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Managing Water Resources under Climate Uncertainty

Examples from Asia, Europe, Latin America, and Australia

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Foreword by WMO

The Fifth Assessment Report (2013) by the Intergovernmental Panel on Climate Change (IPCC), adopted by 110 governments, provides conclusive new scientific evidence that human activities are causing unprecedented changes in the Earth's climate. The report confirms that it is extremely likely (95–100 % probability) that most of the warming since 1950 has been due to human influence.

The new report further states that greenhouse gas emissions at or above current rates would induce changes in the oceans, ice caps, glaciers, the biosphere and other components of the climate system. Some of these changes would very likely be unprecedented over decades to thousands of years. Limiting climate change would require substantial and sustained reductions in emissions of carbon dioxide (CO2) and other greenhouse gases.

In a changing climate, our valuable water resources will be one of those areas most impacted. For example, there is very high confidence that glaciers have continued to shrink and lose mass worldwide, with very few exceptions. By 2100, global glacial volume could, under one scenario, decline further by as much as 35–85 %. Meanwhile, the extent of Northern Hemisphere snow cover has decreased since the mid-twentieth century, especially in spring, and this decline, too, will continue.

It is likely that human influences have affected the global water cycle and its patterns since 1960. For example, in recent decades, precipitation has increased in the mid-latitude land areas of the Northern Hemisphere.

The UN-wide Global Framework on Climate Services (GFCS) led by the World Meteorological Organization (WMO), with a wide range of partners, assists governments to produce and use climate information and predictions for adapting to and mitigating climate change while transitioning to a green economy. Climate services can empower decision-makers, making water resources management decisions more climate resilient. The Integrated Flood Management and Integrated Drought Management approaches, adopted by the WMO in partnership with the Global Water Partnership are just two risk-based, resilience building methodologies that will improve the coordination and collaboration between the climate and water communities as part of the GFCS User Interface Platform.

This book contains a collection of individually authored chapters, which provide increased knowledge of the impacts of climate change on the water cycle and identify practices and procedures that can assist in adaptation to a changing and variable climate. I commend the authors of these chapters for their contributions and the Editors for bringing the material together and urge readers to critically examine, review and make use of the material in the most relevant and practical manner.

Michel Jarraud
Secretary-General of WMO

Foreword by UNESCO

Water—the basic ingredient of life and a fundamental human right—holds the key to global sustainability. The UN International Year of Water Cooperation, 2013, emphasised that cooperation *around* water, *for* water and *through* water must happen everywhere—between states and within states. While we talk about water, we are really talking about human rights, about the sustainable development of our societies, about sustainability of ecosystems. This publication constitutes a joint effort between scientists and other experts from around the world, and is testament to the spirit of the UN International Year of Water Cooperation, during which the preparations for the book started.

UNESCO's International Hydrological Programme (IHP) is the only intergovernmental water science programme of the United Nations. Over the past 12 years, The Netherlands, through the Secretariat of its National IHP Committee, has been one of the most active countries worldwide contributing to the Programme. The Secretary personally has also been instrumental in supporting many water professionals from developing countries and countries in transition. In addition, the Asian Institute of Technology (AIT) has indeed a long history of working together with the United Nations, in research, education and capacity-building, at a high level.

The IHP is an intergovernmental programme that is implemented in phases. IHP operates in accordance with the needs of its Member States, and thrives thanks to their support and contributions. In 2014, the eighth phase of IHP began, focused on six themes along three axes:

- Mobilizing international cooperation to improve knowledge and innovation to address water security challenges;
- Strengthening the science–policy interface to reach water security at local, national regional and global levels;
- Developing institutional and human capacities for water security and sustainability.

Despite the intergovernmental nature of IHP, the essential contributions to the Programme have always been the work of dedicated individuals with their hearts in

the right place. They are the ones who deliver the substance and tangible results that advance humanity. This book is an excellent contribution to the Programme that highlights these achievements. East and West come together: water cooperation and science diplomacy in the true meaning.

It is also due to my personal involvement in the Intergovernmental Panel on Climate Change (IPCC) that I am delighted to see this publication '*Managing Water Resources under Climate Uncertainty'*, addressing one of the most important current issues globally in water resources management. I sincerely hope that it will raise awareness of sensitive and urgent questions related to water resources management and climate uncertainty, in order to ensure that ecological principles, including hydrology, are at the heart of economic development and decision-making. In this regard, I would like to thank the editors of the publication for their excellent work. It reflects the rich expertise of participants from various geographical and cultural backgrounds, and thus the true spirit of water cooperation!

Blanca Elena Jiménez Cisneros
Director, Division of Water Sciences
Secretary, International Hydrological Programme, UNESCO

United Nations
Educational, Scientific and
Cultural Organization

International
Hydrological
Programme

Foreword by SEA-EU-NET

The availability of safe water is a major global challenge for the future owing to a rapidly growing population and unsustainable consumption pattern, increasingly urbanised populations, rapid shifts in land use and climate change. Global water demand has tripled in the past 50 years.[1] and just 2.5 % of the world's water resources are freshwater of which only 0.4 % are available and accessible for use. Water is intrinsically linked to the most pressing challenges we face today, including food security and safety, health, climate change, economic growth and poverty alleviation.

The United Nations projects that by 2025, half of all countries worldwide will face water stress or outright shortages. By 2050, three out of four people around the globe could be affected by water scarcity. Water problems in Asia today are severe—one out of five people (700 million) does not have access to safe drinking water and half of the region's population (1.8 billion people) lacks access to basic sanitation. Although Asia is home to more than half of the world's population, it has less freshwater, i.e. 3,920 cubic meters per person per year, than any other continent. As population growth and urbanization rates in the region rise, the stress on Asia's water resources is rapidly intensifying. Climate change is expected to worsen the situation. According to the Intergovernmental Panel on Climate Change (IPCC), by 2050, more than one billion people in Asia alone are projected to experience negative impacts on water resources as a result of climate change. Experts agree that reduced access to freshwater will lead to a cascading set of consequences, including impaired food production, the loss of livelihood security, large-scale migration within and across borders, and increased economic and geopolitical tensions and instabilities.

Within ASEAN, overall water demand is expected to increase by one-third by 2015.[2] Although most Southeast Asian countries do not experience physical water

[1] UNEP – A Tale of Two Trends: providing information and knowledge for decision-making in water-scare regions through water assessments – http://www.unwater.org/downloads/www.Singh.pdf.

[2] ASEAN (2005) ASEAN Strategic Plan of Action on Water Resources Management. Accessed http://environment.asean.org/files/ASEAN%20Strategic%20Plan%20of%20Action%20on%20Water%20Resources%20Management.pdf 27 May 2011.

scarcity, seasonal water scarcity can be an issue, e.g. in Cambodia and Vietnam. High rates of development put pressure on the sustainable water supply and sanitation, and increase competition for water resources. Some ASEAN member states are unlikely to meet the Millennium Development Goals relating to drinking water and sanitation. The key water challenges for the ASEAN region have already been set out in the ASEAN Strategic Plan of Action of Water Resources and Management.[3] They plan includes aspects such as collecting and maintaining high quality data, mitigating the effects of extreme events on water resources (especially to subsistence farmers and the poor), sustaining and improving water quality, improving governance systems and acquiring financing for the development of new water infrastructure.[4]

To address these challenges, we have initiated the project 'SEA-EU-NET 2—EU-ASEAN S&T cooperation to jointly tackle societal challenges'. The SEA-EU-NET 2 project aims at strengthening the bi-regional dialogue on international S&T cooperation between Europe and Southeast Asia, particularly by tackling societal challenges, creating direct linkages to the policy dialogue, development of additional funding sources and improved dissemination of project results to the interested public. The SEA-EU-NET 2 project is working within the framework of the official EU-SEA cooperation in Science, Technology and Innovation. Cooperation between EU and ASEAN, which has been ongoing for 30 years, has gained significant momentum over the last decade.

One of the primary aims of the project is to stimulate deeper and more productive cooperation in three global societal challenges: health, food and water. The rationale for the selection of the three societal challenges was recognition that these are areas in which the EU and Southeast Asia have strong and complementary interests. In health, Southeast Asia is increasingly coming to resemble Europe, with non-communicable diseases burdening health systems and taking over from infectious disease as the leading cause of death. Yet the region still suffers from high incidences of infectious diseases which Europe—though climate change and global connectedness—is also exposed to. Southeast Asia is a major exporter of food to Europe, providing a strong rationale to work with the region to ensure the security and safety or Europe's food supply. Disruption caused by flooding in Southeast Asia affects the production facilities of European companies and disrupts the plans of holidaymakers, and tensions over transboundary water resources threatens the stability of the region. These challenges are also interlinked; extreme weather events could threaten food supplies while also spreading waterborne diseases. These societal challenges also reflect the areas in which much EU-ASEAN collaboration already takes place.

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[3] ASEAN (2005) ASEAN Strategic Plan of Action on Water Resources Management. Accessed http://environment.asean.org/files/ASEAN%20Strategic%20Plan%20of%20Action%20on%20Water%20Resources%20Management.pdf 27 May 2011.

[4] ASEAN (2005) ASEAN Strategic Plan of Action on Water Resources Management. Accessed http://environment.asean.org/files/ASEAN%20Strategic%20Plan%20of%20Action%20on%20Water%20Resources%20Management.pdf 27 May 2011.

International exchange and collaboration is necessary to tackle these complex and interrelated issues. This book is proving that there is much international knowledge and expertise which should help develop innovative solutions.

Christoph Elineau
SEA-EU-NET Coordinator
International Bureau of the German Federal Ministry
of Education and Research (DLR)

Acknowledgments

A number of individuals have contributed to the preparation of this book, and to whom we extend our deepest gratitude, but because of space constraints it is not possible to mention all the names here. However, it would be an injustice if we failed to mention a few individuals whose contributions are particularly significant. Our sincere thanks to all contributing authors who prepared the chapters despite their busy schedules, and who were always supportive despite constant and frequent reminders. We would also like to thank all the reviewers for their valuable feedback.

Special thanks to Smriti Malla and Kshitij Parajuli for their tireless efforts in communicating with the contributing authors and compiling and formatting all the chapters throughout the publication process.

Contents

Abbreviations

ADB	Asian Development Bank
AGloCAP	Adaptation to Global Changes in Agricultural Practices
ANN	Artificial Neural Networks
ANOVA	Analysis of Variance
AOGCM	Atmosphere-Ocean General Circulation Model
APHRODITE	Asian Precipitation Highly Resolved Observational Data Integration Towards Evaluation of Water Resources
AR4	Fourth Assessment Report
ASR	Aquifer Storage and Recharge
BEA	Bhutan Electricity Authority
BOD	Biochemical Oxygen Demand
BPL	Below Poverty Line
BRO	Border Roads Organisation
CA	Christian Aid
CBOs	Community-based Organisations
CC	Climate Change
CCS	Climate Change Scenarios
CER	Certified Emission Reduction
CH_4	Methane Gases
CIRCE	Climate Change and Impact Research
CNR	National Research Council of Italy
CNRS-L	National Council for Scientific Research of Lebanon
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
CPRC	Chronic Poverty Research Centre
CSO	Combined Sewer Overflows
DCA	DanChurchAid
DD	Dynamical Downscaling
DEFRA	Department for Environment, Food and Rural Affairs
DEM	Digital Elevation Model

DHM	Department of Hydrology and Meteorology
DWT	Depth to Water table
EDA	Exploratory Data Analysis
EI	Efficiency Index
ENSO	El Nino Southern Oscillation
EPA	Environmental Protection Agency
ESD	Ecologically Sustainable Development
ESS	Ecosystem Services
EWEs	Extreme Weather Events
FAO	Food and Agriculture Organization
GCM	General Circulation Model
GDP	Gross Domestic Product
GEC	Global Environmental Change
GHF	Global Heritage Fund
GHG	Greenhouse Gases
GHGES	Gas Emission Scenarios
GHR	Greater Himalayan Region
GIS	Geographic Information System
GLOF	Glacial Lake Outburst Floods
GoI	Government of India
GWL	Global Water Law
HadCM3	Hadley Centre Coupled Model version 3
HFCs	Hydrofluorocarbons
HRUs	Hydrological Response Unit
ICIMOD	International Centre for Integrated Mountain Development
IDFs	Intensity Duration Frequency Curves
IITM	Indian Institute of Tropical Meteorology
IMD	Indian Meteorological Department
INCCA	Indian Network for Climate Change Assessment
INEGI	Instituto Nacional de Estadística, Geografía e Informática
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate Prediction
IRIN	Integrated Regional Information Networks
IUWM	Integrated Urban Water Management
IWMI	International Water Management Institute
K–S test	Kolmogorov–Smirnov test
LAF	Leaf Area Index
LARS-WG	Long Ashton Research Station—Weather Generator
LDOF	Landslide Dam Outburst Floods
LGA	Local Government Authority
LULC	Land Use and/or Land Cover
MB	Mean Bias
MEoF	Ministry of Environment and Forests
MONRE	Ministry of Natural Resources and Environment
MRC	Mekong River Commission

MSL	Mean Sea Level
MVMC	Metropolitan Valley of Mexico City
N_2O	Nitrous Oxide
NAFOSTED	National Foundation for Science and Technology Development
NAFTA	North American Free Trade Agreement
NCEP	National Center for Environmental Prediction
NCRMP	National Cyclone Risk Mitigation Project
NDN	Nitrification/Denitrification
NDTV	New Delhi Television Limited
NGOs	Non-Governmental Organisations
NIW	Nahr Ibrahim Watershed
NMHS	National Meteorological and Hydrological Service
NMSE	Normalised Mean Square Error
NRRC	Nepal Risk Reduction Consortium
NSE	Nash-Sutcliffe Efficiency
NWC	National Water Commission of Mexico
PBIAS	Percent Bias
PDFs	Probability Density Functions
PDS	Public Distribution System
PFCs	Perfluorocarbons
PRECIS	Providing Regional Climate for Impacts Studies
PWD	Public Works Department
R&D	Research and Development
R^2	Coefficient of Determination
RACCM	Regional Assessment of Climate Change in the Mediterranean
RCM	Regional Climate Model
RCOF	Regional Climate Outlook Forum
RGOB	Royal Government of Bhutan
RMA	Royal Monetary Authority
RMSE	Root Mean Square Error
SD	Statistical Downscaling
SDSM	Statistical Downscaling Model
SI	Statistical Interpolation
SRES	Special Report on Emission Scenarios
SRTM	Shuttle Radar Topography Mission
SSO	Sanitary Sewer Overflow
STI	Science Technology and Innovation
SWAT	Soil and Water Assessment Tool
SYB	Statistical Year Book of Bhutan
Tmax	Maximum Temperature
Tmin	Minimum Temperature
ToRs	Terms of Reference
TSS	Total Suspended Solids
UNDP	United Nations Development Program
UNEP	United Nations Environment Program

UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations International Children's Fund
UNISDR	United Nations International Strategy for Disaster
UPaRF	UNESCO-IHE Partnership Research Fund
URE	Urban Rainfall Effect
USACE	US Army Corps of Engineers
USDA	United States Department of Agriculture
UW CIG	University of Washington's Climate Impacts Group
VE	Volume Error
VNU-HCM	Vietnam National University Ho Chi Minh City
VOCs	Volatile Organic Compounds
WEAP	Water Evaluation and Planning
WHO	World Health Organization
WF	Water Footprint
WMO	World Meteorological Organization
WWT	Wastewater Treatment
WWTPs	Waste Water Treatment Plants

About the Editors

Dr. Anil Kumar Anal is an Associate Professor in Food Engineering and Bioprocess Technology at the Asian Institute of Technology (AIT), and coordinator of Food Agriculture and Biosystems cluster. His background expertise is in the valorization as well as bioprocessing of agro-industrial waste and its application in functional foods, neutraceuticals, cosmetics and pharmaceuticals as well as the formulation and delivery of cells and bioactivity for human and veterinary applications, controlled release technologies, and particulate systems. He also has interests in physicochemical characterization, interactions and applications of biopolymers and bioactive compounds in the functionality and delivery of cells and other bioactive compounds, detection and control of food pathogens using biosensor/nanotechnology; and biopackaging. His recent research focusses on the valorization of waste from plant and animal sources including seafood and other marine waste, bioprocess technology, post-harvest technology towards green growth, food safety and food security issues in developing countries, micro-/nanoencapsulation technology of marine omega-3 fatty acids, cells, probiotics, immunoglobulins, peptides, enzymes, vitamins, and antioxidants for gastrointestinal targeted delivery to enhance the stability and bioavailability for optimising health benefits. He has published various articles in peer-reviewed and internationally referred Life Science Journals, books, and conferences. One of his recent works on the encapsulation of probiotics has been granted a U.S. Patent and World Patent. His two books on Food Waste Valorisation and Utilisation and Functional Foods published by Wiley, are under preparation and due to be published soon. He is a guest author in the book series of the Pharmaceutical Manufacturing Handbook and Pharmaceutical Sciences Encyclopedia: and similarly for the chapters in various books. He is currently serving as an Editorial Board Member

in some of the relevant International and Regional Journals. Dr. Anal received his Ph.D. in Bioprocess Technology from the AIT, Thailand. He has held previous academic and research positions in industries and academia including Otago University and Massey University, New Zealand.

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After completing his Ph.D., Dr. Shrestha continued his postdoctoral research in the GCOE project at the University of Yamanashi in Japan until 2007, where he was involved in the development and application of a material circulation model and groundwater research in the Kathmandu Valley. He then worked as a policy researcher at the IGES, where he was actively involved in research and outreach activities related to water and climate change adaptation and groundwater management in Asian cities. Dr. Shrestha has published more than three dozen peer-reviewed international journal articles and presented more than three dozen conference papers ranging from hydrological modelling to climate

change adaptation in the water sector. His recent publications include 'Kathmandu Valley Groundwater Outlook' and 'Climate Change and Water Resources'.

His present work responsibilities at AIT include delivering lectures at the postgraduate and undergraduate levels, supervising research to postgraduate students and providing consulting services on water related issues to government and donor agencies, and research institutions. He has conducted several projects relating to water resources management, climate change impacts and adaptation, with awards from International organisations such as APN, CIDA, EU, FAO, IFS, IGES, UNEP and UNESCO.

Dr. Michael R. van der Valk was trained as a hydrologist with degrees in physical geography and geographical hydrology from VU University, Amsterdam, The Netherlands. Since its initiation in 1993, he has been final editor of Stromingen, the professional magazine of The Netherlands Hydrological Society, where he currently is the board member for international relations. From 2002 to 2008, he served as the water expert in the International Relations and Strategy department of the Royal Netherlands Meteorological Institute (KNMI). From 2008 onwards, he has been coordinator of the Communication and Information portfolio of the Cooperative Programme on Water and Climate (CPWC), which included organising sessions on climate change adaptation during the fifth and sixth World Water Forums, coining the Water and Climate Days during the World Water Week in Stockholm, and a high-level panel on groundwater and climate change in Africa during the UNFCCC COP-15 in Copenhagen. He is currently the Scientific Secretary of The Netherlands National Committee IHP-HWRP (the scientific water programmes of UNESCO and WMO), an advisory commission for the Government of The Netherlands. He is a board member of The Netherlands' chapter of the International Association for Hydrogeologists (IAH) and director of CrossVision Communications.

Michael van der Valk has contributed to the UNECE Guidance on Water and Adaptation to Climate Change, and he was author of the UN Commission's report on Transboundary Flood Risk Management. Over the years he has served on several commissions and working groups of the International Hydrological Programme (IHP) of UNESCO and as a member of the Commission for Hydrology of the World Meteorological Organization (WMO). He is editor of about 25 publications on hydrology, water resources and climate change (adaptation) including Climate Change Adaptation in the Water Sector.

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He studied Environmental Engineering and Philosophy at the Technical University in Berlin, where he focussed on water quality control and integrated water resource management. In addition to his employment at Adelphi, he is writing and pursuing his applied research on IWRM and surface water treatment solutions in rural areas with the Technical University, Berlin and the Jadavpur University, Kolkata.

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