Climate Change and Water Security—An Introduction

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1 Introduction and Background

There is unequivocal evidence that the earth's climate is changing with an unprecedented rise in temperatures globally that subsequently leads to alterations in the hydrological cycle. The three most prominent signals of climate change, that is, increasing global average temperature, changes in precipitation patterns, and rising sea levels, all have significant implications on global and regional water security [1]. Further, such variations are expected to alter not only mean hydro climatic conditions, but also affect intensities, durations, frequencies, and areal extents of extreme events such as floods and droughts. As a result, water resources availability, acceptable water quality for consumption or environmental sustainability, and disaster risk protection come under direct threat. Agricultural water demands are also expected to go up, further resulting in threats to food security. Finally, energy also plays an important role in this nexus.

Rising global temperatures have been uniquely attributed to man-made emissions of greenhouse gases and aerosols [2]. However, changes in hydrologic variables, particularly at regional [6] or river-basin scales [5], are hard to attribute owing to large natural variability or the inability of climate models to represent such processes at smaller scales. Risk is perceived to be a combination of hazard of a disastrous event, and exposure and vulnerability of communities [7]. The latter component is more significant for developing countries owing to the large populations, poor socio-economic conditions, and frail, inadequate infrastructure. Therefore, disaster risk

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reduction efforts are already under stress in low-income countries, resulting from an imbalance in demands and availability of resources.

This book volume offers technical terms, a collective of research studies trying to understand and improve disaster resilience pertaining to water resources under climate change. Water quantity and quality issues are discussed, along with implications on agriculture or energy sectors. Risk assessment of natural hazards are also presented. While some studies are universal or methodological in nature, the primary focus is on developing countries. Further, environmental stressors may often lead to multi-hazard risk [3] necessitating interdisciplinary approaches to mitigate or adapt to such risk. Most of the studies presented in this book offers cross-disciplinary efforts to this end.

2 Climate Change Impact on Water Resources

2.1 Climate Change

Climate change has become an increasingly pressing issue that needs to be tackled by scientists and researchers around the globe in current years. It is necessary to go for modelling the climate change and its impacts on surface and groundwater as an important tool for decision-making. Still, huge uncertainties are associated with climate change and its impacts on our world as it is extremely difficult to quantify the effects of climate change.

2.2 Agriculture and Irrigation

The extreme climate events and climate variability affecting production and access to water for different social groups in various regions were studied as empirical analysis to assess *climate change and its effects on water scarcity through Participatory Rural Appraisal (PRA) approach* in Chirirbandar Upazila, Dinajpur. The climate change also has an impact on irrigation and agriculture in terms of crop productivity and yield.

The climate change impacts on crop yield at Muzza irrigation district in Lombardy, Italy is studied by *Ahmed and Mohammed* by considering two Representative Concentrations Pathways (RCPs) or scenarios, namely, RCP8.5 and RCP4.5 of the fifth assessment report of Intergovernmental Panel on Climate Change (IPCC).

2.3 Flood Risk Assessment and Techniques

Flood is an unusual high stage of the river. Floods are highly destructive natural disasters which results in massive damages to human and nature. This is due to severe storm of unusual meteorological combination, sometimes combined with melting of accumulated snow on the catchment. This may also be due to shifting of the course of the river, earthquake causing bank erosion, or blocking of river, or beaching of the river flood banks. Floods cannot be prevented but can be controlled by suitable structural and non-structural measures. Some of the chapters in this study discuss about non-structural, flood modelling tools, techniques, and case studies.

2.4 Non-Structural Measures

Milkecha et al. in their chapter discussed about impacts of possible *future climate change* scenarios on the stream in the *Upper Dhidhesa river sub-basin.* The future impacts of climate changes in the Upper Dhidhesa river basin is assessed from the hydrological response of new emission scenarios based on the IPCC fifth assessment report (AR5). The hydrological model Hydrologic Engineering Centre Hydrological Modelling System (*HEC-HMS*) was used for calibration and validation for streamflow simulation in Upper Dhidhesa river-sub-basin.

The *OpenDA software* is used to determine flood risk model parameters and coefficient values. Flood risk assessment at the Douro river estuary characterizes the hydrodynamic behaviour under extreme flood events. The chapter *Flood modelling for an urban Indian catchment: Challenges and way forward* used a one-dimensional flood model (MIKE 11) for estimating the river discharge along with storm water drainage discharge coupled with a *two-dimensional flood model (MIKE 21). Geo-SWMM* is used to assess storm water runoff of Padma bridge link road at southwest part of Dhaka in Bangladesh. The peak runoff for each catchment was determined for 5-year and 10-year return period using the *Geo-SWMM* model.

Mahesh et al. discussed advanced *Physics Informed Neural Network* (PINN) for spatial–temporal flood forecasting based upon Saint Venant's equations. The proposed article *Simulation of the flood of El Maleh River by GIS in the city of Mohammedia-Morocco* aims to explain how the flood occurs and the extent to which it may be affected by the region, as well as developing scenarios for the rise in the water level and the extent of its vulnerability and production of various risks, especially since the region contains industrial facilities for oil refining.

Flood hazard mapping is to reduce the risk of losing lives of people. *Reshma Antony* et al. in their chapter discussed about generating flood hazard mapping using G*eographical Information System* (GIS) and *Analytical Hierarchy Process* (AHP) for planning infrastructure development, disaster management or mitigation measures, and emergency services.

Machine Learning Techniques (MLT) are the latest techniques used in the field of flood modelling. The classification methods like *logistic regression* and *decision tree* are normally used in flood prediction studies. The chapter feature selection for rainfall prediction and drought assessment using *Bayesian Network technique* (BN) explores the potential of Bayesian Network (BN), which is a class of *Graphical Modelling* (GM), a feature selection technique for examining the association of monthly rainfall and probable meteorological drivers and subsequent drought assessment.

The study on *open-access precipitation networks* and *Machine Learning (ML) algorithms* adopted as tools for flood severity prediction, a case study in Echaz catchment, aims to develop a simple model to predict flood severity. This ML model is based on open-access precipitation data from a Personal Weather Station (PWS) network and water level measurements from a low-cost ultrasonic sensor.

2.5 Structural Measures

Gautam Das et al. in their chapter discussed about the conceptualization, planning, and design of a flood-proof house for Assam, India's flood plain, as a replacement to the normally used building typology in highly flood-prone areas of Assam. *Palomino Carlos* et al. used *Recycled Plastic Fibres as Concrete Retaining Walls for River Defenses*. In their study design, the two alternatives of *cyclopean concrete*, the one with recycled plastic fibres and the other without it, is adopted and compared for technical, economic, and environmental criteria. *Jun Lim Wong* et al. reviewed the relationship between rainfall variations under climate change and its impacts on slope stability.

2.6 Case Studies on Flood Modelling

The chapter *traditional knowledge* to read hydro-meteorological hazards in Teesta floodplain, Bangladesh is an experience, practices and observations provides valuable aid to forecast local hydro-meteorological hazards. However, traditional knowledge is less documented, often neglected by science, and consequently in danger of being lost. *Thankachan* et al. in this chapter discuss a case study about issues of draining surface water in Kothamangalam town, in Ernakulam district of Kerala with emphasis placed on the *design and planning process*.

2.7 Sedimentation

The primary purposes of creating impounding in the rivers with dams in the form of reservoirs is flood control. The loss of reservoir capacity due to deposition of sediments is major concern in reservoir management. The *sedimentation* in Chulliyar Reservoir in Kerala is considered for a case study. For sedimentation analysis, along with *bathymetric survey,* the entire catchment area is divided into zones with suitable grid size.

The *Particle Image Velocimetry* (*PIV*) experimental approach is used for the flow visualization on coastal problem. The PIV experiment involved the use of laser illumination system, high speed camera, filler particles, and wave-motion generator. The PIV experimental method is discussed in a case study titled *Particle Image Velocimetry Analysis on the Liquid Sediment Model.*

2.8 Extremity in Oceans

In the last few decades, extreme conditions of precipitation and drought have raised concern due to their severity and increasing risks to inhabitants, infrastructures, and other anthropic activities. In recent days, coastal structures overtopping, erosion in stream, and destruction of infrastructures are common along the coasts around the world. There are different methods to analyse extreme conditions like physical, mathematical, and numerical modelling. *Ana Gomes and José Pinho*, in their chapter, used a numerical model on coastal structure at full scale level for simulating the pressures and shear stresses that act on the piers that support the structure, considering different heights of the air gap and assessing the respective CPU simulation times using *CFD modelling*.

3 Drought Analyses and Indices

Droughts are recognized as a natural disaster that is caused by extreme and continuous shortage of precipitation. Total water available on this earth remains constant but its distribution with respect to time at a place is highly variable leading to hydrological extremes of drought (water deficiency) and flood (water surplus in a stream). Among the two extremes of flood and drought, the former is characterized by quick inception, vigorous growth, and evident speed terminating eventually with disastrous impacts. But, drought is a non-event and a creeping phenomenon. Its beginning is subtle and invisible, progress is insidious and deceptively lethargic in spread, and the effect can be devastation. Drought planning, mitigation, and management involve short- and long-term strategies. Drought Impacts are generally non-structural and difficult to quantify. Drought indices quantify a number of tasks, including drought early warning and monitoring by computing severity levels and proclaiming the start and end of drought. Various drought indices were formulated for the forecasting and prediction of spatio–temporal drought characteristics using various *hydro climatological variables*, such as precipitation, evapotranspiration, runoff, soil moisture, etc.

Drought risk mapping is a pre-requisite to identify the severe drought-prone areas. *Landsat satellite* images using ArcGIS is discussed in chapter *drought risk mapping in the North-West region of Bangladesh using Landsat time series satellite images*. The separate spatial maps were generated for each index to identify the most drought-prone districts in Bangladesh. *Rashmi Singh* et al. in their chapter mentioned about quantification of drought condition using drought indices, i.e. a review discussion about *several indices* which can be used for *drought assessment*, *monitoring, and prediction purpose*.

Pallavi Kumari et al. in their chapter adopted *Standardized Precipitation Evapotranspiration Index* (SPEI) as one of the evapotranspiration-based drought indices to understand the drought variability at various time scales along with *Hargreaves model* to calculate *Potential Evapotranspiration* (PET).

Sreedevi and Adarsh studied about spatio–temporal analysis of drought persistence of peninsular India and discuss about drought persistence of the Peninsular India (PI) using a *meteorological drought index*. In this study, they used *Standardized Precipitation Index* (SPI) time series for computing in different aggregation time scales.

4 Water Security

The chief motive of water security is to make sure of water availability at all times. It should ensure enough water to satisfy diverse and sometimes conflicting needs. Water security discusses about good water management, ability to transport, store, provide, regulate, and conserve water. The Global Water Partnership considers water security as the overarching goal of water management [4]. Water security in India has always been one of the major concerns, especially in terms of water quality, availability, and its accessibility as only 40% of the population has access to safe drinking water.

The chapter role of *water governance in ensuring water security*: a case of Indian city discusses about a working definition of water governance, context-specific to the Indian Context. The chapter also critically analyses the *legal and regulatory framework* existing in such a context and provides an empirical foundation for further engagement on a fit-to-purpose implication of such terms and concepts amongst water professionals, academicians, urban planners, and researchers interested in urban water and systems.

India, with merely 4% of the world's freshwater sources and almost one-fifth of the world's population, is facing a water crisis affecting 1 million people every year. The poor urban planning practices and unsustainable use of land and water resources have resulted in frequent urban flooding and threatened many cities with the unavailability of water. The research on *Making Indian Cities Water-sensitive: A Critical Review of Frameworks* critically reviews these toolkits, assessing their scope and replicability in the Indian context. The recommendations from this research include suitable keys taken for Indian cities from the existing *toolkits and framework*.

5 Urbanization and Its Impact on Ground Water Security

The impacts of urbanization on surface water-groundwater security in rapidly urbanizing cities is discussed in chapter *Assessing Groundwater Depletion in Southern India as a function of Urbanization and change in Hydrology.* It discusses about a threat to tank irrigation in Madurai city and an integration of data like rainfall *groundwater*, remote sensing, and *survey* for modelling purpose.

Arif Khan et al. in their chapter developed prediction models on Saskatchewan's water security level by categorizing and assessing the time series parameters of water security using *linear* and *non-linear regression methods.* The seven critical parameters under three significant factors: water consumption, quality, and risk were chosen based on the literature review and available data to quantify the water security and prediction model in Saskatchewan's water security.

The chapter in the water scarcity in the downstream due to factors in the upstream—a case study analyses the sustainability in living conditions in LMRM countries, in concern with the issues in social-economic, and environmental aspects among LMRB countries. In many previous studies, both nationwide and worldwide have indicated negative impacts of hydropower dams on land and water use, especially in *Lower Mekong River Basin* (LMRB).

The study on model prediction for evaluating the raw water quality parameters and its significance in pipe failures of nuclear power plant discusses about prediction and evaluation of raw water quality and the majority of the nuclear system failures could have been minimized by ensuring proper *chemical conditioning* and preventive maintenance.

Rafi et al. assessed drinking water quality of public tube-wells and their spatial distribution in the Rangpur City of Bangladesh and their study aims to assess the water quality of the public tube-wells and find out its suitability as drinking water according to the Bangladesh ECR1997 and WHO guidelines. The *geo-spatial map* generated during study period depicts the distribution of each water quality parameter in Rangpur City. *Farhana Afroz* et al. in their chapter discuss about the water, sanitation, and hygiene condition of the educational institution of Rajshahi known as the educational city of Bangladesh.

The nature's response to river restoration is by limiting the anthropogenic activities as discussed in the chapter analysing the impact of lockdown on the rejuvenation of rivers in Uttar Pradesh, India. During lockdown phases due to restrictions on the upliftment of industrial activities, the rivers restored themselves due to the absence of human anthropogenic activities.

Electro kinetic barrier is the best remediation technology for prevention of saltwater intrusion which allows water and some ion transport but prevents some ions reducing salt intrusion. The methodology adopted for electro kinetic barrier is discussed in the topic prevention of saltwater intrusion: a laboratory-scale study on electro kinetic remediation. The *grey water treatment* by *Biochemical Oxygen Demand* (BOD_5), *Chemical Oxygen Demand* (COD), turbidity, acidity, alkalinity, chloride, phosphorus, and nitrogen were discussed in chapter *integrated onsite grey* *water treatment* with constructed wetland for household application. The development in the field of *Nano-technology* for waste water treatment and the solution of water crisis through Nano-technology is presented in chapter *application of Nano-technology in waste water treatment.*

6 Groundwater Conservation Measures and Modelling Techniques

Storm Water Management (SWM) systems involve many challenges including flooding and associated property damage, combined sewer over-flows, and poor water quality in surface waters. Design of storm tech chambers for critical areas by multi-criteria analysis technique is used for identification of water stressed areas as discussed as a case study in chapter *design of storm water management system for the water stressed areas in Palakkad district*.

Mangukiya et al. discussed a case study about efficient and separate storm water drainage network for the Sardar Vallabhbhai National Institute of Technology campus to safely discharge storm water. The *STORMCAD v10.01* is used in design of storm water drainage network and this method can be useful to other educational institutes in India also.

Developing a *Web Application-based Water Budget Calculator (WBC)* in attaining water security in rural Nashik, India is another advanced technique discussed in this book chapter. *Amman Srivatsava* et al. developed a web application-based water budget calculator for attaining water security in rural Nashik in India. The manual calculation of water budget is a challenging one and to overcome this a web application-based WBC is adopted for better water management policies.

7 Natural Hazards

Natural hazards are naturally occurring physical phenomena caused by rapid or slow events. The slow set events can be geophysical, hydrological, climatological, and meteorological. According to United Nations International Strategy for Disaster Reduction (UNISDR), natural hazards may pose a negative impact on the economy, society, and ecology [8].

The chapter in a review of *energy dissipater as a mitigation for dam risk management* reviews energy dissipaters in connection with dam and spillway structure. This study also describes the different types of energy dissipators with different appurtenances used in hydraulic structures for protection work. It includes topics such as energy dissipation of block ramp, hydraulic jump type stilling basin, stepped spillway, and the deflector (flip bucket and ski-jump bucket).

The study *overview of water resources in Kerala and feasibility of coastal reservoirs to ensure water security* presents the current scenario of water resources in the state and proposes alternative ways to ensure water security considering the unique geography of the state.

The next form of natural hazard is *Landslide,* a common geomorphic hazard in most regions of the Western Ghats in India. A number of *environmental*, *geotechnical*, *geological,* and *geomorphological* factors contribute to the occurrence of landslides in this region but rainfall often is the most common and important triggering factor. The case study related to landslide is discussed in chapter location specific rainfall threshold for landslides in select micro-watersheds in Coonoor Taluk, Tamil Nadu, India.

8 Summary

The subsequent chapters in this book discuss relevant topics for assessment of water quantity and quality in a changing environment, disaster risk, their possible future prognosis, as well as adaptation and protection measures. Some of the chapters also pertain to agricultural or energy sectors. Collectively, they cover topics related to hydrology, atmospheric science, remote sensing, energy studies, social sciences, agriculture, as well as environmental science and engineering. Such a collection of state-of-art scientific studies can potentially guide disaster risk resilience, particularly for densely populated highly vulnerable low-income countries of the world.

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