awwâm (published in Paris between 1864 and 1867). Ibn Khaldun undoubtedly asserts in Muqaddimah, 3.151–52 (120), that he condensed the 'Greek' work Kitâb al–Falâhah an-Nabatîyah, which is properly attributed to 'Nabataean' academics. See Despois (J.), La Tunisie orientale: Sahel et Basse Steppe, étude géographique, 2.ed. Paris, 1955, p. 255–70 (olives), 286–91 (cereals) for information on the practices themselves, and Mayerson, op. cit., p. 212 for information on the ancient Negev.

[6] Agrimensores: An Introduction by Dilke, (O.A.W.), The Roman Land Surveyors. Iulius Frontinus is discussed in Newton-Abbott, 1971, p. 41.

[7] The Po River is the longest river in Italy (661 km); it originates from Pian del Re of Monte Viso and flows eastward till the Adriatic Sea near Venice. The Po Basin has a drainage area of 71,327 km^2, 70,000 km^2 of which are in Italy, the rest in Switzerland; 29,000 km^2 are on the Po plain. The basin population is close to 17 million inhabitants, almost 1/3 of the population of Italy. The main land use of the Po plain is intensive agriculture. Half of the river length is controlled by dikes to minimize flooding risk. Table 1 presents the main characteristics of the basin.

[8] Les irrigations dans le centre de la Tunisie. C.T., t. 5, 1957, p. 63–74, and compare the same 'technology' in Morocco, Célerier (J.), Les Merjas de la plaine du Sebou. Hesperis, t. 2, 1922, p. 109–38, 209–39.

Merguellil are tapped by the dikes.[9] Ad hoc syndicates were formed to construct dikes and canal networks in the plains of ancient Byzacium, which were established in Roman times to construct sections of dikes along the Po Valley in Italy. Each autumn, the rushing water from each of these wadi valleys that drain over the Qairwân Plain is meticulously controlled through primary dams, subsidiary dams, and small dikes (mgoud) before being directed onto the various fields.

In order to regulate its flooding for their own use, the North Africans were able to construct a network of canals and dams in the plains surrounding Baga in southeast Numidia (ibid). The main wadi, the Abigas river, which flows from the Aurès, was exploited through the installation of a complex network of canals and dams that allowed the indigenous to manage its floodwaters for their own use. Diversion channels drained the wadi's floodwaters by downstream diversion dams. Waters from wadis were directed into some of these waterways, called also aqueducts. According to Ertop et al. (2023), the type of system that uses or regulates the runoff waters produced by precipitation directly on the slopes of hillsides is a variation of flood-zone technology. Many of these plans were spotted along Numidia's Saharan border, such as the regular network intersecting J. Metlili's southern slopes that face the Daia plain and the Guérira Roman fort. The method was simply to construct a series of parallel dry-stone walls perpendicular to the slope's gradient. The grid patterns of walls built on hill slopes, like the flood-zone systems in the plains, are less anti-erosional methods than they are ways for farmers to make use of erosion's impacts.

Desert farmers, whether Roman or not, were driven to struggle against the ills of erosion by ecological concerns is not only false but also extremely deceptive in its implications. Because the soil on highland slopes is completely useless to arid-zone farmers, erosional forces that strip the soil away and convey it downslope and benefit the farmers. However, cultivation is mostly limited in the wadi bed itself where the seasonal water flow is limited to drainage ravines or wadis. The installation transverse walls stop the seasonal flooding (hardly qualifying as true dams). Arable soil "terraces" are created with the help of the silt deposits trapped between each of the dams. These dams are designed to force alluvium deposits behind the dam face by forcing the heavy silt-laden wadi flood flows to do so. They are not intended to serve as water storage reservoirs. The terrace dam accomplishes two tasks at once by forming the cultivable soil plot, which also functions as a water storage basin. Compared to an open water surface, the soil dries out at a considerably slower rate. The hardy arboreal plants that grow on these wadi terraces in arid regions are often adapted to the severe conditions of their surroundings. The Jabaliyya people of western J. Nafûssa (Tripolitania), who still engage in this sort of desert agriculture, cultivate their terraces (or "jesser") largely with fig and olive trees, with cereals interspersed throughout the winter.

[9] The analyses are those of Penet and Les irrigations dans la plaine de Gamouda, Tunis, 1910 (also carried out under the auspices of the Protectorat français, Direction de l'Agriculture, du Commerce, et de la Colonisation); these collaborative efforts result in a fairly complex division of labor (see Penet, op. cit., 1909, 10 f. and plates I & II). Costa, art. cit., p. 77, provides information on analogous ancient Italian systems (cf. Lucan, Phars. 6.272–73).

4 Developing Traditional Knowledge to Address Contemporary Challenges: Promoting Traditional Water Management in Drylands

In arid regions, water is poorly dispersed and frequently arrives in powerful bursts, leading to surface runoff and unrestrained rill and gully water flow. Uncontrolled runoff deprives the soil of its fair share of rain, which causes growing plants to experience periods of extreme moisture stress. The natural resource that primarily restricts growth in dry environments is water. In these regions, agricultural production is typically impossible due to limited and uneven rainfall, and water harvesting is becoming very helpful in this case. Water harvesting systems can provide adequate water supply to replace rainfall in rainfed locations, where crops can be grown but with low yields and high chance of failure. Hillsides may be treated before being used for water harvesting to prevent runoff and soil erosion. In these regions, most of the rainwater is collected and put to good use, increasing thus plant growth, with enhancing the livelihoods of local communities.

For those who live in drylands, managing the land is problematic. Dryland inhabitants have surmounted this difficulty throughout history by using conventional techniques for managing and harvesting water. To properly meet the research demands of dryland drought and land management, UNU developed an initiative in 2001. The backdrop for the studies discussed in this chapter. It explains how it has aided in the advancement of a more complete understanding of conventional water management technology (Schuster & Bigas, 2008). Meanwhile, human communities in arid regions have developed strategies for managing water scarcity that frequently closely mirror social and cultural development. Traditional knowledge has two distinguishing characteristics: (i) it produces socially acceptable activities and (ii) is connected to the sustainable exploitation and management of natural resources. The last aspect is especially important for drylands, where maintaining access to water resources might be the difference between life and death. By using sustainable management of water resources, traditional techniques of water harvesting, and management address this difficulty.

Thus, indigenous/traditional water harvesting systems have great promise. When an appropriate method is devised, the productivity of rainwater in dry environments can be significantly boosted. The development of sustainable and ecologically friendly agricultural systems has several acute obstacles, one of which is the effective integration of existing indigenous knowledge with contemporary technology. When a suitable water-harvesting technique is used, the productivity of rainwater in the drier regions can be significantly boosted (Oweis et al., 2001). The Oases system illustrates how to effectively use the surrounding physical and geomorphological features (Safriel & Adeel, 2005). However, oases often include (i) a system for distributing and managing water, guaranteeing, thus, the steady growth of plants which help to withstand aridity and salt deterioration effects, and (ii) methods for stabilizing sand dunes, which make the oases a good illustration of an efficient management system.

In Tunisia, a million hectares are effectively covered by water harvesting systems, which effectively sustain rainfed agriculture. In the southeast, jessours are used to collect runoff from the Matmata mountain series, while spate irrigation or mgoud techniques are frequently used in areas surrounding the major wadis in central Tunisia. In addition, hill lakes and both large and small cisterns—fesquia and majel—help to store and use rainwater. Water-harvesting techniques serve a variety of purposes, including water supplementation, flood prevention, water table replenishment, and water and wind erosion control. To deal with such a problem on a national level, a long-term strategy is needed. Observation implies that the answer consists in persuading the relevant communities that environmental conservation boosts agricultural output in the region. Meanwhile, in Morocco, the matfia (cistern), which the Portuguese brought to Morocco in the sixteenth century, and the khettara (qanat), which was created during the Almohad era, are two well-known water-harvesting systems used in the country's arid and semi-arid regions (AD 1147–1269). The Moroccan government has promoted extensive irrigation since the 1960s. In addition to the issue of scarce water, only 1.6 million ha of Morocco's 9.2 million ha of arable land exhibit irrigation potential. On the other hand, in Libya, all indigenous water collecting systems have changed over the years because of locals' experiences living in various regions. Depending on the description and language used by various authors and local users in the North African region, there are various methods to categorize these traditional water management systems. Water-harvesting systems can be categorized in several ways depending on the concept and lingo used by various authors and local users in a specific nation or region.

4.1 Khettara (Foggara, Qanat, Karez)

A historic water management system known as "Khettara", also known as Karez in Asia, Foggara or Khettara in Northern Africa, and Falaj in the Arab world. Several nations in Northern Africa and Western Asia, as well as other Asian nations including Afghanistan, Iran, Pakistan, and China, have used variations of the same underground "engineered" water management system for ages. The management method draws water from aquifers using a gradient that has been created by humans.

According to Fitzwilliam-Hall (2009), four theories have been put forth regarding where the technology originated. The first is that it originated in al-Andalus (Muslim Spain) during the Almoravid dominance in the twelfth century and was brought there by Syrian or possibly Yemeni settlers. The second is that between the first and seventh centuries CE, Moroccan khettaras may have been transported from al-Andalus to the High Atlas Saharan oasis of Touat, Gourara, and Tidikelt in what is now Algeria. Al-Idrisi, a geographer from the twelfth century, claims that between 1107 and 1143 C.E., an individual named 'Abd Allah ibn Yunus al-Muhandis ("the Engineer") brought the technique to that region for the first time. Garbrecht (1983) asserted that the Khettara/Foggara was first used in Urartu and Persia, and their use eventually expanded from those regions to India in the east, Arabia, Egypt, and North Africa in the south, and Spain in the west.

Under the water table, this system in the form of a tunnel serves as a porous infiltration gallery. The upper section of the gallery, or transportation gallery, which may be lined with masonry to avoid collapse or sealed to prevent leaking, allows water to seep in and flow down. Water is sent in open channels to the oasis' gardens from the outlet of the Khettara, where it emerges at the surface positioned at a lower level. Vertical shafts or "wells" from the surface that provide air, access for employees, and a place to haul up the debris are scattered throughout the gallery (Fitzwilliam-Hall, 2009).

The Khettara is more than just an access shaft-equipped underground water-harvesting gallery. It is a sophisticated, all-encompassing hydraulic system that frequently includes water dividers, storage containers, and distribution pipes. They are all essential components of the Khettara system. The Khettara is normally a collective system; it is uncommon for an individual or family to own one and is more frequently the property of a group of users, which may include an entire town or ksar. It is not an overstatement to say that the Khettara is the main organizing principle of the oasis where it is used, guiding not only its morphology and layout but also all facets of its economic, social, cultural, and political life. Like all traditional knowledge and practice, it is ingrained in and the result of a specific culture. In some of the driest and hottest places on earth, the Khettara system produces a productive oasis. Since it cannot exhaust non-renewable underground aquifers and fossil water, it is viable indefinitely. However, external circumstances compromise its capacity to satisfy the needs of the current oasis communities. As we've seen, it is also environmentally favorable because it emits no carbon dioxide, minimizes water loss due to evaporation, and has a linear structure that encourages successional downstream re-use.

The growing over-extraction of groundwater and illegal pumping pose one of the biggest obstacles to maintaining qanats and other traditional water management systems. Overexploitation has led to a rapid drop in groundwater levels in both Tunisia and Morocco, which has in turn caused Khettaras to dry up and eventually be abandoned on a massive scale. Traditional groundwater extraction techniques based on gravity, such as Khettaras, and possibly unsustainable contemporary technologies, such as pumping, must be combined in a national water management plan that balances and recharges groundwater levels to restore traditional systems. Meanwhile, the lack of funds for necessary upkeep, maintenance, repairs, and renovations is the current issue. Kettaras were being refurbished or expanded in collaboration with foreign NGOs and EU-funded projects. These admirable but fragmented efforts may temporarily increase the local water supply (and local earnings). However, they are unable to oppose the macro-forces of growth economics, globalization, and climate change.

4.2 Runoff Agriculture

Since ancient times, runoff agriculture and rainwater harvesting have been used, and numerous methods have been developed to ensure agricultural production in marginal desert areas (El Amami & Chaabouni, 1981; El Amami, 1984; and Ennabli, 1993). Cultivation is mostly limited to the wadi bed itself in areas of the dry zone where the seasonal water flow is constrained to clearly defined drainage ravines or wadis. Building a series of transverse walls/dams across the wadi bed prevents the wadi from flooding during the seasonal flood. The silt deposits trapped between the dams contribute to the construction of a succession of "steps" or "terraces" of arable soil. Since this method is only used in the and semi-arid regions of the Maghrib, it seems true that when alternative agricultural exploitation methods are available, they tend to take precedence, and terrace farming is not used. The primary difficulty of arid-zone agriculture is the lack of cultivable soils in lowland regions with exploitable water supplies, these dams are conceived of works that force heavy silt-laden wadi flood flows to deposit alluvium behind the dam face rather than as water storage reservoirs. Although it does not impede the flow to the terrace downstream, the sedimentary soils of the dam's terrace immediately absorb and retain some of the flood water. As a result of the soil's reduced evaporation rate compared to an exposed surface, the water is kept in storage for a longer period of time. Therefore, the terrace dam accomplishes two tasks: (i) it both generates the cultivable soil plot and (ii) plays the role of a water storage basin.

The regular intervals at which these dams were constructed have frequently been interpreted as a sign that the communities in charge of their construction possessed a high enough level of technological understanding to foresee those specific set of intervals between the dams would result in the best conditions for soil and water retention along a particular wadi. This skillful application of engineering principles may have developed through a process of trial and error, but if the builders of the dikes had attempted to work within the limitations imposed by erratic and violent wadi flood regimes, then small, purpose-built dams would have instigated the spacing between succeeding terraces. These wadi terraces are generally located in arid regions, and they are typically covered with resistant arboreal plants that are well adapted to the harsh conditions of their environment. The Jabaliyya of western J. Nafûssa, who still engage in this sort of desert agriculture, cultivate their terraces (or "jesser") largely with figs and olives, interspersing cereals in the winter (Gasmi et al., 2022). Olive trees were at least a common component of the terrace economy in North Africa antiquity, as demonstrated by the frequently unearthed remnants of olive presses and mills in desert villages of the Roman era above wadis.

Traditional runoff agriculture flourished in Tunisia and the Maghreb during the thirteenth and fourteenth centuries thanks to the influx of agricultural knowledge from Arabian-Persia and Andalusian (Ennabli, 1993). Agricultural knowledge that was introduced was combined with pre-Roman native Tunisian traditional methods like "meskat" and "jessour" (Nasri et al., 2004; Jebari et al., 2015). These systems, which were formed precisely in response to the geography, geology, climate, history, and social organization of the rural population, still partially exist in Tunisia. According to Gasmi et al. (2022), the jessour is an ancient runoff farming method used in the dry mountains of southern Tunisia. Water and silt from the upstream collection area are collected by a stone wall across a sharp slope wadi bed. Vegetables, palm, and olive trees are planted on the terrace that has been created. In the catchment area, there is annual sedimentation of 10–12 cm (ibid). The whole economic activity of southern Tunisia is still supported by these systems, which are still in active use. The main challenge is how to handle their ongoing upkeep in a new socioeconomic environment. The meskat is another pre-Roman water collection technology existing in Tunisia. Two sections make up the upstream collection area; (i) the uppermost portion of the slope is left clear to provide runoff water for the (ii) lower portions of the slope where the trees will grow. With an average yearly rainfall of 250 mm, the system was created for dry lands. It permits around 75% of the annual average rainfall to infiltrate. According to how much of each property was covered by trees, the owners divided it up proportionally, which make the managed lands in meskat are crucial to the region's socioeconomic and environmental balance.

5 The Role of Indigenous Knowledge in Climate Change Adaptation

Climate change is harming an estimated 370 million indigenous people around the world. This is a result of an increase in the frequency and severity of extreme climate events, including heatwaves, storms, floods, and cyclones, among others. Indigenous populations have received less consideration when developing efforts to mitigate climate change, leaving them more susceptible to its effects. Despite this, many indigenous groups have consistently adopted a range of coping strategies developed from indigenous and local knowledge (ILK). Different ILKs are intended to solve regional ecological constraints by preserving sustainable use and conservation of naturally shared resources (Ayal et al., 2015; Abednico et al., 2018). ILK is used regularly and is essential for the well-being of Indigenous people in many ways, including forecasting and making decisions about impending climate change threats (Asmamaw et al., 2020; Omari et al., 2018; Abednico et al., 2018; Adger et al., 2014). A variety of ILK techniques are used to manage resources, boost output, and address different biophysical concerns.

Leal Filho et al. (2021) emphasized the possibility to build resilience against climate-related stresses and shocks by understanding the ILK-derived strategies that indigenous groups have used to deal with ecological uncertainty—environmental risk—, such as droughts, food insecurity, and human displacement. ILK's methodology can be utilized for current and upcoming community applications. According to ILK, indigenous communities' ability to withstand shocks brought on by climate change is under threat. However, if current trends continue, the speeds and variations of modern climate change pose a threat to outpace and overwhelm many indigenous societies' capacity for adaptation. Planning an efficient adaption requires an understanding of several ILK methods. ILK, which identifies the ecological roles played by diverse ecosystem components, can also be utilized to promote developmental treatments. For instance, when ILK is incorporated into the planning and execution of an intervention, new agricultural technologies can be created in a way that is more suited for a variety of scenarios. The possibility that development interventions will be accepted increases when Indigenous technologies are recognized and adopted in conjunction with those for development (Leal Filho et al., 2022).

Indigenous knowledge contains an understanding of linkages between society and nature that have stood the test of time, been shown to be sustainable, and can help to reduce the consequences of risks. Indigenous knowledge derives from the relationship between a community and a special natural environment, as well as from the continuation of a particular historical period (developed over several generations). According to Baumwoll (2008), the community alone is responsible for generating Indigenous knowledge, whether it incorporates outside information or not. Moreover, Indigenous disaster management methods have also been imperiled as a result of Western influence, in addition to their structural marginalization by mainstream organizations. The reliance on humanitarian aid has resulted in the renunciation of conventional coping mechanisms (Mercer et al., 2010). The diminished status of Elders within Indigenous communities is another potential drawback. Additionally, colonialism and later globalization's social, political, economic, and cultural developments have eroded Indigenous disaster risk reduction knowledge and raised vulnerability (Mercer et al., 2010).

5.1 Reactivation of Traditional Water Management Systems (TWMS)

Traditional water management systems (TWMS) can only be restored if the socioeconomic structure is renewed or retrofitted. The fusion of traditional and contemporary technologies, according to Balali et al. (2009), is a hallmark of the reflexive modernity paradigm. By using rainwater that has been collected and stored in cisterns or tanks, a rainwater harvesting (RWH) system, also known as a rainwater collecting system or a rainwater catchment system, is a potentially viable solution to boost water productivity at the production system level. It has been used for thousands of years practically everywhere, but especially in the countries of the Maghreb. To fulfill the increasing demand for water and to some part manage the limited rainfall, rainwater harvesting is a great method of sustainable water management. It also minimizes flood and soil erosion risk and may lessen the likelihood of recurrent drought (Simon, 2011).

In Lybia, rainwater harvesting systems are a strategy to conserve water in the area; its methods, including storage and prevention dams, cisterns, contour lines, and lunar basins, have become more widely used. Additionally, rainwater harvesting (RWH), which enables the evacuation of rainwater and hence fights against floods, has proven to be a practical alternative water source in the Mauritanian capital, Nouakchott. In Morocco, a system created and constructed by a moroccan NGO Dar Si Hmad is currently the largest operational fog-water harvesting system in the world and includes more than 10,000 meters of piping, seven storage basins, six solar panels, and about 600 square meters of mesh netting. In areas where fog is common, fog harvesting is a creative way to alleviate ongoing water stress. It uses a specific mesh to collect the fog droplets, and gravity pulls the water into containers that slowly fill up in order to maintain a sufficient water supply (Brittlebank, 2016).

In order to reduce water shortages, water harvesting has been successfully used also in Tunisia, notably in the southeast. The country supports a new policy that promotes water harvesting methods, including surface runoff water collection, floodwater collection, and spreading irrigation. In Algeria, due to severe water shortages, the algerians are employing rainwater collection from the rooftops of houses as a solution, which works well in many regions. In Egypt's northeast and along the northwest coast, the government is currently attempting to maximize the benefits of winter rains. In the Dabaa region, 2.5 million feddans of flat ground are being given special consideration since they receive enough rain to support agricultural growth all winter. A national rainwater harvesting system is being implemented to lessen the damage caused by flash floods and utilize the water that would otherwise be squandered. A system of canals, tunnels, and artificial lakes will be used to store water.

6 International Disaster Risk Reduction Strategies and Indigenous Peoples

Indigenous knowledge (IK) has been generally disregarded by policymakers in favor of catastrophe risk reduction strategies that place a greater emphasis on science and technology (Lambert & Scott, 2019). All IK should be acknowledged as having been produced in certain social circumstances, according to Hilhorst et al. (2015) argument. Universalism is impossible given the variety of indigenous settings and experiences. All IK should be acknowledged as having been produced in particular social circumstances. Besides, larger societal processes need to be understood concerning indigeneity and modernity.

According to the UNDRR,[10] a fundamental framework for the implementation of DRR was established by the UN General Assembly with the adoption of the 2030 Agenda for Sustainable Development in 2015. IK is constantly in danger of being lost, corroded, or improperly used even as it is treasured and acknowledged. There are many similarities between indigenous viewpoints on the environment and

[10] https://www.undrr.org/implementing-sendai-framework/what-sendai-framework

sustainable development. Indigenous Peoples frequently don't have enough chances to take part in the creation, implementation, monitoring, and assessment of initiatives and policies (Secretariat of the Permanent Forum on Indigenous Issues, 2017; Hsu, 2016; Lambert, 2015; Uekusa & Meatthewman, 2017). This framework came after the failure in some aspects of the Yokohama Strategy and Plan of Action for a Safer World were part of the International Decade for Natural Disaster Reduction that took place in the 1990s followed by the Hyogo framework (2005–2015). The Sendai Framework drastically expanded the definition of DRR to include both anthropogenic and natural disasters as well as associated environmental, technological, and biological risks (de Tozier & Baudoin, 2015). Reduced disaster risk was elevated as an expected outcome, and resilience was to be enhanced. Seven global targets were selected, and a set of guiding principles was developed, including the fundamental duty of nations to prevent and reduce disaster risk (UNISDR, 2015, 2017). The formulation and execution of plans and systems, particularly those for early warning, benefit greatly from the input of indigenous peoples. To ensure the inclusion of traditional, indigenous, and local knowledge and practices in disaster risk assessment, a cross-sectoral approach is required. The Sendai Framework advocated the direct integration of Indigenous perspectives into DRR strategies. There are indicators for two Sustainable Development Goals (SDGs) that specifically include Indigenous Peoples. Indigenous communities and DRR indicators are still a contentious issue, and strong metrics for the indicators are still required (Secretariat of the Permanent Forum on Indigenous Issues, 2017).

7 Conclusion

Traditional water management techniques are deteriorating over time, with government negligence being the biggest cause, followed by the availability of groundwater and poor maintenance. This pattern has several causes, including shifts in the socioeconomic climate of these nations. The workforce available to maintain these predominantly rural applications decreases as urban populations rise and the exodus of rural residents to cities increases. A weak understanding exists regarding the social, cultural, and economic ramifications of this change in water management strategy. The social, cultural, and economic ramifications of this shift in water management strategy are poorly understood; in contrast, there are limited financial incentives, especially for young entrepreneurs, to use these strategies.

The utilization of indigenous (TWMS) is impacted by many reasons, including system limitations, low economic returns from rain-fed agriculture, rising rural-urban mobility, and the availability of alternative sources of income. The involvement of the states was noted as a significant determinant in the revival of indigenous TWMS, despite the necessity of coordinated work by the government, local communities, and development actors. The governments actively encourage the use of groundwater at the expense of TWMS, which receives minimal funding, by offering incentives for useful initiatives. Consequently, North African countries need to have a clear strategy and policy for the revival of TWMS. This entails increasing awareness, gaining the assistance of the neighborhood, and reviving state- and community-owned TWMS networks. Such a strategy must include the evaluation of water resources in various locations as well as the implementation of the required enabling policies, regulations, and plans for utilizing and prioritizing rainwater sources among other sources, including limited groundwater supplies.

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