

M. Dinesh Kumar  
Yusuf Kabir  
Rushabh Hemani  
Nitin Bassi *Editors*

# Management of Irrigation and Water Supply Under Climatic Extremes

Empirical Analysis  
and Policy Lessons from India

# **Global Issues in Water Policy**

Volume 25

## **Editor-in-Chief**

Ariel Dinar, University of California, Riverside, CA, USA

## **Series Editors**

José Albiac, Unidad Economía, CITA-DGA, Zaragoza, Spain

Guillermo Donoso, Pontificia Universidad Católica de Chile, Macul, Chile

Stefano Farolfi, CIRAD UMR G-EAU, Montpellier, France

Rathinasamy Maria Saleth, Chennai, India

## **Global Issues in Water Policy is now indexed in SCOPUS.**

\* \* \*

Policy work in the water sector has grown tremendously over the past two decades, following the Rio Declaration of 1992. The existing volume of water-related literature is becoming dominant in professional outlets, including books and journals. Because the field of water resources is interdisciplinary in nature, covering physical, economic, institutional, legal, environmental, social and political aspects, this diversification leads in many cases to partial treatment of the water issues, or incomplete analysis of the various issues at stake. Therefore, treating a whole host of a country's water resources issues in one set of pages will be a significant contribution to scholars, students, and other interested public. This book series is expected to address both the current practice of fragmented treatment of water policy analyses, and the need to have water policy being communicated to all interested parties in an integrated manner but in a non-technical language. The purpose of this book series is to make existing knowledge and experience in water policy accessible to a wider audience that has a strong stake and interest in water resources. The series will consist of books that address issues in water policy in specific countries, covering both the generic and specific issues within a common and pre-designed framework.

More information about this series at <http://www.springer.com/series/8877>

M. Dinesh Kumar • Yusuf Kabir  
Rushabh Hemani • Nitin Bassi  
Editors

# Management of Irrigation and Water Supply Under Climatic Extremes

Empirical Analysis and Policy Lessons  
from India

 Springer

*Editors*

M. Dinesh Kumar  
Institute for Resource Analysis & Policy  
Hyderabad, Telangana, India

Yusuf Kabir  
UNICEF Mumbai Field Office  
Mumbai, Maharashtra, India

Rushabh Hemani  
UNICEF, Jaipur Field Office  
Jaipur, Rajasthan, India

Nitin Bassi  
Institute for Resource Analysis  
and Policy (IRAP), Liaison Office  
New Delhi, India

ISSN 2211-0631

ISSN 2211-0658 (electronic)

Global Issues in Water Policy

ISBN 978-3-030-59458-9

ISBN 978-3-030-59459-6 (eBook)

<https://doi.org/10.1007/978-3-030-59459-6>

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG 2021

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG  
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

# Preface

Over the past one decade or more, several publications, both academic and popular in nature, have come out from around the world on the theme of climate change and water. While some of them have focused on the global situation with regard to the impact of climate change on water availability and food production, others have focused on the likely impacts on South Asia, especially India, and China. Several academic and research studies have used Global Circulation Models (GCMs) and many Regional Climate Models (RCMs) to predict the changes in temperature and precipitation in different regions across the world.

One major limitation of these studies is their failure to capture the effect of the phenomenon of climate variability such as variability in annual precipitation and variability in the mean annual and seasonal temperature on the reliability of the predictions. This is in spite of the fact that for several centuries, many South Asian countries are historically known for severe droughts and devastating floods as a result of extreme climatic conditions. Understanding the effects of such phenomena are vital as historically many of the largest falls in crop productivity in countries like India have been attributed to anomalously low precipitation events, and greater risks to food security may be posed by changes in year-to-year variability and extreme weather events; therefore, knowing the magnitude of extreme event is more important. Most predictions that are based on average trends significantly reduce the utility of the models for regions that experience extreme variability in climatic variables between years. The reason is that many a time, the percentage change in value of the predicted variable (say, rainfall) is less than the percentage change in the annual rainfall, which the region experience, between a dry year and a wet year.

In the same way, several of the modelling studies, which tried to predict the impact of climate change on water resources at basin scales, have also failed to capture the impact of variability in precipitation and many other weather parameters on the hydrological processes and their outcomes, that is, stream-flows and ground-water recharge, in the basin. Such omissions make the predictions of hydrological impacts of climate change a futile exercise when the ratio of the annual runoff in a very wet year and that in a dry year is very high. A quick comparison between the

stream flows of wet years with that of dry years of major rivers of the semi-arid regions of India, such as Godavari, Pennar, Cauvery and Krishna, will illustrate this point in ample measure. Analysis of such complex hydrological processes calls for pragmatic approaches that suit the local weather, land use and soil conditions rather than using routine models that predict average conditions that never occur in the basin in real life.

Capturing the stresses that the variations in hydrological conditions induce on the socio-economic system in terms of changes in irrigation water availability, drinking water supplies and sanitation is more important than capturing the small changes in the precipitation and its consequences on basin yield and water supplies.

In spite of the growing body of research on climate change and water in India, there is too little clarity on how reduction or increase in rainfall due to climate change in different river basins would impact basin water availability and water supply situation on an annual basis and the risks they pose to the communities which are dependent on such systems. This would require complex analytical frameworks that are compatible with real-life situation vis-à-vis weather conditions, hydrology, water resource system characteristics and socio-economic realities. This is attempted in the volume.

While most of the available scientific literature dealt with climate change issues only at the macro and national level, the uniqueness of this volume is that it addresses the same in the specific context of irrigation and water supply and sanitation, with empirical studies both at the national, provincial and local levels with case studies. In addition, practical and policy interventions are suggested to reduce the stresses induced by climate extremes on irrigation and domestic water supply and on the socioeconomic system.

We are sure that researchers working on climate impacts on water, practitioners working on climate adaptation and climate resilience in irrigation and WASH, and policy makers working on climate actions in the water sector would find this volume useful.

Hyderabad, Telangana, India  
Mumbai, Maharashtra, India  
Jaipur, Rajasthan, India  
New Delhi, Delhi, India

M. Dinesh Kumar  
Yusuf Kabir  
Rushabh Hemani  
Nitin Bassi

# Acknowledgement

First of all, the editors of this volume would like to thank Prof. Rathinasamy Maria Saleth, one of the esteemed members of the editorial board of Global Water Policy Series of Springer who has been a friend and philosopher of the lead editor of this volume. It was because of the strong encouragement and continued persuasion from Prof. Saleth that we decided to prepare and submit a proposal for an edited volume to the series editor Prof. Arial Dinar sometime during the last year.

The initial proposal for the book had undergone several changes based on two rounds of review by the members of the editorial board, whose comments and suggestions had immensely helped improve the richness of the contents and focus of this volume. The contents proposed initially for the volume were more of empirical research on the impact of climate variability on water supply and sanitation in India. This has changed to accommodate more work on irrigation, and focus on policy aspects have been strengthened. The editors would like to express a deep sense of gratitude to all the members of the editorial board of the series for their valuable comments.

Special thanks are due to Prof. Arial Dinar who was very supportive of the idea of having a book from India on the theme.

We would also like to profusely thank Ms. Rajeshwari Chandrasekar and Ms. Isabelle Bardem, the heads of UNICEF field offices in Mumbai and Jaipur, respectively, who had not only permitted their colleagues, Yusuf Kabir and Rushabh Hemani, to be co-editors of this volume, but also encouraged their other colleagues to contribute chapters based on the outputs of the research their offices had supported on climate variability and WASH (water supply and sanitation and hygiene) to the volume.



Lastly, we would also like to express our deep sense of gratitude to Dr. Saurabh Kumar and Mr. Ajath Sanjeev of the Institute for Resource Analysis and Policy for their great assistance to bringing this volume to fruition. They helped in obtaining high-quality versions of several of the maps used in this volume. They also worked hard to check, correct and format the references of individual chapters.

M. Dinesh Kumar  
Yusuf Kabir  
Rushabh Hemani  
Nitin Bassi

# Contents

<b>1</b>	<b>Climate Risks for Irrigation, Water Supply and Sanitation in India: Overview and Synthesis . . . . .</b>	<b>1</b>
	M. Dinesh Kumar, Yusuf Kabir, Rushabh Hemani, and Nitin Bassi	
<b>2</b>	<b>Climate Variability and Its Implications for Water Management in India . . . . .</b>	<b>19</b>
	Vedantam Niranjan, M. Dinesh Kumar, and Nitin Bassi	
<b>3</b>	<b>Water Management Challenges of Climate Extremes: A Case Study of Adaptive Strategies and Management Options . . .</b>	<b>45</b>
	M. Dinesh Kumar and Nitin Bassi	
<b>4</b>	<b>Managing Climate-Induced Water Risks: A Case Study of Institutional Alternatives . . . . .</b>	<b>91</b>
	M. Dinesh Kumar and Nitin Bassi	
<b>5</b>	<b>Planning for Water Resources Management Under Climatic Extremes: The Case Study of a Hyper-Arid Region . . . . .</b>	<b>123</b>
	M. Dinesh Kumar, A. J. James, and Nitin Bassi	
<b>6</b>	<b>Planning of Rural Water Supply Systems: Role of Climatic Factors and Other Considerations . . . . .</b>	<b>161</b>
	Nitin Bassi, Yusuf Kabir, and Anand Ghodke	
<b>7</b>	<b>A Framework for Assessing Climate-Induced Risk for Water Supply, Sanitation and Hygiene . . . . .</b>	<b>179</b>
	M. Dinesh Kumar, Arijit Ganguly, Yusuf Kabir, and Omkar Khare	
<b>8</b>	<b>Mapping Climate-Induced Risk for Water Supply, Sanitation and Hygiene in Maharashtra . . . . .</b>	<b>209</b>
	Arijit Ganguly, Yusuf Kabir, Omkar Khare, and Anand Ghodke	

<b>9</b>	<b>Predictions of Disease Spikes Induced by Climate Variability: A Pilot Real Time Forecasting Model Project from Maharashtra, India . . . . .</b>	<b>229</b>
	Sujata Saunik, Pratip Shil, Subrata N. Das, Sangita P. Rajankar, Omkar Khare, Krishna A. Hosalikar, and Yusuf Kabir	
<b>10</b>	<b>Mapping Climate-Induced Risk for Water Supply, Sanitation and Hygiene in Rajasthan . . . . .</b>	<b>241</b>
	Rushabh Hemani, Nitin Bassi, M. Dinesh Kumar, and Urvashi Chandra	
<b>11</b>	<b>Action Plans for Building Climate-Resilient Water Supply and Sanitation Systems: Results from Case Studies . . . . .</b>	<b>287</b>
	Nitin Bassi, Rushabh Hemani, and Prasoon Mankad	
<b>12</b>	<b>Managing Climate-Induced Water Stress Across the Agro-Ecological Regions of India: Options and Strategies . . . . .</b>	<b>313</b>
	M. Dinesh Kumar, Nitin Bassi, Rushabh Hemani, and Yusuf Kabir	
<b>13</b>	<b>Conclusions and Areas for Future Research . . . . .</b>	<b>355</b>
	M. Dinesh Kumar, Yusuf Kabir, Rushabh Hemani, and Nitin Bassi	
	<b>Index . . . . .</b>	<b>369</b>

# Contributors

**Nitin Bassi** Institute for Resource Analysis and Policy (IRAP), Liaison Office, New Delhi, India

**Urvashi Chandra** UNICEF, Lucknow, Uttar Pradesh, India

**Subrata N. Das** Maharashtra Remote Sensing Application Centre, Nagpur, Maharashtra, India

**Arijit Ganguly** PwC India, Kolkata, West Bengal, India

**Anand Ghodke** UNICEF Field Office for Maharashtra, Mumbai, India

**Rushabh Hemani** UNICEF, Jaipur Field Office, Jaipur, Rajasthan, India

**Krishna A. Hosalikar** Regional Meteorological Centre (RMC), Mumbai, Maharashtra, India

**A. J. James** Consultant, Natural Resource Economics, Cochin, Kerala, India

**Yusuf Kabir** UNICEF Mumbai Field Office, Mumbai, Maharashtra, India

**Omkar Khare** UNICEF Field Office for Maharashtra, Mumbai, India

**M. Dinesh Kumar** Institute for Resource Analysis & Policy, Hyderabad, Telangana, India

**Prasoon Mankad** UNICEF Rajasthan State Office, Jaipur, India

**Vedantam Niranjana** Freelancer (Environment Specialist), Hyderabad, Telangana, India

**Sangita P. Rajankar** Maharashtra Remote Sensing Application Centre, Nagpur, Maharashtra, India

**Sujata Saunik** Skill Development & Entrepreneurship Department, Government of Maharashtra, Mumbai, Maharashtra, India

**Pratip Shil** ICMR-National Institute of Virology, Pune, Maharashtra, India

## About the Editors

**M. Dinesh Kumar** did his B-Tech in Civil Engineering in 1988, M. E. in Water Resources Management in 1991 and Ph. D in Water Management in 2006. He has 30 years of experience in the field of water resources. He is the Executive Director of the Institute for Resource Analysis and Policy in Hyderabad since 2008. He has offered consultancy services to many international agencies, including the World Bank (India and Sri Lanka offices), Asian Development Bank (ADB), US AID, Australian Council for International Agricultural Research (ACIAR), UNICEF; international consulting firms such as Deltares (Holland) and Sheladia Associates (US), and many Indian government agencies (in Gujarat, Maharashtra, Andhra Pradesh and Kerala).

He has nearly 200 publications to his credit, including seven books, seven edited volumes, several book chapters, and many journal articles. He has published in many international peer-reviewed journals viz., *Water Policy*, *Energy Policy*, *Water International*, *Journal of Hydrology*, *Water Resources Management*, *Int. Journal of WRD* and *Water Economics and Policy*. He is currently also Associate Editor of *Water Policy* and Member of the Editorial Board of *Int. Journal of WRD*. His research works of global relevance are: integrated water resources management in river basins; water use efficiency and water productivity in agriculture; global virtual water trade; methodology for assessing global water & food security challenges; climate risk in WASH; and socio-economic impacts of large water systems.

**Yusuf Kabir's** areas of specialization are Rural Drinking Water Supply and Sanitation, Environment, Climate Change Adaptations, and Sustainable Development. He has two post-graduate degrees and had attended several International certificate courses. His first master's degree is in Environment Engineering and Management from India's premier management Institute: Indian Institute of Social Welfare and Business Management (IISWBM), and the second one is in Sustainable Development from Staffordshire University, U.K. Yusuf is a Commonwealth scholar. He has several publications in International Journals, Papers, and Books on water and sanitation issues and State Level Committee Members of different state bodies and knowledge management platforms of CSR.

He is working in the Water, Sanitation and Environment sector for the last 20 years. He is with UNICEF India since 2007. Prior to that he worked with organizations like DFID, National Level NGOs, Social and Marketing research consultancy firms like GFK-MODE, ORG India Pvt Ltd. He is a commonwealth scholar and a trained policy writer from Central European University, Budapest, Hungary where he had undergone a summer course on 'Evidence-Based Policy Formulation'. He runs a blog on Sanitation in the name of WASH Garage: Blog: <http://safaiwala.blogspot.in/>

**Rushabh Hemani** is a development professional with over fifteen years of comprehensive work experience in the field of Water, Sanitation and Hygiene (WASH). He is currently working as WASH Specialist in UNICEF Rajasthan state Office and has also worked in Gujarat, Chhattisgarh and Assam Offices of UNICEF in India. His core area of work in UNICEF includes water safety and security, climate-resilient WASH pilot, reducing open defecation, WASH in schools, pre-schools, health centers as well as social and behavior change communication. He has worked across several partners including Government, civil society organizations, academic institutions, and other development partners. He has been actively engaged in the development of various knowledge management products including process documentation, monograph and technical papers on issues concerning WASH. Some of his work has been published as journal papers and also a chapter in a book.

**Nitin Bassi** is a Natural Resource Management specialist (M. Phil) having nearly 13 years of experience undertaking research, consultancy, and training in the field of water resource management. Presently, he works as a Principal Researcher with the Institute for Resource Analysis and Policy (IRAP) and is based at their Liaison Office in New Delhi. His areas of work include River Basin and Catchment Assessment, Water Accounting, Institutional and Policy Analysis in Irrigation and Water Supply Management, Water Quality Analysis, Climate Variability, and Climate-induced Water Risk Analysis and Wetland Management. He has been engaged as a consultant/specialist in projects, research studies, and assignments supported by various national and international organizations. Some of these organizations include European Commission, World Bank, GIZ, DFID, WRG 2030/IFC, UNICEF, WWF, IWMI, SRTT, and SDTT.

He was involved as one of the specialists for establishing the first phase of the 'India-EU Water Partnership' between EU and Ministry of Water Resources, River Development & Ganga Rejuvenation (MoWR, RD & GR), Government of India. In its second phase, he is engaged as one of the specialists for providing advisory services for the EU/BMZ co-financed action on 'Development and implementation support to the India-EU Water Partnership (IEWP)' and 'Support to Ganga Rejuvenation (SGR)'.

He has co-edited two books that were published by Routledge UK, and has several book chapters, and peer-reviewed journal articles. Also, he regularly reviews manuscripts for Water Policy; International Journal of Water Resources Development; Journal of Hydrology; and Journal of Hydrology: Regional Studies.

# List of Figures

Fig. 2.1	Spatial variation in rainfall of India. (Source: Kumar 2010 (Based on Pisharoty 1990)) .....	25
Fig. 2.2	Monthly mean rainfall and temperature in India (1900–2009). (Source: Authors’ analysis based on World Bank data) .....	26
Fig. 2.3	Spatial variation in coefficient of variation in annual rainfall of India. (Source: Kumar 2010 (Based on Pisharoty 1990)) .....	27
Fig. 2.4	Average relative humidity in India. (Source: Atlas of the Biosphere, Center for Sustainability and the Global Environment, University of Wisconsin, Madison) .....	29
Fig. 2.5	Relative humidity and wind speed–Aurangabad (2009–2010). (Source: Authors’ analysis using India Meteorological Department (IMD) data set) .....	30
Fig. 2.6	Temperature and rainfall of Aurangabad (2009–2010). (Source: Authors’ analysis using India Meteorological Department (IMD) data set) .....	31
Fig. 2.7	Wind speed–Aurangabad (2009–2010). (Source: Authors’ analysis using India Meteorological Department (IMD) data set) .....	33
Fig. 2.8	Variation in solar radiation in India. (Source: India solar resources maps ( <a href="http://www.mnre.gov.in/sec/solar-assmnt.htm">http://www.mnre.gov.in/sec/solar-assmnt.htm</a> ) developed by the US national renewable energy laboratory in cooperation with ministry of new and renewable energy, Government of India) .....	35
Fig. 2.9	Variation in potential evaporation in India. (Source: Kumar 2010) .....	37
Fig. 3.1	Estimated stream-flows upstream of Hirakud reservoir in Chhattisgarh. (Source: Authors’ estimate based on the CWC data) .....	52
Fig. 3.2	Total estimated monsoon and non-monsoon flows in Mahanadi upstream of Hirakud reservoir. (Source: Authors’ estimate based on the CWC data) .....	53

Fig. 3.3	Rainfall-runoff relationship, Andhiyarkore. (Source: Authors' analysis based on the data from the Chhattisgarh State Water Data Centre) .....	55
Fig. 3.4	Rainfall-runoff relationship, Kurubhata. (Source: Authors' analysis based on the data from the Chhattisgarh State Water Data Centre) .....	55
Fig. 3.5	Average monsoon water level fluctuations (1996–2014) in MMB across observation wells. (Source: Authors' analysis using the Central Ground Water Board (CGWB) data set) .....	60
Fig. 3.6	Average water level fluctuation in MMB during monsoon across years (1999–2014). (Source: Authors' estimates using the Central Ground Water Board (CGWB) data set) .....	60
Fig. 3.7	Water level fluctuation during monsoon vs pre-monsoon depth t water level: Patsenduri. (Source: Authors' analysis using the Central Ground Water Board (CGWB) data set) .....	62
Fig. 3.8	Long-term change in water levels in observation wells in mid Mahanadi basin: 1996–2014. (Source: Authors' estimates using the Central Ground Water Board (CGWB) data set) .....	62
Fig. 3.9	Long-term average (1996–2014) of water level fluctuation in UMB during monsoon in different observation wells. (Source: Authors' analysis using the Central Ground Water Board (CGWB) data set) .....	64
Fig. 3.10	Average water level fluctuations in observation wells during monsoon in UMB: 1996–2014. (Source: Authors' estimates using the Central Ground Water Board (CGWB) data set) .....	64
Fig. 3.11	Long-term change in pre-monsoon water levels in different ob. wells (1996–2014). (Source: Authors' estimates using the Central Ground Water Board (CGWB) data set) .....	65
Fig. 3.12	Monsoon water level fluctuation vs pre-monsoon water levels: Abhanpur. (Source: Authors' analysis using the Central Ground Water Board (CGWB) data set) .....	66
Fig. 3.13	Rainfall trend indicated by point rainfall in Chhattisgarh. (Source: Authors' analysis based on the data from the Chhattisgarh State Water Data Centre) .....	69
Fig. 3.14	Rainy days indicated by point rainfall in Chhattisgarh. (Source: Authors' analysis based on the data from the Chhattisgarh State Water Data Centre) .....	69
Fig. 3.15	Duration of monsoon as recorded in Admabad Tandula. (Source: Authors' analysis based on the data from the Chhattisgarh State Water Data Centre) .....	69
Fig. 3.16	Duration of monsoon as recorded in Dararikorba. (Source: Authors' analysis based on the data from the Chhattisgarh State Water Data Centre) .....	70



Fig. 3.17	Duration of monsoon over Khutaghat. (Source: Authors' analysis based on the data from the Chhattisgarh State Water Data Centre) .....	70
Fig. 3.18	Cropping and irrigation pattern in Chhattisgarh, Mahanadi basin. (Source: Authors' estimates based on the data from the Directorate of Economics and Statistics, Government of India) .	72
Fig. 3.19	Irrigation intensity vs canal irrigation. (Source: Authors' analysis based on the data from the Directorate of Economics and Statistics, Government of India) .....	73
Fig. 3.20	WEAP estimated outflows from Chhattisgarh part of Mahanadi river basin. (Source: Authors' estimates based on the WEAP model results) .....	83
Fig. 4.1	Institutional arrangements for water management in Mahanadi river basinSource: Based on Authors' own analysis .....	117
Fig. 5.1	Observed streamflows at Gandhav, Luni river basin (1970–71 to 2009–10). (Source: Authors' estimates using CWC data) .....	127
Fig. 5.2	Weighted average annual rainfall: Luni river basin (1957–2012). (Source: Authors' estimates based on data from the Rajasthan Water Resources Department) .....	133
Fig. 5.3	Rainfall-runoff relationship for Luni river basin (1971–2010). (Source: Authors' analysis based on data from the Rajasthan Water Resources Department) .....	134
Fig. 5.4	Reference evapotranspiration for two locations in Luni river basin. (Source: Authors' own estimates) .....	136
Fig. 6.1	Access to piped water across the income distribution in India. (Source: Based on data presented in Jalan and Ravallion 2003)	166
Fig. 6.2	Volume of water required for hydration. (Source: Based on data presented in Howard and Bartram 2003) .....	169
Fig. 8.1	Map (not to scale) showing different regions of Maharashtra state. (Map Source: IndiaSpend) .....	211
Fig. 8.2	Climate-induced risk in water, sanitation and hygiene (WASH) in Marathwada region, Maharashtra. (Source: Authors' estimates based on computed index values) .....	214
Fig. 8.3	Climate-induced risk in water, sanitation and hygiene (WASH) in Vidarbha region, Maharashtra. (Source: Authors' estimates based on computed index values) .....	214
Fig. 8.4	Climate-induced risk in water, sanitation and hygiene (WASH) in Marathwada region, Maharashtra. (Source: Authors' estimates based on computed index values) .....	215
Fig. 8.5	Climate-induced risk in water, sanitation and hygiene (WASH) in Vidarbha region, Maharashtra. (Source: Authors' estimates based on computed index values) .....	215

Fig. 8.6	Map showing extent of hazard in the districts of Marathwada and Vidarbha region. (Source: Prepared by authors using computed index values) .....	217
Fig. 8.7	Map showing extent of exposure in the districts of Marathwada and Vidarbha region. (Source: Prepared by authors using computed index values) .....	218
Fig. 8.8	Map showing degree of vulnerability in the districts of Marathwada and Vidarbha region. (Source: Prepared by authors using computed index values) .....	219
Fig. 9.1	(a) Disease cases reported. (b) Weather parameters. (c) GIS representation of the cases count. (d) Sanitation data representation. (Source: MRSAC, Government of Maharashtra)	233
Fig. 9.2	(a) Dengue occurrences and meteorological parameters in Nagpur district. (b) Actual number of dengue cases ( <b>D</b> ) and Estimated number of cases ( <b>estD</b> ) from the Poisson regression model. Time period covered 2012–2015. (Source: Authors' own analysis) .....	235
Fig. 10.1	Sources of drinking water in different divisions of rural Rajasthan. (Source: Census India 2011) .....	247
Fig. 10.2	Sources of drinking water—comparisons between western and eastern rural areas of Rajasthan. (Source: Authors' estimates based on Census India 2011) .....	247
Fig. 10.3	Access to water supply in different divisions of rural Rajasthan. (Source: Census India 2011) .....	248
Fig. 10.4	Physical access to water supply sources in eastern and western parts of rural areas of Rajasthan. (Source: Census of India 2011) .....	248
Fig. 10.5	Types of sanitation facility in different divisions of rural areas of Rajasthan. (Source: Census of India 2011) .....	249
Fig. 10.6	Comparison of types of sanitation—eastern and western rural areas of Rajasthan. (Source: Authors' estimates based on Census of India 2011) .....	250
Fig. 10.7	Per capita renewable water availability in different river basins of Rajasthan. (Source: UNICEF Rajasthan and Institute for Resource Analysis and Policy 2017) .....	255
Fig. 10.8	WASH hazard sub-index. (Source: Authors' analysis using the computed index values) .....	274
Fig. 10.9	WASH system exposure sub-index. (Source: Authors' analysis using the computed index values) .....	274
Fig. 10.10	Vulnerability sub-index. (Source: Authors' analysis using the computed index values) .....	275
Fig. 10.11	Climate risk index. (Source: Authors' analysis using the computed index values) .....	275
Fig. 10.12	The three dimensions of risk in Rajasthan. (Source: Authors' analysis using the computed index values) .....	276

Fig. 10.13	Water-related diseases versus climate risk index in WASH. (Source: Authors' own analysis) .....	281
Fig. 11.1	Map showing the location of Rajasthan and its different divisions and districts. (Source: Institute for Resource Analysis and Policy) .....	290
Fig. 11.2	Mean monthly rainfall of Barmer District (2006–2010). (Source: Authors' analysis based on data from Water Resources Department, Government of Rajasthan) .....	293
Fig. 11.3	Blockwise HHs access to drinking water sources in rural areas of Barmer District. (Source: Authors' analysis based on Census of India 2011a) .....	295
Fig. 11.4	Blockwise access to sanitation facilities within the HH premises in rural areas of Barmer District. (Source: Authors' analysis based on Census of India 2011a) .....	295
Fig. 11.5	Blockwise HHs access to drinking water sources in rural areas of Sirohi District. (Source: Authors' analysis based on Census of India 2011b) .....	297
Fig. 11.6	Blockwise access to sanitation facilities within the HH premises in rural areas of Sirohi District. (Source: Authors' analysis based on Census of India 2011b) .....	298
Fig. 12.1	River basins of India. (Source: CWC, Government of India) ....	316
Fig. 12.2	Average rainfall and runoff rates of major river basins of India. (Source: CWC, Government of India) .....	318
Fig. 12.3	Geohydrology of India. (Source: CGWB, Government of India)	319
Fig. 12.4	Topography of India. (Source: CWC and NRSC, Government of India) .....	321
Fig. 12.5	Households' access to tap water in India (%): state-wise. (Source: Based on Census of India 2011) .....	327
Fig. 12.6	Live storage of large dams in major Indian states (billion cubic metre). (Source: Authors' analysis based on data from the CWC, Government of India) .....	328
Fig. 12.7	Map of Godavari river basin. (Source: CWC and NRSC 2014) .	330
Fig. 12.8	Map of Karnataka showing major river basins. (Source: Water Resources Department, Government of Karnataka) .....	332
Fig. 12.9	Map of Tamil Nadu showing the major river basins. (Source: Water Resources Department, Government of Tamil Nadu) ....	333

# List of Maps and Diagram

Map 3.1	Drainage-basins of Mahanadi river. (Source: CWC and NRSC 2014) .....	48
Map 3.2	Mahanadi basin showing major water systems. (Source: CWC and NRSC 2014) .....	50
Map 3.3	Showing the aquifer systems of Chhattisgarh, with Mahanadi basin boundary. (Source: CGWB, North Central Chhattisgarh Region, 2012) .....	57
Map 3.4	Location of groundwater observation wells in middle Mahanadi basin (only wells in Chhattisgarh portion were considered for analysis). (Source: CWC and NRSC 2014) ....	58
Map 3.5	Location of groundwater observation wells in Upper Mahanadi basin. (Source: CWC and NRSC 2014) .....	63
Map 10.1	Rainfall in different districts of Rajasthan. (Source: UNICEF Rajasthan and Institute for Resource Analysis and Policy 2017) .....	252
Map 10.2	Distribution of soils. (Source: UNICEF Rajasthan and Institute for Resource Analysis and Policy 2017) .....	253
Map 10.3	Physiography and drainage of Rajasthan. (Source: UNICEF Rajasthan and Institute for Resource Analysis and Policy 2017) .....	254
Map 10.4	Geo-hydrological map of Rajasthan. (Source: UNICEF Rajasthan and Institute for Resource Analysis and Policy 2017) .....	256
Map 10.5	Groundwater salinity-affected areas in Rajasthan. (Source: Ground Water Department, Government of Rajasthan) .....	258
Map 10.6	Fluoride-affected areas in Rajasthan. (Source: Ground Water Department, Government of Rajasthan) .....	258

Map 10.7	Frequency of occurrence of droughts in different districts of Rajasthan. (Source: Disaster Management, Relief & Civil Defence Department, Government of Rajasthan) .....	259
Map 10.8	Variation in population density across Rajasthan districts. (Source: Institute for Resource Analysis and Policy (IRAP)) .	262
Map 10.9	Variation in climate hazards (having implications for WASH) across districts of Rajasthan. (Source: Prepared by Authors' using computed index values) .....	276
Map 10.10	Variation in exposure of the WASH systems to climate hazards across districts of Rajasthan. (Source: Prepared by Authors' using computed index values) .....	277
Map 10.11	Variation in vulnerability to climate hazards. (Source: Prepared by Authors' using computed index values) .....	277
Map 10.12	Variation in climate risk in WASH across districts of Rajasthan. (Source: Prepared by Authors' using computed index values) .....	278
Map 12.1	Showing depth to groundwater level. (Source: CGWB, Government of India) .....	323
Map 12.2	Showing EC in micro siemens/cm at 25° C. (Source: CGWB 2010) .....	324
Map 12.3	Showing % blocks in the districts reported excessive fluorides in groundwater. (Source: CGWB 2010) .....	325
Map 12.4	Showing percentage of blocks affected by arsenic in groundwater. (Source: CGWB 2010) .....	326
Diagram 3.1	WEAP configuration for Chhattisgarh part of Mahanadi river basin. (Source: Model configured by the Authors) .....	78
Plate 5.1	Drainage map of Luni Basin, western Rajasthan (Area: 69,000 km <sup>2</sup> ). (Source: Study on Planning of Water Resources of Rajasthan, Draft Final report submitted to SWRPD, GoR, Tahal Consultants, December 2013) .....	125

# List of Tables

Table 2.1	Rainfall variability regimes of selected Indian states .....	28
Table 2.2	Characteristics of relative humidity. (Location: Aurangabad, Maharashtra, India) .....	30
Table 2.3	Characteristics of temperature (location: Aurangabad, Maharashtra) .....	32
Table 2.4	Peak sunlight hours in different regions of India .....	36
Table 3.1	Inter-annual variation in stream-flow .....	51
Table 3.2	Rainfall-runoff models for the four selected catchments .....	56
Table 3.3	Area under different geological formations in Mahanadi basin drainage area of Chhattisgarh .....	56
Table 3.4	Analysis of point rainfall of seven locations in Chhattisgarh part of Mahanadi basin .....	67
Table 3.5	Analysis of data of rainy days of seven rain gauge stations in Chhattisgarh part of Mahanadi basin .....	68
Table 3.6	Gross and live storage capacity of major reservoir projects in Chhattisgarh part of Mahanadi river basin (capacity exceeding 100 MCM) .....	71
Table 3.7	Estimated irrigation water use rates for different crops in Chhattisgarh part of Mahanadi river basin .....	76
Table 3.8	Past growth trends in rural and urban population and projected growth in population in Chhattisgarh part of Mahanadi river basin .....	77
Table 3.9	Overall water demand, water supply requirement and actual water supply under different scenarios in Chhattisgarh part of Mahanadi river basin as estimated by the WEAP model .....	80
Table 3.10	Streamflow under different scenarios in Chhattisgarh part of Mahanadi river basin as estimated by the WEAP model .....	81
Table 3.11	Water balance during drought years (drought scenario) in Chhattisgarh part of Mahanadi river basin as estimated by the WEAP model .....	82

Table 4.1	Gauging stations maintained by the central agencies in the Chhattisgarh part of Mahanadi river basin .....	94
Table 4.2	Gauging stations maintained by the state agencies in the Chhattisgarh part of Mahanadi river basin .....	95
Table 4.3	Scheme-wise coverage of rural water supply estimated for the Chhattisgarh part of Mahanadi river basin .....	104
Table 5.1	Groundwater resources in Luni river basin .....	129
Table 5.2	Imported water in Luni river basin .....	135
Table 5.3	Estimated monthly potential evaporation values for two locations in Luni river basin .....	137
Table 5.4	Estimated consumptive water use in irrigation in Luni river basin .....	139
Table 5.5	Crop water demand, Pali district, 2011–12 .....	145
Table 5.6	Indicative water requirements for different types of livestock . .	147
Table 5.7	Current and projected sectoral water demands (MCM) .....	149
Table 5.8	Block-wise estimates of static and dynamic groundwater resources of Pali (2005–09) .....	152
Table 5.9	Available water supplies from surface and underground sources	154
Table 5.10	Agricultural water demand and water availability, Pali district, 2011–12 (MCM) .....	154
Table 5.11	Potential impact of drip irrigation on row crops in Pali district (100% coverage): 2011–12 .....	155
Table 5.12	Impact of plastic mulching on rain-fed crops in Pali district (2011–12) .....	155
Table 5.13	Water management scenarios for the district: 2011–25 .....	156
Table 6.1	Water use by rural households (lpcd) in developing countries in relation to access to water supply .....	170
Table 6.2	Drinking water requirement for animals in different livestock production systems .....	171
Table 6.3	Voluntary water intake of livestock under different climatic conditions .....	172
Table 6.4	Household domestic and productive water needs as estimated for different climates, activity levels and diet requirements .....	173
Table 7.1	Identified factors influencing climate-induced risk in rural water and sanitation .....	193
Table 7.2	Matrix for computing the values of various Indices for assessing the climate-induced risk in water and sanitation in Maharashtra .....	199
Table 8.1	Proposed financial provision for drinking water sector in Maharashtra .....	220

Table 10.1	Number of villages covered by different types of water supply schemes (as on 2011) .....	245
Table 10.2	Types of household access to water supply in rural and urban areas (as on 2011) .....	246
Table 10.3	Percentage of household by availability of toilet connectivity in Rajasthan .....	249
Table 10.4	Population of different types of livestock in Rajasthan .....	264
Table 10.5	Norms on per capita water supply per day as per PHED, Rajasthan .....	265
Table 10.6	Identified factors influencing climate-induced risk in rural water and sanitation .....	268
Table 10.7	Computed values of WASH risk index and sub-indices .....	272
Table 10.8	Public health impacts of disruptions in WASH caused by climate extremes in Rajasthan .....	279
Table 10.9	Frequency analysis of climate risk in WASH and occurrence of water-related diseases .....	281
Table 11.1	Blockwise status of groundwater resources (2009) in Barmer District .....	294
Table 11.2	Blockwise groundwater resources (2009) in Sirohi .....	297
Table 11.3	Block-specific suggested interventions for climate-resilient water supply infrastructure in Barmer and Sirohi .....	306



# Chapter 1

## Climate Risks for Irrigation, Water Supply and Sanitation in India: Overview and Synthesis



M. Dinesh Kumar, Yusuf Kabir, Rushabh Hemani, and Nitin Bassi

**Abstract** This chapter will provide the overall context and setting for the volume. Based on available empirical data, it will discuss the issue of variability in rainfall and other climatic parameters in India. It will illustrate the need for assessing the impact of climate variability on water resources, by discussing its implications for the design of water management systems vis-à-vis the stress they induce on water flows and alterations they affect in the demand for water in various sectors, including domestic sector. It will also discuss the need for assessing the climate-induced risk in WASH (water, sanitation, and hygiene systems), particularly due to extreme climatic conditions and events, for designing water supply and sanitation systems that are climate-resilient, risk informed and sustainable. The chapter will also present the objectives and scope of the book, and the outline of individual chapters.

**Keywords** Climate variability · Water resources · Water management systems · Climate-induced risk · Climate-resilient WASH

---

M. Dinesh Kumar (✉)  
Institute for Resource Analysis & Policy, Hyderabad, Telangana, India  
e-mail: [dinesh@irapindia.org](mailto:dinesh@irapindia.org)

Y. Kabir  
UNICEF Mumbai Field Office, Mumbai, Maharashtra, India  
e-mail: [ykabir@unicef.org](mailto:ykabir@unicef.org)

R. Hemani  
UNICEF, Jaipur Field Office, Jaipur, Rajasthan, India  
e-mail: [rhemani@unicef.org](mailto:rhemani@unicef.org)

N. Bassi  
Institute for Resource Analysis and Policy (IRAP), Liaison Office, New Delhi, India

## 1.1 Context

The last nearly one and half decades have witnessed a great deal of enthusiasm among climate researchers from all over the world to work on climate change issues, particularly in the Asia Pacific region. It has its origin in the strong belief based on limited evidence to the effect that the global climate is undergoing unprecedented changes, which went unnoticed in the recorded human history, in terms of change in temperature. The monsoon weather system of the Asia-Pacific region, which is a complex system and not so easily amenable to predictions by weather forecasting models, and which has significant implications for India's climate, has also been a subject of scientific inquiry in the recent past to know what would be the impact of climate change on it. Understanding the cause of monsoon is crucial to deepening our understanding of how monsoon in India would change as a result of larger changes occurring in global and regional climate. There are contesting theories about the cause of Monsoon. Halley (1753) suggested that the primary cause of the monsoon was the differential heating between the ocean and land. This is still considered as the basic mechanism for the monsoon by several scientists (e.g. Webster 1987). In an alternative hypothesis, monsoon is considered as a manifestation of the seasonal migration of the inter-tropical convergence zone (Charney 1967). The two hypotheses have very different implications for the variability of the monsoon (Gadgil 2003).

Nevertheless, the Indian sub-continent and the ocean surrounding it is at the centre of the monsoon region (Gadgil 2003). Indian Monsoon has been a subject of intensive study for the spatial and temporal (season and annual) variations (Gadgil 2003; Pisharoty 1990). Though climate modellers have used both Global Circulation Models (GCMs) and Regional Climate Models or Regional Circulation Models (RCMs) to predict changes in monsoon precipitation for different scenarios of temperature change, the 'scientific accuracy' or robustness of such models have been a subject of debate among climate scientists in India and elsewhere. The underlying concern has been that 'how the temporal variability that exists in monsoon precipitation in different regions and the precipitation variation across space get captured in the 'climate simulation models', and how far the model predictions address these key characteristics of Indian monsoon'. 'Climate variability' has significant implications for the way climate change predictions need to be made for the sub-continent. An understanding of 'climate variability' and its impact on hydrological systems would also help understand the likely impact of the change in climate over time on the hydrological system and water resources. Unfortunately, these concerns were very narrowly addressed by the advocates of climate change, with the key contention being the increase in variability in precipitation with a greater frequency of extreme events such as floods and droughts. Much less is known about the impact that these hydrological stresses will have on the performance of irrigation systems, and on the communities in terms of risk in water, sanitation, and hygiene (WASH). That said, the rainfall and climatic variables (solar radiation, relative humidity, wind speed, and temperature) in India display

remarkable spatial and temporal variation. The temporal variation includes not only inter-annual and inter-seasonal but also intra-day variations.

### ***1.1.1 Rainfall Variability in India***

India receives precipitation from two sources, viz., rainfall and snowfall. But rainfall is the major source of precipitation in terms of the geographical area which benefits from it, and also the total quantum of water produced from the precipitation. Snowfall occurs only in the Himalayas during the winter season and benefits the hydrological system through the snow-fed rivers viz., Ganges, and the Indus which originate from the Himalayas. However, in this note, we would discuss the rainfall which occurs in different parts of the Indian sub-continent.

Pisharoty (1990) discussed the characteristics of the Indian monsoon, particularly the spatial and temporal variations in the rainfall, and the rainy days, and spatial variation in potential evaporation. Analysis shows that Gujarat and Rajasthan have 11% and 42% area, respectively, experiencing extremely low rainfalls (< 300 mm); and 39 and 32%, respectively under low rainfall (300–600 mm). The other states by and large fall in the medium rainfall (600–1000 mm) and high rainfall (1000–1500 mm) regimes. In the case of Maharashtra, MP, AP, Karnataka and Tamil Nadu, a lion's share (85% and above) falls in medium rainfall regime, and in the case of Orissa and Chhattisgarh, 45 and 40%, respectively fall in high rainfall regime.

The Indian monsoon is characterized by significant inter-annual variability and more or less follows a cyclic pattern of high and low rainfall. Analysis shows that the year to year variation in annual rainfall is high in regions of low rainfall and low in regions of high rainfall. In regions such as western Rajasthan and Kachchh, the coefficient of variation in the rainfall is as high as 50% and above. In the north eastern region and in the Western Ghats region, the coefficient of variation in rainfall is very low, meaning high dependability. The Indian monsoon is also known for its erratic nature, for many regions. The regions which receive fewer days of rain coincide with those experiencing low rainfall and high evaporation and high variability in rainfall. The regions which experience many wet days coincide with those which experience high and reliable rainfall.

### ***1.1.2 Temporal Variability in India's Climate***

Climate is the net effect of the interplay of precipitation, humidity, temperature of the atmosphere, winds (speed) and rainfall. Atmospheric temperature and temperature on the surface of the earth is the effect of solar radiation. Besides rainfall, the other climate parameters also vary from region to region, influenced by their geographic

positioning with respect to oceans, mountains, desert, and the latitude and longitude, and would change with change in seasons, that is, rainy season, winter and summer.

Humidity is a measure of the amount of vapour in the air, and is measured in terms of the vapour pressure of the air. While humidity itself is a climate variable, it also interacts strongly with other climate variables. The humidity is affected by winds and by rainfall. At the same time, humidity affects the energy budget and controls the movement of vapour from the surface of water bodies and transpiration from plants—the former affecting water supplies and the latter affecting water demands in agriculture.

Coastal areas are generally more humid than inland areas, so are the areas receiving higher rainfall over extended time periods. Normally, if the amount of moisture in the air remains the same, then an increase in temperature would reduce relative humidity as warmer air can hold more moisture than cold air. But, in humid tropics, an increase in temperature would also result in higher evaporation adding to the atmospheric vapour content, and hence there would be no reduction in relative humidity. Normally, in any region, the relative humidity in an area would increase during monsoon, though the variation would be much higher in hot climates.

Kumar (2018) reported the following points with regard to variation in humidity between two consecutive years, that is, 2009 and 2010: (1) the highest difference encountered in the relative humidity values between morning and evening of any day over the entire year during 2009 and 2010 is higher than the difference in relative humidity values for both morning and evening between the most humid day and the least humid day of the year; (2) relative humidity is excessively high in the range of 80–90% during the rainy season; and (3) the RH values for both morning and evening for the same day of the month can vary significantly between years.

### ***1.1.3 Spatial Variability in Climate***

Potential evaporation for a particular location is the net result of the solar radiation flux, wind speed and relative humidity experienced in that location and to a lesser extent the temperature, and is a strong indicator of the location's climate, along with rainfall. This parameter is extensively used in hydrology for estimating water losses from open reservoirs and water requirements for crop physiological processes. The variations in solar radiation, air temperature, wind speed and relative humidity across space in India ultimately result in significant variation in potential evaporation (PE). Lower rainfall, coupled with higher PE reduces the runoff potential and high evaporation from the impounded runoff, thereby increasing the dryness (Hurd et al. 1999).

Variation in these parameters with respect to space and time also results in significant variation in reference evapotranspiration values and therefore potential evapotranspiration (PET) for the same crop across regions and also within the same regions with time, respectively (Howell and Evett 2004).

A general pattern is encountered in the spatial variation of PE across India. Regions with relatively low rainfall are found to have higher potential evapotranspiration due to relatively low humidity, and a higher number of sunny days (Pisharoty 1990). Analysis of spatial data on mean annual rainfall and mean annual potential evaporation shows that regions which have very low rainfall are also the regions which experience very high evaporation and vice versa. The reason is these regions experience rainfall in very few rainy days, which increases the number of days of sunshine, increasing the temperature. The lower rainfall and prolonged days of sunshine also reduce the relative humidity. Both the factors together increase the annual evaporation rate.

## 1.2 Rationale for the Book

In the past couple of decades, researchers and academicians in the field of climate, water and agriculture in India have tried to predict future changes in India's climate at various scale from sub-continental level to regional level to basin level, using various assumptions about likely changes in temperature in the future and by using GCMs and RCMs. The most important predicted variable is the precipitation/rainfall. However, none of the climate models have tried to factor in variability in climate, particularly the inter-annual variability in temperature and rainfall in the model. The model predictions are based on average values, significantly reducing the utility of such predictions for regions that experience high variability in climate factors (Kumar and Rao 2012; van Oldenborgh et al. 2013). The reason is that many a time, the value of the predicted variable is less than the percentage change in the annual mean value of the variable that the region experiences between a dry year and a wet year. From a practical point of view, historically, many of the largest falls in crop productivity have been attributed to anomalously low precipitation events (Kumar et al. 2004; Sivakumar et al. 2005), and greater risks to food security may be posed by changes in year-to-year variability and extreme weather events (Gornall et al. 2010) and therefore knowing the magnitude of an extreme event is more important.

In the same way, the model predictions of the impact of climate change on water resources done at basin scales, have also failed to capture the impact of variability in precipitation and many other weather parameters on the hydrological processes and their outcomes, that is, streamflows and groundwater recharge, in the basin. Analysis of such complex processes calls for pragmatic approaches that suit the local specific context rather than using routine models that predict average conditions that never occur in the basin in a real-life situation.

From a purely utilitarian perspective, what one would like to know is the 'reference levels' to which these increase and reduction are likely to occur and how it would look like in dry and wet years (Kumar and Rao 2012). More importantly, from a water management perspective, capturing the current variations in the hydrological conditions in the basin and the stress that induces on the socioeconomic

system might appear to be more important than capturing the small changes in the precipitation and its consequences on basin yield and water supplies. Currently, there is too little clarity on how reduction or increase in rainfall due to climate change in different river basins would impact basin water availability and water supply situation on an annual basis. This would require a complex modelling exercise. This is attempted in the volume, through an assessment of the climate-induced threat to irrigation water supplies, climate-induced risk in WASH faced by communities, and the public health hazards associated with climate extremes. More importantly, climate change issues have been addressed in the literature only at the macro and national levels. But this volume addresses the same in the specific context of irrigation and water supply and sanitation, with empirical studies both at the national, provincial and local levels with case studies.

### ***1.2.1 Analyzing the Implications for Water Management Institutions***

When water flow varies and the demand for water change, water management strategies also have to change. The institutions dealing with water resources management and water supply provisions have to adapt to the changing situation with regard to water availability and water demands. In the same river basin, the interventions to deal with a drought situation will be different from the one adopted during a wet year when the flows are excessively high. Hence, the approach to water management has to change to give more emphasis to institutions and market instruments such as water rights, water allocation, water pricing, etc. than mere engineering interventions that focus on resource appropriation and distribution that remain largely static, as the rules and criteria concerning water rights, water allocation and water pricing can be changed depending on the situation. However, traditional water institutions are designed to deal with either water supply provisions or flood control.

### ***1.2.2 Implications of Regional Climate for Planning and Designing of WASH Systems***

Climate and environmental conditions can significantly impact the way water supply and sanitation systems perform in a region or locality. While climatic variability affects the availability of water that can be tapped for water supply provisioning, and the water ecology of a region, in rural areas climatic conditions also influence the demand for water for domestic and livestock uses and therefore can affect the performance of the WASH systems. The environmental conditions (climate, soils, geohydrology and rainfall) influence the way onsite sanitation systems