

International Conference on Climate, Water and Policy (ICCWP) 2012

Exploring Climate Application Series I

ICCWP Handbook

Busan, Republic of Korea
September 11-13, 2012



International Conference on Climate, Water and Policy (ICCWP) 2012:

Climate Information for Water Manager :
Opportunities and Challenges

Contents

Greeting Message	/ 03
ICCWP Organizers	/ 04
ICCWP Organizing Committee	/ 05
ICCWP Program	/ 06
Keynote Speakers	/ 09
Invited Speakers	/ 13
Abstract / Plenary Session	/ 21
Session I	/ 27
Session II	/ 51
Session III	/ 77
Session IV	/ 89
Poster Session	/ 103
Index of Posters	/ 154



Welcome Message

On behalf of the organizers, the APEC Climate Center (APCC) is delighted to welcome you to Busan, Republic of Korea, for the International Conference on Climate, Water and Policy (ICCWP) 2012. Through close collaboration with the Korea Meteorological Administration (KMA), the Australian Bureau of Meteorology (BoM), and the Korea Water Resources Corporation (K-Water), the APEC Climate Center has developed this conference to maximize the use of timely and well-designed climate information for decision-making in the water management context.

With various participants from over 20 different developed and developing countries to share their experiences and significant keynote and invited speaker presentations from climate scientists, hydrologists, water resources managers, and policy makers, the conference will provide a forum for presenting and discussing strategies for examining various modes of climate information applications with different time-scales in the water management context and how these are taken into account for water policy at the regional, national, and international levels.

ICCWP would not be possible without the strong support of our valuable partners, so we would like to offer our sincere thanks to all of our Organizing Committee members, the Korea Meteorological Administration (KMA), the Australian Bureau of Meteorology (BoM), and the Korea Water Resources Corporation (K-Water), as well as to all the speakers and participants.

We hope that you enjoy the conference.

Thank you.

Chin-Seung Chung
Director, APEC Climate Center

ICCWP Organizers



APEC Climate Center (APCC), Republic of Korea

The APEC Climate Center was established in 2005 with the endorsement and warm welcome of APEC senior officials and leaders. The Center produces climate information products and services based on a multi-model ensemble prediction system. We organize the annual APEC Climate Symposium which allows various scientists, academics, policy-makers and other stakeholders to share the latest science and technology in climate prediction and explore climate applications.



Korea Meteorological Administration

KMA is a governmental organization of the Republic of Korea under the Ministry of Environment (MOE). Its mission is defined to protect citizens' lives and properties from natural disasters and improve the commonwealth of the public in ways such as support for economic activities. In this regard, KMA undertakes the observation and analysis of meteorological phenomena on the ground, in the ocean, and in the atmosphere, while providing weather forecasts and warnings, and presents climate statistics and industrial-meteorological data.



Bureau of Meteorology (BoM), Australia

The Bureau of Meteorology is Australia's national weather, climate and water agency. Its expertise and services assist Australians in dealing with the harsh realities of their natural environment, including drought, floods, fires, storms, tsunamis and tropical cyclones. Through regular forecasts, warnings, monitoring, and advice spanning the Australian region and Antarctic territory, the Bureau provides one of the most fundamental and widely used services of government.



Korea Water Resources Corporation (K-Water), Republic of Korea

Since its establishment in 1967, K-water has been implementing national water resources management policies regarding multi-purpose dams, water supply dams and regional water supply systems. It is also making a significant contribution toward the development of the national economy and improving the quality of life for local people. In commemoration of the 40th anniversary of its foundation, K-water has launched the strategic mission "Water for the Happier World" and it is pursuing innovation and change, in order to become the "Best Water Partner" in the world.

ICCWP Organizing Committee



Dr. Narendra Tuteja

Manager Extended Hydrological
Prediction Section, Water
Forecasting Branch, Climate and
Water Division, Bureau of
Meteorology (BoM), Australia



Mr. Mark Svoboda

Climate Based Monitoring
Program Area Leader, The
National Drought Mitigation
Center, USA



Dr. Deghyo Bae

Professor, Department of Civil &
Environmental Engineering,
Sejong University, Korea



Dr. Boosik Kang

Professor, Department of Civil &
Environmental Engineering,
Dankook University, Korea



Dr. Soo-Jin Sohn

Research Fellow,
Climate Prediction Team,
APEC Climate Center, Korea



Dr. Ok-Yeon Kim

Research Fellow, Climate Change
Research Team, APEC Climate
Center, Korea



Mr. Hwa-Ick Lee,

Manager, Future Water Project
Planning Team, Korea Water
Resources Corporation (K-Water),
Korea

ICCWP Program

September 11, 2012 (Tuesday)		International Conference on Climate, Water and Policy (ICCWP) 2012
08:30-09:00	Registration / Arrival Tea and Coffee	
09:00-09:20	Opening Ceremony	
09:00-09:05	Opening Remarks	Chin-Seung Chung (Director, APEC Climate Center, Korea)
09:05-09:10	Congratulatory Address	Kenneth C. Crawford (Vice Administrator, Korea Meteorological Administration, Korea)
09:10-09:15	Congratulatory Address	Neil Plummer (Assistant Director, The Australian Bureau of Meteorology, Australia)
09:15-09:25	Group Photo	
09:25-10:45	Plenary Session	Chair: Jin-Ho Yoo (APEC Climate Center, Korea)
09:25-10:05	Neil Plummer (Keynote speaker, The Australian Bureau of Meteorology, Australia)	Water managers adopting climate forecasts: opportunities and challenges
10:05-10:45	George Kuczera (Keynote speaker, University of Newcastle, Australia)	Climate-based uncertainties and decision making: probability and beyond
10:45-11:05	Morning Tea and Coffee	
11:05-17:40	Session I	Chair: Narendra Tuteja (The Australian Bureau of Meteorology, Australia) Theme 1 : Application of seasonal climate forecasting to hydrologic forecasting and water resource management Theme 2 : Assessment of the accuracy and reliability of climate, seasonal and short-term streamflow forecasts at hydrologic scales
11:05-11:45	Narendra Kumar Tuteja (Keynote speaker, The Australian Bureau of Meteorology, Australia)	Application of seasonal climate forecasting to hydrologic forecasting and water resources management
11:45-12:25	Geoffrey M. Bonnin (Keynote speaker, National Oceanic and Atmospheric Administration, United States)	Probabilistic hydrologic forecasting with short to long lead-time at the U.S. National Weather Service
12:25-13:30	Lunch	
14:00-14:30	Young-Oh Kim (Invited speaker, Seoul National University, Korea)	Use of seasonal climate forecasts for water resources management in Korea: limitations and future
13:30-14:00	Kingtse Mo (Invited speaker, National Oceanic and Atmospheric Administration, United States)	Research on extreme events and water resources at the climate prediction center
14:30-15:00	Q J Wang (Invited speaker, CSIRO, Australia)	Making the best use of GCM outputs for seasonal streamflow forecasting
15:00-15:30	Hyun-Han Kwon (Invited speaker, Chonbuk National University, Korea)	Case studies of streamflow forecasting using climate forecasting and information
15:30-15:50	Afternoon Tea and Coffee	
15:50-16:20	Dmitri Kavetski (Invited speaker, University of Adelaide, Australia)	Impact of model implementation and numeric on the reliability of hydrological predictions
16:20-16:50	Hyun-Suk Shin (Invited speaker, Pusan National University, Korea)	Hydrological and water environmental effects on future Climate change for Nakdong River basin in South Korea
16:50-17:10	Byung-Ju Lee (Korea Meteorological Administration, Korea)	Evaluation of the AWS observed data applications for short-range streamflow forecasting
17:10-17:30	R.H Kripalani (Indian Institute of Tropical Meteorology, India)	Exploring Climate Research Applications over Korea-Japan Peninsula
17:30-17:50	Soo-Jin Sohn (APEC Climate Center, Korea)	Development of a multimodel-based seasonal prediction system for extreme droughts and floods: a case study for South Korea
18:30-20:00	Welcome Reception hosted by APEC Climate Center	

International Conference on Climate,
Water and Policy (ICCWP) 2012 :
Exploring Climate Application Series I

September 12, 2012 (Wednesday)		International Conference on Climate, Water and Policy (ICCWP) 2012
08:30-09:00	Arrival Tea and Coffee	
09:00-18:00	Session II	Chair: Lawrence Band (University of North Carolina, USA) Theme 3 : Long term climate variability and change and water resource management
09:00-09:40	Deghyo Bae (Keynote speaker, Sejong University, Korea)	Climate change studies on water resources in Korea
09:40-10:20	Lawrence Band (Keynote speaker, University of North Carolina, USA)	Ecosystem processes at the watershed scale: Climate change, ecosystem feedbacks and implications for water resources
10:20-10:40	Morning Tea and Coffee	
10:40-11:20	Eiichi Nakakita (Invited speaker, Kyoto University, Japan)	Climate change impact assessment on natural disaster in Japan under the Kakushin program
11:20-12:10	Boosik Kang (Invited speaker, Dankook University, Korea)	Water budget projection at the major Korean multipurpose dams based on IPCC climate change scenario
12:10-13:10	Lunch	
13:10-13:40	Francis Chiew (Invited speaker, CSIRO, Australia)	Climate variability and climate change impact on water
13:40-14:10	Rajeshwar Mehrotra (Invited speaker, UNSW, Australia)	Decadal hydrologic forecasting - how viable is it?
14:10-14:40	SeongJoon Kim (Invited speaker, Konkuk University, Korea)	A grid-based modeling for assessing climate change impact on watershed hydrology
14:40-15:00	Sunmin Kim (Kyoto University, Japan)	Estimating the systematic bias in the present and future precipitation output of AGCM60KM
15:00-16:40	Poster Session [See page 153 for the Index of Posters]	
16:40-17:00	Amir AghaKouchak (University of California Irvine)	A Multi-index multivariate drought monitoring framework: application to climate change impact assessment
17:00-17:20	Ok-Yeon Kim (APEC Climate Center, Korea)	Statistical assessment of changes in daily precipitation extremes in the Asia-Pacific region
17:20-17:40	Eun-Soon Im (CENSAM, Singapore)	Potential Increase of Hydroclimatic Extremes in Korea due to Global Warming from a Regional Climate Simulation
17:40-18:00	Kwangmin Kang (APEC Climate Center, Korea)	The effect of uniform and non-uniform bias correction methods on improving NEXRAD rainfall accuracy for distributed hydrologic modeling

ICCWP Program

September 13, 2012 (Thursday)		International Conference on Climate, Water and Policy (ICCWP) 2012
08:30-09:00	Arrival Tea and Coffee	
09:00-11:50	Session III	Chair: Mark Svoboda [The National Drought Mitigation Center, United States] Theme 4 : Developing effective communication channels and toolkits among climate scientist, water resource managers and policy makers
09:00-09:40	Roger Pulwarty (Keynote speaker, National Oceanic and Atmospheric Administration, United States)	Being proactive about drought: long-term risks and early warnings
09:40-10:10	Mark Svoboda (Invited speaker, The National Drought Mitigation Center, United States)	Drought information services: Bridging the science/policy interface
10:10-10:40	Mike Harrison (Invited speaker, Climate-Insight, United Kingdom)	Developing effective communication channels and toolkits among climate scientists, water resource managers and policy makers
10:40-11:00	Morning Tea and Coffee	
11:00-11:30	Mark Thyer (Invited speaker, University of Adelaide, Australia)	Towards robust predictions of the hydrological impacts of climate change: the Bayesian total error approach
11:30-11:50	Andrew Onwuemele (Nigerian Institute of Social and Economic Research, Nigeria)	Managing water resources under global climate variability: responses of water resource managers and policymakers in Nigeria
11:50-12:50	Lunch	
12:50-16:10	Session IV	Chair: Tony Slatyer [Department of Sustainability, Environment, Water, Population & Communities, Australia] Theme 5 : International cooperation and policy
12:50-13:30	Jason Hyon (Keynote speaker, NASA-Jet Propulsion Lab, United States)	Making an informed decision on freshwater resource management by integrating remote sensing data with traditional data
13:30-14:00	Tony Slatyer (Invited speaker, Department of Sustainability, Environment, Water, Population & Communities, Australia)	Lessons for climate adaptation policy from water reform experience in Australia
14:00-14:30	Roger Pulwarty (Invited speaker, NOAA, United States)	Adaptation challenges in international (and transboundary) river basins
14:30-14:50	Afternoon Tea and Coffee	
14:50-15:10	Seree Supratid (Strategic Committee for Water Resources Management (SCWRM), Thailand)	Thailand great flood 2011: Looking back and looking forward
15:10-15:30	Nelly Florida (BMKG, Indonesia)	Strengthening of climate information services concerning water availability to support food security program in Indonesia
15:30-15:50	Sam Wong (University of Liverpool, United Kingdom)	A Polycentric Approach to Deal with Uncertainty and Climate Change Adaptation - A Case Study of Trans-boundary Water Governance in Volta River Basin in West Africa
15:50-17:00	Wrap-up Session	Chair: Jin-Ho Yoo (APEC Climate Center, Korea)

ICCWP Speakers

Keynote Speakers



Neil Plummer

Neil Plummer is currently Assistant Director Climate Information Services with the Bureau of Meteorology. Neil joined the Bureau in 1986 and started his career as a weather forecaster. He has held positions on various World Meteorological Organization expert teams and management committees and has been a coordinating author with the Intergovernmental Panel on Climate Change. In 2008 he shifted into the world of hydrology as Manager Extended Hydrological Prediction before taking up his current position. Neil has tertiary qualifications in meteorology, management and IT and these include Masters degrees in Science (climate change) and Business Administration.



George Kuczera

George Kuczera is professor of water engineering at the University of Newcastle. He obtained his PhD from Harvard University in 1980 and spent 5 years in the water industry before joining the University of Newcastle in 1986. His research interests span a range of areas including calibration and testing of hydrologic models using Bayesian methods, stochastic hydrology and risk assessment and water resource systems simulation and optimization. He has published extensively on these topics and has developed a range of software for use in research and industry.

ICCWP Speakers

Keynote Speakers



Narendra Kumar Tuteja

Narendra Kumar Tuteja is Manager of the Extended Hydrological Prediction Section, Water Branch, Bureau of Meteorology, Australia. He is responsible for development and delivery of the water availability forecasts for Australia and the modeling systems required for Bureau's water forecasting services. He obtained his PhD from National University of Ireland in 1996. He has over 25 years of experience in industry, applied research and academia in hydrology and water resources across Australia, Ireland, India and Czech Republic. His work has supported development of policies and decision making in the watersector. He has published many peer reviewed papers and industry reports on catchment hydrology, water forecasting, eco-hydrology, and snow and glacier hydrology.



Geoffrey M. Bonnin

Geoffrey Bonnin manages science and technique development for flood and stream flow forecasting, and water resources services provided by the U.S. National Weather Service.

His primary areas of expertise are in the science and practice of real time hydrologic forecasting, estimation of extreme precipitation climatologies including the potential impact of climate change, data management as the integrating component of end-to-end systems, and the management of hydrologic enterprises. Mr. Bonnin was one of the developers, and the primary implementer, of Standard Hydrometeorological Exchange Format (SHEF). He initiated and manages the development of NOAA Atlas 14, Precipitation Frequency Atlas of the United States and was lead author for the first three volumes. He is a technical advisor for Australian Institution of Engineers' led update of precipitation frequency estimates for Australia, and developed a plan cooperation between NWS and BoM which identifies specific techniques and technologies for sharing.



Deghyo Bae

Deghyo Bae is a native of South Korea. He received his B.E. degree from Yonsei University, Seoul, Korea in 1983 and M.E. and Ph.D. degrees from the University of Iowa, USA in 1989 and 1992, respectively. After he received his Ph.D. degree, he worked for USDA-ARS as a research scientist for two years in Oregon, USA. He came back to Korea in 1994 and currently works for Sejong University, Seoul, Korea as a professor since 2001. He teaches Hydrology and Water Resources Engineering for undergraduate students and Hydrometeorology and Statistical Hydrology for graduate students.

His areas of academic interest include atmosphere and surface runoff interaction study, climate change and variability study, real-time flood and flash flood prediction system development, radar rainfalls and their hydrologic application, and GIS-based water resources engineering. His current research topics are climate change impact assessments on Korean water resources, utilization of short- and long-term weather forecasts for water resources applications, development of radar-based flood forecasting system, and development of coupled atmosphere and urban sewer flood prediction model.

He honored outstanding paper awards from several water-related societies and served as an associate editor of J. of Hydro-environment research, Elsevier and associate editor of KSCE and KWWA of Korea. He has been working for Asia Water Cycle Initiative (AWCI) as a Korean representative and co-chair of climate change division of GEOSS/AWCI. He published more than 90 peer-reviewed papers on water resources area including climate change impact study.



Lawrence Band

Lawrence Band is the Voit Gilmore Distinguished Professor of Geography and the Director of the Institute for the Environment at the University of North Carolina, Chapel Hill. He has been at Carolina since 1998, with previous faculty appointments at the University of Toronto and Hunter College, City University of New York. He teaches and does research in watershed hydrology, geomorphology, geographic information systems and environmental modeling. From 2002 through 2007 Dr. Band was Department of Geography Chair at UNC. Dr. Band's research is in the ecohydrology of watersheds, including the cycling of water, carbon and nutrients, the development and impacts of droughts and floods, and human/environment interactions. His current research focuses in two Long Term Ecological Research sites: the Coweeta LTER in western North Carolina, and the Baltimore Ecosystem Study. Past research has included projects in the Pacific Northwest, Rocky Mountains, China, Canada, and Australia. In 2010 he was Board Chair for the Consortium of Universities for the Advancement of Hydrologic Sciences, a consortium of ~130 US and foreign universities, non-profit institutes, and domestic and foreign water science and management agencies. Band was a visiting scientist at the CRC for Catchment Hydrology in 1992-1993 and at the Bureau of Meteorology and CSIRO in 2008. In 2010 he was Chair of the Board of Directors for the Consortium of Universities for the Advancement of Hydrologic Science (www.cuahsi.org).

Dr. Band has published 120 papers, book chapters and technical reports in his career. He has consulted with the EPA, Chesapeake Bay Program, the South Florida Water District and State of California on watershed protection, stormwater and ecosystem restoration.

ICCWP Speakers

Keynote Speakers



Roger S. Pulwarty

Roger S. Pulwarty is the Climate and Societal Interactions Division Chief and the director of the National Integrated Drought Information System at US National Oceanic and Atmospheric Administration. Roger's research focuses on climate, vulnerability and adaptation and on developing climate information services to address those issues. He is a convening lead author on adaptation in the IPCC Fifth Assessment Report, lead author on the UNISDR Global Assessment Report on Disaster Risk Reduction [2011], and on the IPCC Special Report on Managing the Risks of Extremes and Disasters [2011]. Roger has acted in advisory capacities on climate risk management to several national, U.S. state and tribal governments, and to the UNDP, UNEP, WMO, OAS, and the World and InterAmerican Development Banks and has provided testimonies before the US Congress on climate, water and, adaptation. He is Professor-adjunct to the University of Colorado and the University of the West Indies.



Jason J. Hyon

Jason J. Hyon is Chief Technologist for Earth Science and Technology Directorate at NASA Jet Propulsion Laboratory. He has managed developments of spaceborne and airborne remote sensing instruments such as radiometer, radar, lidar, GPS, and spectrometers. In the past, as a manager of the Earth Science Data Systems section at JPL, he managed ground data system developments for NASA Earth science missions, including MISR on Terra; ASTER, AIRS on Aqua; TES on Aura, Topex/Poseidon; and SeaWinds on ADEOS. He has expertise in instrument technology, information technology, and spaceborne mission concepts. He is currently working on infusion of remote sensing data to decision support systems. He received MSEE from the University of Southern California in 1988 and BA in Physics and Mathematics from Occidental College and EE from Caltech.

ICCWP Speakers

Invited Speakers



Francis Chiew

Francis Chiew has 20 years experience in research, teaching and consulting in hydrology and water resources. Francis holds a Bachelor of Engineering and PhD in hydrology from the University of Melbourne. Francis is currently a Science Leader in the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Canberra, where he leads about 50 surface water hydrologists working on catchment hydrology, hydrological modelling, climate impact on water, streamflow forecasting and irrigation hydrology. Francis is highly regarded internationally in the areas of hydrological modelling and hydroclimatic variability, where he has received numerous awards and published over 250 research papers. Francis is also active in converting research outcomes into modelling tools and guidelines for the water industry. Francis is currently a lead author in the Intergovernmental Panel on Climate Change Fifth Assessment Report.



Mike Harrison

Mike's experience has been built in the UK and Africa, in the UK Met Office, and in the UN both working directly in the World Meteorological Organisation (WMO) and on numerous external UN-related projects. Well known as an international leader in the field of seasonal prediction through his management of the WMO CLIPS (Climate Information and Prediction Services) Project, which followed his contribution to the establishment of the Regional Climate Outlook Forums in Africa, Mike also has wide experience in predictions on time scales from a few days to climate change, and a major interest in approaches to the use of forecasts and in the impacts of weather and climate. With a Ph.D. in Climate from the University of the Witwatersrand, Johannesburg, and degrees from Imperial College, London, Mike has managed numerous international projects dealing with predictions on a variety of time scales and their uses, as well as completing successful a variety of independent consultations. Amongst his extensive publications list is editorship of and authorship in the book "Seasonal Climate: Forecasting and Managing Risk".

ICCWP Speakers

Invited Speakers



Boosik Kang

Boosik Kang is the professor of the department of civil and environmental engineering in Dankook University. The major research area is Hydrology and Water Resources. Before stepping on the university carrier, he had been working at Korea Water Resources Corporation from 1995 to 2005 where he experienced the professional carrier of design of navigation canal, integrated water resources management, short and long term streamflow prediction, etc.

During the Ph.D. course in Colorado State University in United States, he majored climate change impacts on water resources under the direction of professor Jorge Ramirez. The title of his Ph.D. thesis is "Precipitation Downscaling and its Use in the Assessment of Hydrologic Effects of Climate Variability and Change". His academic interests are downscaling of GCM output, climate change adaptation strategy, streamflow prediction, drought monitoring and management, flood prediction and warning, risk-based design of flood facilities, etc.

Since 2007 he has served as the secretary of AHWG[Applied Hydrology Working Group] of IAHR(International Association of Hydro-environment Research).



Dmitri Kavetski

Dmitri Kavetski's research interests focus on mathematical and statistical modelling of environmental systems under conditions of data and process uncertainty, with a current focus on catchment-scale hydrology. Dmitri has made important contributions in Bayesian statistics and data analysis in hydrology, in numerical and computational methods for surface water and groundwater models, in risk analysis for carbon sequestration, and in others fields of environmental sciences. Dmitri has also contributed a number of computer packages implementing his techniques, including Bayesian Total Error Analysis (BATEA), a comprehensive suite for general model development, calibration and uncertainty analysis. The BATEA software is used in hydrological research with colleagues in the USA and Europe, and is being adopted for operational use in Australia. Dmitri completed his PhD at the University of Newcastle (Australia) and, following research appointments at Princeton University and University of Newcastle, has joined the University of Adelaide as Professor of Civil and Environmental Engineering in early 2012.



Young-Oh Kim

Young-Oh Kim is a professor of Department of Civil and Environmental Engineering at Seoul National University, Korea. After receiving a Ph.D. degree from University of Washington, he worked at Global Hydrology and Climate Center of NASA, USA. His research interests include hydrologic forecasting, integrated climate change assessment, risk analysis, water resources systems analysis.

As the principle investigator, Dr. Kim has been leading a 3-year project named "the Climate Change Assessment and Projection for Hydrology in Korea (CCAPH-K)". Supported by the Ministry of Land, Transport and Maritime Affairs, Korea, CCAPH-K aims to make future projections of basin-scale precipitation, streamflow, drought, and flood according to climate change.

In addition, Dr. Kim has been active in his broad ranging profession. He is the Vice-Chair for the Committee on Water Resources Management in the International Association for Hydro-Environment Engineering and Research (IAHR) and an associate editor of two international journals such as the Journal of Hydro-Environment Research (JHER) and the KSCE Journal of Civil Engineering (KSCE).



SeongJoon Kim

SeongJoon Kim has a Ph.D. (1991) in Agricultural Engineering from Seoul National University; M.S. (1987) in Agricultural Engineering from Seoul National University; B.S. (1985) in Agricultural Engineering from Seoul National University. As a professor in the departments of agricultural engineering and civil and environmental system engineering at Konkuk University, Dr. Kim has continued to transfer his sphere of knowledge and experience to his students over the past 13 years. Through research over 26 years, he has had the opportunity to share current spatial science technology as applied to water resources management with society by providing leadership, technical knowledge, and service through participation in local, national, and international organizations.

Dr. Kim has experience of watershed scale project such as water resources informatics, hydrological and water quality modeling, climate and land use change impact assessment. Dr. Kim has published more than 280 reviewed publications, several hundred national and international conferences and professional meeting presentations and has earned wide recognition and numerous awards at Laboratory, Research Center, University and State levels for his scientific contributions. As a further recognition of his scientific contributions, Dr. Kim holds membership of prestigious academic societies such as American Society of Agricultural Engineers (ASAE), and American Water Resources Association (AWRA) besides serving as an Associate Editor for Journal of Paddy and Water Environment.

ICCWP Speakers

Invited Speakers



Hyun-Han Kwon

Currently, Hyun-Han Kwon is an assistant professor at Chonbuk National University. He has fifteen years of experience in water resources and hydrometeorology, especially in climate-based applications. He has co-authored over 60 peer-reviewed journal papers and over 80 peer-reviewed conference papers. His work integrates hydrology, stochastic systems, risk analysis and climate variability to characterize key dynamics in water systems and to identify the means to foster sustainability in a changing world. He is now working on various hydroclimate based projects, including water resources management, eco-hydrology, hydroclimatology, climate information based prediction/simulation, climate change on water resources, infrastructure risk analysis and index insurance. He has been involved with projects directed on understanding and prediction of at a regional scale for sustainable water resource management and development accounting for climate variability. His research goals are to enhance society's capability to understand, anticipate and manage the impacts of climate fluctuations to improve human welfare and the environment using advanced statistical approaches. In pursuit of this objective he is undertaking research designed to unravel the direct and indirect factors that lead to climate related socio-economic outcomes and thereby provide the best evidence available to inform policy and decision-making about climate-related risk.



Rajeshwar Mehrotra

Rajeshwar[Raj] Mehrotra specialises in the application of statistical techniques to problems in hydrology and climatology. He possesses more than 19 years experience in both fields. His main contribution to the field has been development and application of stochastic downscaling techniques for simulation of multisite daily rainfall, temperature and evaporation sequences. Raj's research has resulted in one edited book, 2 book chapters, 24 research papers in refereed journals, 21 papers in refereed conferences and about 20 technical reports. Raj has been continuously working on the problems associated with climate and its impact on the water resource planning and management.



Kingtse Mo

I am a physical scientist at the Climate Prediction Center / National Centers for Environmental Prediction. I just celebrated my 25-year anniversary at CPC. I love my work, my colleague and researchers in the hydroclimate community. My earlier research was more focused on atmospheric sciences. In 2000, I chaired the AMS STAC Committee on Meteorology and Oceanography of the Southern Hemisphere. We had the international meeting on Southern Hemisphere meteorology in Chile. I served on the VAMOS Panel for three years and participated in the North American Monsoon Experiment in 2004.

In 2006, CPC recognized the importance of climate variability and water resource management and we started to build research activities to support our Drought Outlook and Drought Monitor authors. The monthly drought briefing started in 2007. Currently, my work is more focused on drought monitoring and prediction.



Eiichi Nakakita

Eiichi Nakakita is a professor of Kyoto University, Japan. He obtained his Doctor of Engineering from Division of Applied Systems Science, Graduate School of Engineering, Kyoto University and has held position on Director for Planning & Strategy Institute of Sustainability Science at Kyoto University. His special field of research is Hydrometeorology, Radar Hydrology and River Hydrology.

ICCWP Speakers

Invited Speakers



HyunSuk Shin

HyunSuk Shin is present who steadily studied in hydrological environment and water resources since 1986 belongs to Presidential Committee on Green Growth and is an advisor of Environment Subcommittee of Cheong Wa Dae as well as works in various fields of actively in water environment and water resources management by qualifying one of the members of River Planning Division of Director General for Water Resources Policy in Ministry of Land, Transport and Maritime Affairs (MLTM) in South Korea. Mr. Shin is also a chairman of subcommittee in Nakdong River Water Resources and an advisor of Four-River Restoration Project of MLTM in a government-affiliated organization. He has areas of expertise in dealing with forecasting rainfall-runoff and flash flood based on GIS using artificial neural network in his first study. In recent, his research with increasing concerns about climate change all over the world has been widely extended as following national projects: Study on the estimation of environmental flow considering climate change, water resources effects evaluation and management measure establishment due to climate change, and forecasting hydrological variation according to climate change, etc. He is an engineer studying analysis techniques of hydrologic and environmental data for several years.



Tony Slatyer

Mr Slatyer is a First Assistant Secretary in the Australian Government Department of Sustainability, Environment, Water, Population and Communities. He heads the Water Reform Division of the Department.

Before holding this position, Mr Slatyer held a number of senior executive positions in the Australian Government, with environment, transport and regional development policy responsibilities. Mr Slatyer has also held the positions of Executive Director of the Australian Government Bureau of Transport and Regional Economics, and overseas assignments.

Mr Slatyer holds degrees in Law and Arts from the Australian National University.



Mark Svoboda

Mark has been with the NDMC since it was formed in 1995. As the NDMC's Monitoring Program Area Leader, his duties include overseeing the center's operational national drought monitoring activities. Mark's responsibilities include providing expertise on climate and water management issues by working closely with states, federal agencies and international governments as well as the media and private sector. Mark co-founded the development of the U.S. Drought Monitor in 1999 and serves as one of the principal authors of both the weekly USDM and monthly North American Drought Monitor products. Mark is heavily involved with drought monitoring, assessment and prediction committees at state, regional and national levels. He currently sits on the American Meteorological Society's Applied Climate Committee and as well as NOAA's National Integrated Drought Information System (NIDIS) Program Office's Implementation Team and was appointed as a co-chair for NIDIS Portal development. In addition, he has extensive experience working with the international drought, water and climate community via project collaboration, consultation and through various training and outreach opportunities with over 50 countries and international organizations to date. Mark earned both his Bachelor's Degree in Geography specializing in Climatology and a Masters Degree in Geography with a specialization in Remote Sensing, Climatology and GIS from the University of Nebraska-Lincoln.



Mark Thyer

Mark Thyer is Senior Lecturer in Environmental Engineering at the University of Adelaide. He has over 12 years research experience in developing physical-statistical models to enhance predictions for hydrological, environmental and water resource models. His research interests include flood/drought risk assessment; quantifying predictive uncertainty in hydrological models and behavioural water use modelling for integrated urban water management. He is an internationally recognised expert on use of Bayesian approaches to quantify uncertainty (input/parameter/data) in stochastic models. He has published numerous journal papers in top international water resources which are highly cited and is co-investigator on research grants worth over \$3.7 million dollars. Mark has undertaken consultancy projects on stochastic modelling and drought risk assessment for Hunter Water, Gosford-Wyong Water Supply Authority, Sydney Catchment Authority, and Wimmera Mallee Pipeline Project. He is regularly invited to review Australian Research Council grant applications and journal papers for top international journals, and is associate editor for the Australian Journal of Water Resources. Mark was invited by the CRC for Catchment Hydrology to contribute his research to the stochastic climate library of the catchment modelling toolkit. Over the past 5 years he was research leader for an eWater CRC project on the development of the behavioural end-use stochastic simulator (BESS) for household water use simulation, incorporated into eWater's Urban Developer tool.

ICCWP Speakers

Invited Speakers



QJ Wang

QJ Wang graduated in 1984 from Tsinghua University with a "Graduate of Excellence" award. He completed his MSc and PhD studies at the National University of Ireland, Galway. Dr Wang was a Senior Lecturer at the University of Melbourne before taking up the position of Principal Scientist at the Victorian Department of Natural Resources and Environment in 1999. He joined CSIRO Land and Water as an OCE Science Leader and Senior Principal Research Scientist in May 2007.

Dr Wang leads in CSIRO research on improving water prediction and forecasting in Australia by integrating climate, hydrological, mathematical and computational sciences. He led the development of a Bayesian joint probability modelling system, which has been in operation since December 2010 by the Australian Bureau of Meteorology to provide seasonal streamflow forecasts across Australia. His research team is also developing the next generation of flood and short-term river flow forecasting system for Australia.



Plenary Session

WATER MANAGERS ADOPTING CLIMATE FORECASTS: OPPORTUNITIES AND CHALLENGES

Wilson, T., Plummer, N., Perkins, J., Zhou, S.



CLIMATE-BASED UNCERTAINTIES AND DECISION MAKING: PROBABILITY AND BEYOND

George Kuczera

20
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21



WATER MANAGERS ADOPTING CLIMATE FORECASTS: OPPORTUNITIES AND CHALLENGES

Wilson, T., Plummer, N., Perkins, J., Zhou, S.

Climate and Water Division, Bureau of Meteorology, Australia

Abstract: Australian water managers face challenging decisions relating to future rainfall and water availability. To help address this need the Bureau of Meteorology (the Bureau) released the Seasonal Streamflow Forecasting service in December 2010. This service provides forecasts of total streamflow volumes for the three months ahead for 50 forecast locations across eastern Australia. Users were involved very early in development of the service to inform the Bureau of their needs and to provide input into product design. Maintaining a high level of user satisfaction is essential and for climate and water forecasts to have a real impact, the forecasts need to be an integral part of the water managers' decision making processes.

Keywords: *Climate, Water, Forecasts, Streamflow, Seasonal*

1. INTRODUCTION AND PURPOSE

Australia is the driest inhabited continent and experiences high rainfall variability. The amount of rainfall that becomes runoff is generally low because of Australia's arid climate, a high rate of evapotranspiration and large areas of flat topography. The Murray-Darling Basin is a large area located in the southeast interior of Australia. It typically experiences only 4% runoff but more than 50% of Australia's agricultural water use occurs within this basin. Water managers within the Murray-Darling Basin and across Australia face challenging decisions such as setting water allocations for irrigation, setting restrictions on urban water supply and environmental watering. Seasonal rainfall and streamflow forecasts provide valuable insight for these decisions.

We will describe the Bureau's evolving Seasonal Streamflow Forecast service and the opportunities and challenges in assisting water managers in using the service to make better water management decisions.

2. THE SEASONAL STREAMFLOW FORECAST SERVICE

The Seasonal Streamflow Forecasting service provides forecasts of total streamflow volumes for the three months ahead. The service, which initially focussed on the southern Murray–Darling Basin, has recently expanded to 50 forecast locations across eastern Australia (Fig. 1). The forecasts are available on the Bureau's website (www.bom.gov.au/water/ssf). We present the forecasts in three different ways - as a probability distribution, exceedence probability and tercile pie chart. The forecast probability distribution shows the range of possible streamflow values and how likely it is that they will occur. This forecast probability distribution product is useful for seeing how the forecasts may be shifted higher or lower compared to the historical data. The forecast exceedence probability product, or flow duration curve, shows how likely it is that a particular streamflow value will be exceeded (Fig. 2). Historical streamflow volume data are presented alongside the forecasts to provide context. In order to give guidance on the forecast confidence, the forecast skill is displayed on each forecast.

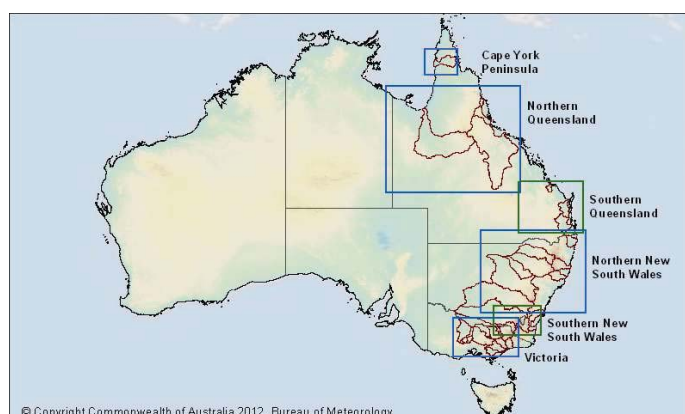


Figure 1. Forecast locations over eastern Australia (indicated by the blue dots) and the catchment boundaries (indicated by the red outlines).

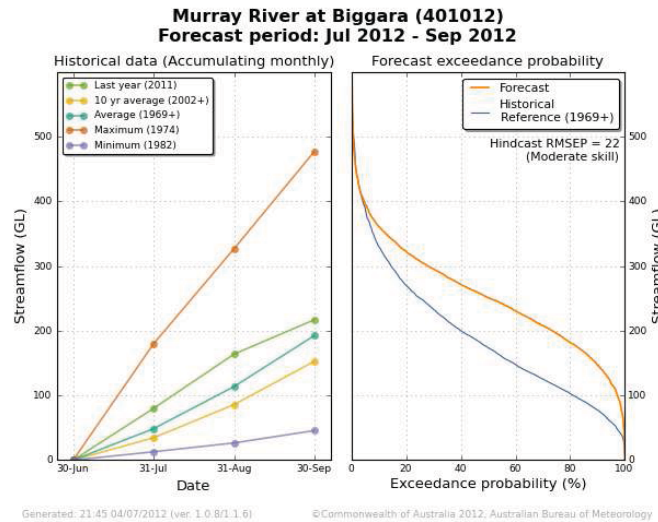


Figure 2. An example of the exceedance probability product for the location Biggara on the Murray River. The left hand panel shows the historical data and the right hand side shows the forecast compared to a historical distribution.

3. USER NEEDS AND PRODUCT DESIGN

We engaged with users very early in development of the Seasonal Streamflow Forecast service. The reasons for the early user involvement was to ensure that the service meets the water managers needs, the users understand the forecasts and that they are more likely to use them for real decisions. During the two year period of service development, water managers attended workshops to (i) be informed about the Bureau's progress on the service and (ii) to provide user feedback on their needs. The user needs of water forecasting services were then matched with the priorities, responsibilities and capabilities of the Bureau.

During the workshops, we also asked for feedback on the product design. We responded to this feedback by making changes to the products. These changes included displaying the skill score on the forecast products, displaying the historical analogues next to the forecasts to give context and plotting the latest streamflow data on previous, but still current forecasts, to enable easy verification.

Forecast skill varies depending on the location and time of year. At times, the forecast skill can be low and comparable to relying on only historical data. We developed an options paper that outlined possible ways to present low skilled forecasts and requested user feedback. From the user's response we developed a trial solution that users could view via the registered user version of the Seasonal Streamflow Forecasts website. Further feedback was sought and incorporated.

4. CHALLENGES

Feedback on the level of user satisfaction with the Seasonal Streamflow Forecast service is very important. To gather feedback we will survey the users on a regular basis, at least yearly, to continually monitor the satisfaction levels and make service improvements in response as needed. However, the ultimate measure of success of the service is the adoption of the forecasts in the water managers decision making processes. The adoption of seasonal streamflow forecasts amongst water managers will be challenging. Traditionally some water managers, particularly those involved in setting water allocations, are risk adverse. This should not, however, be a barrier to adoption as the actual forecasts can inform and assist in determining the water allocation outlooks rather than the actual allocations. Commercial operators such as hydropower generators have a higher tolerance for risk and may more readily use the forecasts if skilful. There has been particular interest in using the streamflow forecasts as part of the decision making process for environmental watering and setting urban water restrictions. We will publish case studies that demonstrate how seasonal streamflow forecasts can be used within a water management context and take on board learnings from market research and a user centred design approach to seasonal climate forecasts. These will give us a better understanding of how the forecasts can be best adopted and allow us to demonstrate to other users the benefits of using forecasts to achieve better outcomes.

CLIMATE-BASED UNCERTAINTIES AND DECISION MAKING: PROBABILITY AND BEYOND

George Kuczera¹

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Abstract: There exists a spectrum of uncertainty types. At one end there is quantitative uncertainty amenable to the tools of probability and statistics. At the other end is total ignorance. In between there is scenario uncertainty which pervades virtually all water resource decision making and, in its more difficult manifestations, is not amenable to probability calculus. Forecasts of future rainfall (and other hydrologically relevant variables) are affected by all these uncertainties. Decision makers deal with these uncertainties in different ways. These are illustrated with several water resource case studies ranging from seasonal streamflow forecasting (which is largely amenable to the tools of quantitative uncertainty and classical decision making under uncertainty) to urban water resource planning in the face of future climate change scenario uncertainty (where the emphasis shifts from identifying solutions that optimal in an expected sense to solutions that are robust). Understanding this uncertainty spectrum and its ramifications for decision making is an important consideration in guiding the development of rainfall-based forecast information.

Keywords: *Quantitative uncertainty, scenario uncertainty, decision support, robustness.*

1. INTRODUCTION

The former US Secretary of Defence, Donald Rumsfeld, was much derided when he made the following statement in 2002:

“There are known knowns; there are things we know we know.

We also know there are known unknowns; that is to say we know there are some things we do not know.

But there are also unknown unknowns – the ones we don’t know we don’t know.”

On reflection one realizes that Rumsfeld was voicing a reality faced by many decision makers, namely that there are different types of uncertainty and, by implication, decision makers often have to deal with the whole spectrum of uncertainties. Decision makers in the water resources sector would have little difficulty relating to Rumsfeld’s observation with future rainfall (and other hydrologically relevant variables)¹ affected by the full spectrum of uncertainties.

The objective of this presentation is to explore the different types of uncertainty, how they affect forecasts of future rainfall over a wide range of time scales and positions, and how that uncertainty is processed by decision makers.

2. THE UNCERTAINTY SPECTRUM

The calculus of probability and statistics largely deals with the world of quantitative uncertainty where the “unknowns” are “known”. Characteristic elements of this calculus are a known set of outcomes and the ability to learn from observations and data-based prior knowledge. It can distinguish between intrinsic or natural uncertainty that is capable of being defined by probability distributions and epistemic uncertainty that arises from limited information and is the subject of statistics.

The world of quantitative uncertainty grades into the more nebulous world of, for want of a better word is called, scenario (or assumption) uncertainty. Here a scenario is taken to be a set of assumptions upon which the decision analysis is conditioned. In this world not all the “unknowns” are “known” - not all scenario possibilities are known, there are fewer data to validate assumptions and there is a greater reliance on judgment. Taken to its extreme, scenario uncertainty degenerates to ignorance, the world of “unknown unknowns”.

3. COPING WITH THE UNCERTAINTY SPECTRUM IN WATER RESOURCE DECISION MAKING

Water resource decision makers make decisions that affect system performance over a range of time scales. Short-term or operational decisions affect immediate performance, while decisions on policy, strategic direction and investment in major infrastructure affects performance over longer, possibly multi-decadal, time scales. Figure 1 illustrates an idealized formal decision support framework. At the centre of the framework is a simulation model of the water resource system. This model simulates the response of the system to stochastic forcing of which climate is a major component and to decisions or interventions. The response is used to

¹ For convenience the focus will be on rainfall which is the major driver of hydrologic response. It is acknowledged that other forcing variables such as potential evapotranspiration and temperature also affect hydrologic response.

evaluate metrics of performance important to decision makers who attempt to formally or informally search for decisions that optimize these metrics. Within this framework uncertainty is expressed in different ways. Quantitative uncertainty can be propagated through the simulation model using well known probability techniques such as Monte Carlo simulation. However, scenario uncertainty is more awkward to deal with. It pervades the whole framework and, in the worst case, the best that can be done is to condition performance metrics on the scenarios.

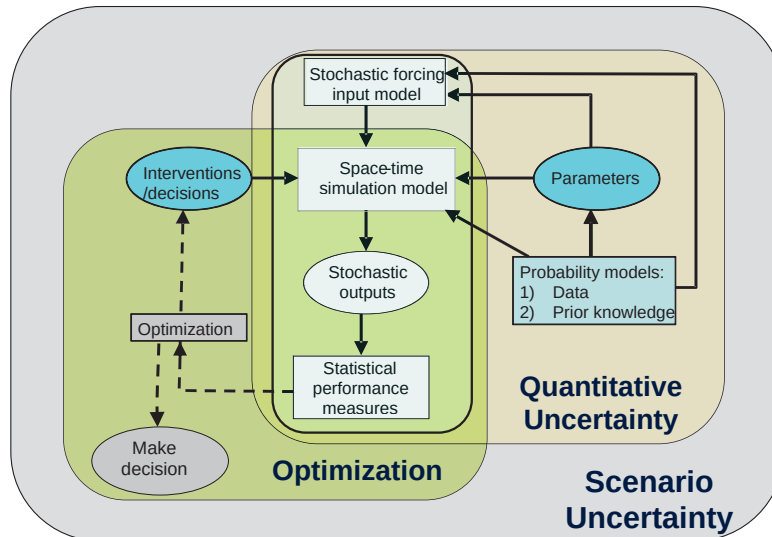


Figure 1. Idealized formal decision support framework.

The type of uncertainty affecting climate-based products that forecast future rainfall and streamflow is a function of lead time and position in the future. Forecasts made in the present range from flood forecasts over scales of hours to days to seasonal forecasts over scales of months. While the skills of such forecasts may not be strong and the technology is evolving, the saving grace is that the technology is founded on the calculus of quantitative uncertainty. As the lead time extends to multi-year or decadal time scales, the transition from quantitative to scenario uncertainty commences. Thyer *et al.* (2006) argue that the instrumental record cannot adequately identify multi-decadal variability in hydrological variables. Henley *et al.* (2011) explore the value of paleo reconstructions of multi-decadal variability to better inform current forecast but caution about the difficulties.

As forecasts move from the present to the future, non-stationarity of the climate in the guise of future climate change complicates matters further. Scenario uncertainty grows in dominance. While it can be argued the future paths of climate change may be plausibly identified, there is insufficient data and prior knowledge to meaningfully assign probabilities to such events. Dessai *et al.* (2009) argued that the accuracy of model predictions of future climate is limited by “fundamental irreducible uncertainties” such as knowledge limitations (e.g., cloud physics and sub-grid variability), the inherent chaotic nature of climate and uncertainty about human behaviour to reduce Greenhouse emissions.

Water resource decision makers deal with these uncertainties in different ways. Several water resource case studies illustrate these differences. We start with seasonal streamflow forecasting which is largely amenable to the tools of quantitative uncertainty and classical decision making under uncertainty. The more elusive multi-decadal climate variability requires an adaptive decision making where decisions evolve over time. In the case of urban water resource planning in the face of future climate change scenario uncertainty, the emphasis shifts from identifying solutions that optimal in an expected sense to solutions that are robust.

It is suggested that understanding this uncertainty spectrum and its ramifications for water resources decision making is an important consideration in guiding the development of rainfall-based forecast information.

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Session I

APPLICATION OF SEASONAL CLIMATE FORECASTING TO HYDROLOGIC FORECASTING AND WATER RESOURCE MANAGEMENT

Tuteja, N.K., Wang, Q.J., Kuczera, G., Shin, D., and Laugesen, R.

PROBABILISTIC HYDROLOGIC FORECASTING WITH SHORT TO LONG LEAD-TIME AT THE U.S. NATIONAL WEATHER SERVICE

Geoffrey M. Bonnin

USE OF SEASONAL CLIMATE FORECASTS FOR WATER RESOURCES MANAGEMENT IN KOREA: LIMITATIONS AND FUTURE

Young-Oh Kim

RESEARCH ON EXTREME EVENTS AND WATER RESOURCES AT THE CLIMATE PREDICTION CENTER

Kingtse C. Mo

MAKING THE BEST USE OF GCM OUTPUTS FOR SEASONAL STREAMFLOW FORECASTING

Q.J. Wang, Andrew Schepen, David Robertson and Sandra Hawthorne

CASE STUDIES OF STREAMFLOW FORECASTING USING CLIMATE FORECASTING AND INFORMATION

Hyun-Han Kwon, Upmanu Lall

26
27



IMPACT OF MODEL IMPLEMENTATION AND NUMERICS
ON THE RELIABILITY OF HYDROLOGICAL PREDICTIONS

Dmitri Kavetski and Martyn Clark



HYDROLOGICAL AND WATER ENVIRONMENTAL EFFECTS
ON FUTURE CLIMATE CHANGE FOR NAKDONG RIVER
BASIN IN SOUTH KOREA

HyunSuk Shin, TaeSeok Shon, MiEun Kim



EVALUATION OF THE AWS OBSERVED DATA
APPLICATIONS FOR SHORT-RANGE STREAMFLOW
FORECASTING

Byong-Ju Lee, Young-Jean Choi



EXPLORING CLIMATE RESEARCH APPLICATIONS OVER
KOREA-JAPAN PENINSULA

Ramesh Kripalani, Jai-Ho Oh



DEVELOPMENT OF A MULTIMODEL-BASED SEASONAL
PREDICTION SYSTEM FOR EXTREME DROUGHTS AND
FLOODS: A CASE STUDY FOR SOUTH KOREA

First Author, Soo-Jin Sohn, Chi-Yung Tam, and Joong-Bae Ahn



APPLICATION OF SEASONAL CLIMATE FORECASTING TO HYDROLOGIC FORECASTING AND WATER RESOURCE MANAGEMENT

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Abstract: The seasonal water availability prediction service of Australia relies on the development and integration of the statistical and dynamic modelling approaches. A statistical prediction system is based on a Bayesian joint probability modelling approach (BJP), and it provides reliable forecasts of ‘seasonal’ streamflow over the next three months. In parallel, a dynamic modelling approach has been developed whereby outputs from climate models are downscaled to a catchment scale to provide inputs to hydrological models of various degrees of complexity. The key climate models are the Centre for Australian Weather and Climate Research’s (CAWCR) Predictive Ocean Atmosphere Model for Australia (POAMA). All prediction systems are accompanied with verification systems that measure skill and reliability of the forecasts. In delivering on these responsibilities, the Bureau relies on considerable research, particularly through CAWCR, the Water Information Research and Development Alliance (WIRADA) between the Bureau of Meteorology and CSIRO, and the university sector.

Keywords: Climate, Water, Forecasts, Streamflow, Seasonal, Statistical, Dynamic, Model

1. INTRODUCTION

A seasonal water forecasting service has been needed in Australia for many years, and the Australian Government’s recent investment in water information is addressing this need. Skilful and reliable seasonal forecasts of streamflows are highly valuable for providing water allocation outlooks, informing water markets, planning and managing water use and managing drought. The opportunity for the Bureau to expand its seasonal forecasting service is a result of its new responsibilities, which largely came about because of the impacts of the prolonged drought. In early 2007, the Australian Government announced ‘Water for the Future’, a \$12.9 billion water investment program. This included \$450 million for the ‘Improving Water Information Program’ administered by the Bureau and backed by the *Commonwealth Water Act 2007* and key stakeholders.

We will describe the Bureau’s evolving Seasonal Streamflow Forecast service and the opportunities and challenges in assisting water managers in using the service to make better water management decisions. This work is supported by key research groups from CAWCR, CSIRO and the university sector in Australia.

2. THE SEASONAL STREAMFLOW FORECASTING APPROACHES

Seasonal forecasts of water availability can be made using dynamical, statistical or hybrid modelling approaches (Figure 1). The statistical approach is based upon direct relationships derived from observed data and derived predictor indices. Many climate indicators based on atmospheric pressure and sea surface temperature (SST) anomalies have been linked to future seasonal rainfalls. Such relationships have been exploited to forecast streamflow several months or seasons ahead.

The Bureau launched a new Seasonal Streamflow Forecasting (SSF) service in December 2010. The service delivers probabilistic forecasts of streamflow volumes for the next three months at a site or total inflows into major water supply storages (<http://www.bom.gov.au/water/ssf>). The operational service is based upon the Bayesian joint probability (BJP) modelling approach to streamflow prediction at multiple sites, developed by Wang et al. (2009) within the auspices of the Water Information Research and Development Alliance Program (WIRADA) between CSIRO and the Bureau. This approach assumes that a set of predictors and predictands is described by a Box-Cox transformed multivariate normal distribution. The predictors and predictands are linearly related and a Bayesian inference of model

parameters and uncertainties is implemented using with Markov chain Monte Carlo sampling. Continuous probabilistic forecasts of future streamflows for the next three months are produced. This approach overcomes many of the limitations of previous statistical prediction techniques. The model flexibility and data handling capability has enabled the BJP modelling approach to be applied widely across Australia.

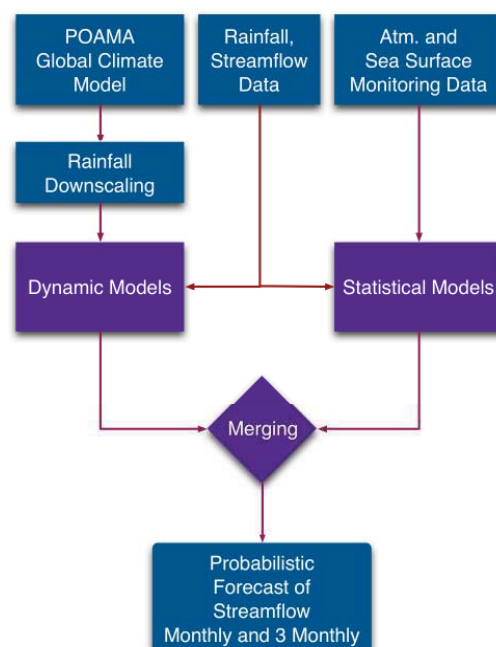
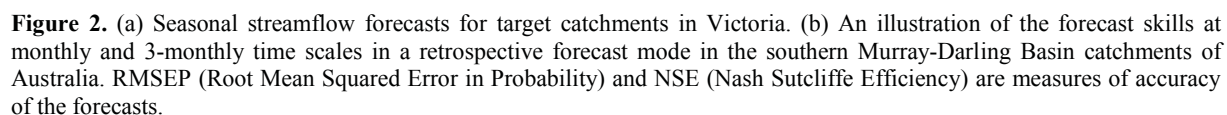


Figure 1. Seasonal streamflow forecasting approaches.

The Bureau has a keen interest in rigorous treatment of predictive uncertainty in hydrologic modelling, particularly in the context of seasonal forecasting. We use the ‘Bayesian Total Error Analysis (BATEA)’ framework for hydrologic model calibration including the estimation of forecast uncertainty in the dynamic approach. The BATEA technology has been developed by researchers from the University of Newcastle (UoN), Australia, and the University of Adelaide (UoA), Australia. The science underpinning BATEA has been extensively reviewed, and published in leading hydrology and water resources journals (e.g. Kavetski et al., 2006). It explicitly formulates the statistical models of errors in the observed input/output data and the model structure and exploits modern Bayesian techniques to process this information into probabilistic parameter estimates and model predictions.

Accuracy and reliability of the seasonal streamflow forecasts are assessed using rigorous verification methods through the use of a variety of skill scores and reliability diagrams. The current service has achieved the performance thresholds established from user needs analysis conducted with the water managers (Figure 2a). Streamflow forecasts derived from the statistical approach in the current service are shown to be accurate and reliable. Comparison of monthly and three monthly streamflow forecasting capability from the dynamic approach indicates that we can deliver monthly streamflow forecasts as accurate and reliable as three monthly streamflow forecasts (Figure 2b). Bias-corrected streamflow forecasts derived from the dynamic approach have comparable skills than those from the statistical BJP model. Therefore, we believe that blended streamflow forecasts derived from a combination of statistical and dynamic approaches in future work are likely to provide better streamflow forecasts. Research is also currently underway on increasing forecast lead times beyond 3-months.



We acknowledge the contributions of a large team of scientists from the Bureau, CSIRO, CAWCR and the university sector in Australia. The work is funded through Water Information Program of the Australian Government.

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PROBABILISTIC HYDROLOGIC FORECASTING WITH SHORT TO LONG LEAD-TIME AT THE U.S. NATIONAL WEATHER SERVICE

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Abstract: The U.S. National Weather Service (NWS) has been developing and prototyping a new Hydrologic Ensemble Forecast Service (HEFS) and is now implementing HEFS operationally. HEFS will provide short to long lead-time, ensemble-based, probabilistic, hydrologic forecasts. HEFS hydrologic and hydraulic models will be driven by debiased weather forecasts from numerical weather prediction (NWP) models. The hydrologic forecasts will also be debiased and have lead times ranging from hours to almost a year without discontinuities across the lead-times. NWS has been delivering seasonal hydrologic forecasts since the 1940s using regression techniques. In the late 1970s we began adding probabilistic forecasts based on ensembles driven by current conditions and historical time series. The forecasts have been used successfully for water supply, stream flow and flood forecasting and in the future will be used for complex water supply system operation including control of water quality.

Keywords: *Streamflow, Soil Moisture, Flood, Drought, Water Resources Management*

1. INTRODUCTION

The National Oceanic and Atmospheric Administration's (NOAA) NWS provides river and flood forecasts and warnings for the protection of lives and property, as well as hydrologic forecast information for environmental and economic well being, including the management of water resources in the U.S. Forecasts are provided with lead times of hours through to almost a year. They are provided in both deterministic and probabilistic terms. Numerical weather prediction (NWP) systems have improved in quality and now show appreciable skill for hydrology beyond 3-5 day lead-times.

I will describe how we will take advantage of that skill by introducing probabilistic, hydrologic forecasts driven by NWPs. I also will provide an overview of the history of development of the longer lead-time hydrologic forecasts as a background for discussing our experience with various forecasting technologies. I will illustrate the nature of the hydrologic models used and the types of data incorporated into the models. I will conclude by showing examples of the use of these forecasts for making water management decisions.

2. THE HYDROLOGIC ENSEMBLE FORECAST SYSTEM (HEFS)

In 2007, based on known and expected improvements in the quality of NWP systems, the NWS Office of Hydrologic Development (OHD) began the design and scientific development of a prototype eXperimental Ensemble Forecast System (XEFS) (Demargne et al., 2012). In a departure from past practice (see ESP below), the hydrologic ensembles are generated by running multiple instances of detailed models of the target river system with current starting conditions. The repetitions are based on the forcing ensembles from the weather models. The weather forcings (currently precipitation and temperature) are generated by debiasing NWP outputs to improve their skill and reliability. The Meteorological Ensemble Forecast Processor (MEFP), which operates on the NWP outputs, also considers the time/space scale of the hydrologic models in each basin and the climatology of the temporal distribution of those forcings. MEFP can also incorporate explicit deterministic forecasts created by human forecasters. XEFS incorporates forecasts from a short, medium and long range NWP blending between them and climatology in the time dimension, based on relative skill at each forecast period. The blending process is designed to avoid discontinuities resulting from the overlap of different NWP forecasts.

The ensemble of outputs produced by repeated runs of the hydrologic models are also debiased to provide a reliable and skilful set of hydrologic forecast ensembles. The step of debiasing outputs from the hydrology accounts for error from a variety of sources such as observations, and the structure, physics, and parameterization of the hydrologic models. The error in the meteorological forecasts is represented in the debiased meteorological ensembles. An Ensemble Verification System (Brown et al., 2010) was also developed to assess the quality of the resulting forecasts both post-event, and by the forecaster during forecast production.

In 2011, following scientific verification at OHD and extensive prototyping at NWS River Forecast Centers, NWS began the transition of the prototype to operations by preparing HEFS (Fresch et al., 2013). HEFS will be implemented in phased deliveries of increasing useability and reliability taking place from Spring 2012 through 2013. The implementation includes testing at five of the thirteen NWS River Forecast Centers. HEFS requirements are based on assessment of the prototype system as well as user needs and user feedback on the prototype. A team largely comprised of operational forecasters from the River Forecast Centers developed the

requirements. Personnel whose normal duties involve assessing user needs and evaluating NWS performance in meeting those needs led the requirements team.

HEFS has been designed to incorporate forecasts from the NWS' Short Range Ensemble Forecast (SREF) system, the Global Ensemble Forecast System (GEFS) and the Climate Forecast System (CFS). However that interface will readily incorporate other NWP. These three NWPs are each targeted at different lead times. In the future HEFS will be modified to incorporating forecasts from multiple NWPs for the same lead-time, taking appropriate account of their relative skill in various dimensions.

3. REGRESSION TECHNIQUES AND ENSEMBLE STREAMFLOW PREDICTION (ESP)

NWS has been delivering seasonal hydrologic forecasts since the 1940s using regression techniques. In the late 1970s we added Extended Streamflow Prediction (ESP) (Day, 1985) which provided probabilistic forecasts based on ensembles of the output of models of the hydrologic system driven by current conditions and historical time series. ESP addressed seasonal lead-times. In the last decade the term ESP was redefined as "Ensemble Streamflow Prediction" in recognition of the NWS' new use of ensembles to provide short and medium lead-time forecasts as well as seasonal. Both the regression and ESP techniques worked well in areas where river flow was based primarily on snowmelt. Regression technique performance suffered under conditions of early or late melt or unusual rainfall. ESP went a long way to overcoming these limitations. The use of observed forcings from each of the prior 30 years as a surrogate for future conditions provided a reasonable representation of future possibilities. The advent of NWPs with appreciable skill for hydrologic forecasting created an opportunity to make direct use of NWP forecasts rather than using past history as a surrogate.

4. WATER SUPPLY FORECASTING

ESP is currently the primary basis for NWS water supply forecasts in the U.S. Particularly in the western U.S. where the primary source of water is snow melt, management of water resources relies heavily on joint seasonal water forecasts prepared by NWS and the U.S. Department of Agriculture's Natural Resources Conservation Service. The "Pick-Sloan" reservoir system on the Missouri River, the Colorado River system including Hoover Dam, and the Columbia River system are examples of systems, which rely on these forecasts. They are operated to balance multiple purposes including urban and agricultural water supply, hydropower generation, thermal power cooling, navigation, recreation, and the health of fish habitat and other ecosystems.

5. FLOOD FORECASTING

Using ESP, NWS forecast major flooding, months in advance, in the Missouri River Basin in 2009, 2010, 2011. The reliability and long lead-time of the forecasts allowed the U.S. Army Corps of Engineers to release water from the reservoir system well in advance to mitigate the impact of flooding. Communities in the path of the floods conducted further mitigation efforts through sandbagging, evacuations and protection of major facilities such as nuclear power plants.

6. COMPLEX WATER SUPPLY SYSTEM OPERATION

New York City is faced with challenges in meeting environmental and water quality regulations for the extensive system that supplies their water. Furthermore they'd like to manage their water supplies more efficiently. They are building a complex new water management system which will rely largely on moving and selectively withdrawing water based on HEFS probabilistic forecasts rather than building new and expensive physical infrastructure for water treatment.

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USE OF SEASONAL CLIMATE FORECASTS FOR WATER RESOURCES MANAGEMENT IN KOREA: LIMITATIONS AND FUTURE

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Abstract: This paper discusses problems employing climate information for hydrological forecasting and water resources management in Korea. Some methodologies which have been developed by the Hydrology Research Group of Seoul National University to solve the current problems are presented as examples. It is concluded that current climate information is limited but worthwhile to be utilized for hydrological forecasting as well as for the water resources management in Korea and that there is need for further research.

Keywords: *Climate forecast, Ensemble prediction, Hydrologic forecasting, Korea Meteorological Administration (KMA), Water resources management*

1. INTRODUCTION

Like other developed countries, the accuracy of medium and long-term forecasts has been improved in Korea due to a better understanding of the interactions between global and regional climate systems. However, the application of meteorological forecasts for water resources management in Korea is still limited to short-term applications such as flood mitigation. This is because the format of the available climate forecasts is not flexible enough to be easily utilized for water managers and because the value of using climate forecast information in such a manner has not been well verified thus far. To solve these problems in Korea, the Hydrology Research Group of Seoul National University has been working on a series of studies such as (1) a diagnosis of the accuracy of the available climate forecasts of the KMA (Korean Meteorological Administration), (2) the development of methodologies to utilize the available climate forecasts of the KMA for hydrological forecasting, and (3) an assessment of the value of using climate forecasts for water resources management. Although this paper merely summarizes some specific examples, it is expected the demand in Korea for such research is significant.

2. DIAGNOSIS OF THE ACCURACY OF KMA CLIMATE FORECASTS

Climate forecast data has become an important factor in streamflow prediction since the accuracy of the data has improved as a result of the increased understanding of climate systems and ENSO and the improvement of meteorological models. Lee et al. (2006) investigated available climate forecast information to improve extended streamflow predictive measurements used in Korea such as the MIMI (Monthly Industrial Meteorological Information) and the GDAPS (Global Data Assimilation and Prediction) and measured their accuracies. While the GDAPS gives deterministic climate forecasts twice a day with a prediction period of 240 hours, MIMI forecasts the most probable ranges of monthly temperatures and rainfall. When Lee et al. (2006) evaluates the forecasts, both the MIMI and the GDAPS were superior to simple forecasts and performed better during the flood season.

3. DEVELOPMENT OF METHODOLOGIES TO UTILIZE KMA CLIMATE FORECASTS FOR THE HYDROLOGICAL FORECASTING

The Ensemble Streamflow Prediction (ESP) approach was first introduced in 2000 by the Hydrology Research Group (HRG) at Seoul National University as an alternative probabilistic forecasting technique for improving the 'Water Supply Outlook' which is now issued every month by the Ministry of Construction and Transportation in Korea. That study motivated the Korea Water Resources Corporation (K-water) to establish their seasonal probabilistic forecasting system for 5 major river basin areas using the ESP approach.

In addition to the practical aspects, the recent research on ESP has raised some concerns regarding ways of improving the accuracy of ESP in Korea. Lee et al. (2006) showed that ESP accuracy could be improved using climate forecast information such as the MIMI and GDAPS of the Korea Meteorological Administration. Stedinger and Kim (2010) proposed a simple but general probability adjustment procedure for creating climate-series/probability sets which reflect historical frequencies adjusted for climate forecast information. The proposed adjustment is based on a frequency model of the unconditional and conditional distributions of key variables. This framework allows derivation of a consistent and smooth set of probabilities for climate series across the entire range of the key variables reflecting the changes in the likelihood of each individual climate series. Kang et al. (2010) applied the Schaake shuffle (Schaake et al., 2007), Quantile mapping, and the PDF-

ratio (Stedinger and Kim, 2010) to update ESPs with the categorical forecasts offered by the KMA and the deterministic forecasts of a regional climate model called the SNURCM (Seoul National University Regional Climate Model). This research carried out a comparison study of the various combinations of these updating techniques. When the updated ensemble is compared to simple meteorological ensembles, the improvement rate was up to 8.7 %.

For developing a monthly and weekly drought outlook, Kim et al. (2012) proposed ESP based techniques updated using the MIMI and GDAPS. A drought index, the surface water supply index (SWSI), was modified and used for drought outlooks. The modified SWSI creates values which are similar in magnitude to those of the Palmer index (Garen, 1993) and match the SWSI range with the well-known PDSI. The drought outlooks offer a most-probable range which is categorized based on the modified SWSI. Application to the Geum River basin in Korea showed that the accuracy of the monthly drought outlook is expected to improve as the climate forecast accuracy increases and the weekly outlook with the GDAPS also performed better than the simple forecasts. In order to assess drought conditions, Ann et al. (2012) selected two indices- the Standardized Precipitation Index (SPI), which is a meteorological index, and the Soil Moisture Index (SMI), an agricultural index- and the long-range forecasts provided by the KMA, to target the Korean peninsula. Based on the interval forecasts provided by the KMA, the forecast probability of the corresponding intervals were differentiated and optimized for each study basin by modifying the probability adjustment coefficient. Probability forecasts established in this manner were applied to three basins in Korea and the results for both the SPI and SMI were proved accurate.

4. ASSESSMENT OF THE VALUE OF USING FORECASTS FOR WATER RESOURCES MANAGEMENT

Eum et al. (2010) proposes a new monthly Ensemble Streamflow Prediction (ESP) forecasting system which can update the ESP in the middle of a month to reflect the meteorological and hydrological variations during that month. The reservoir operating policies were determined based upon a stochastic dynamic programming sampling model using ESP scenarios. The application results clearly demonstrate that updating the ESP scenario improves the accuracy of the forecasts and consequently their practical benefit. This study also proves that the accuracy of the ESP scenario, particularly when high flows occur, has a considerable effect on reservoir operations. The water shortage in the well forecasted years with ESP is reduced by 20 % as compared to that in the poorly forecasted year.

5. CONCLUSIONS

The past research examples of the HRG at Seoul National University verified that current climate information is limited but worthwhile for use in hydrological forecasting as well as for water resources management in Korea. Since each country issues its climate forecasts in its own format and their accuracies are all different, it is necessary for countries to develop their own methodologies to utilize climate forecasts and verify their worth when incorporating them into water resources management. Moreover, hydrological research should be updated as new climate information is made available in the future.

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RESEARCH ON EXTREME EVENTS AND WATER RESOURCES AT THE CLIMATE PREDICTION CENTER

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Keywords: drought, extreme events, prediction

1. INTRODUCTION

The CPC mission is to deliver climate prediction, monitoring and diagnostic products for timescales from weeks to years to the Nation and the global community for the protection of life and property and the enhancement of the economy. One of the climate strategy priorities is the NIDIS to monitor and predict drought and floods and to give integrated services for decision support.

We routinely produce the Drought Outlook and participate in the Drought Monitor operation. To support the operational functions, we monitor the drought and water resources. The monitoring and prediction efforts are the collaboration of CPC, National Weather Service regional centers and universities. Information can be found at the CPC web site (<http://www.cpc.ncep.noaa.gov/products/Drought>)

2. DROUGHT MONITORING

The drought monitoring is based on the drought indices, which are designed to provide objective measures of drought severity and to facilitate drought classification. Keyantash and Dracup (2002) suggested three types of droughts. Meteorological drought is defined by precipitation (P) deficits and is often measured by the standardized precipitation index (SPI) (Mckee et al. 1993, 1995). Agricultural drought is caused by soil moisture (SM) deficits. Total soil water storage or SM anomaly percentiles are now commonly used to monitor agricultural drought (Andreadis et al. 2005). Hydrological drought is reflective of runoff deficits, which can be monitored by using the standardized runoff index (SRI) or streamflow anomaly percentiles (Shukla and Wood 2008, Mo 2008).

While precipitation station data are available over the CONUS from the 1850s to present, there are few long-term, in-situ measurements of SM. Therefore, we rely on the North American Land Data Assimilation System (NLDAS) to obtain information on the SM percentiles and runoff. SM and runoff from the NLDAS systems depend on the model and input forcing. There are two NLDAS systems operating in near real time and we use them routinely for monitoring. One system is from the National Centers for Environmental Prediction (NCEP) and another system is from the University of Washington. Each system has four land surface models and they derive forcing terms differently. The NCEP uses the CPC unified precipitation and other input forcing terms are derived from the North American Regional Reanalysis. The UW system uses precipitation and temperature from index stations. Research indicates that there are large uncertainties among the NLDAS systems.

We performed an assessment of differences in drought characteristics estimated using both systems for the period 1979-2008. For SM percentiles and runoff indices, differences are relatively small among different land surface models in the same system. However, the ensemble mean differences between the two systems are large over the western United States – in some cases exceeding 20% for SM and runoff percentile differences. These differences are most apparent after 2002 when the NCEP system went into real-time operation (the UW system went into real-time operation in 2005). We report experiments that show that precipitation forcing differences are the primary source of the SM and runoff differences. While temperature, short wave and long wave radiation and wind speed forcing differences are also large after 2002, their contributions to SM and runoff differences are much smaller than precipitation.

3. DROUGHT PREDICTION

For drought prediction, we have the ensemble flow prediction (ESP) from the University of Washington and the hydroclimate forecast system based on forcing derived from the Climate Forecast system version 2 (CFSv2) after bias correction and downscaling. In the near future, we will use the multi model ensemble based products.

For the hydroclimate forecasts over the western interior United States, skill on short lead times comes from the persistence of the initial conditions. Therefore, accurate hydrologic states at the initial forecast time are crucial for successful hydroclimate forecasts. For example: The SM seasonal forecasts taken directly from the CFSv2 have lower skill in comparison to forecasts based on persistence because of the errors in the SM, temperature and snow water equivalent due to the spin up problems.

The CFSv2 daily precipitation and temperature forecasts can be used to derive forcing. The forcing in turn drives a land surface model such as the Variable Infiltration Capacity (VIC) model to obtain SM and runoff forecasts (CFSv2_VIC). For

short term prediction at one to two months lead, the ESP forecasts which have accurate initial conditions and have the knowledge of seasonal cycle have higher or equal skill in comparison with the CFSv2_VIC especially over the western interior region. In the areas, rainfall depends on the dynamical path of the low level flow, the CFSv2_VIC can contribute. For CFSv2_VIC to have equal or high skill than the ESP, the global model needs to have skillful precipitation forecasts at lead time 2 months or longer.

4. GLOBAL DROUGHT INFORMATION SYSTEM

In the next few years, we will participate in developing the Global Drought Information System. It is a coherent integrated drought information system on global drought development around the world. The objective component comes from the observational data and the Global Land Data Assimilation System (GLDAS). The forecast component includes drought forecasts from the multi model ensemble project and drought indices from operational centers. We welcome the participation of the APEC.

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MAKING THE BEST USE OF GCM OUTPUTS FOR SEASONAL STREAMFLOW FORECASTING

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Abstract: Skilful forecasts of rainfall are critical to seasonal streamflow forecasting. Current general circulation models (GCMs) still have only very limited skill in forecasting rainfall. We explore a number of ways to best use GCM outputs to improve seasonal rainfall forecasts. We show that greater spatial and temporal coverage of positive forecast skill can be achieved by merging calibration and bridging forecasts based on GCM outputs. Merging rainfall forecasts of multiple international models can further enhance the skill.

Keywords: *Seasonal rainfall forecast, seasonal streamflow forecast, general circulation model, calibration, bridging, merging*

1. INTRODUCTION

Seasonal forecasts of streamflows are valuable for water resources management. The Australian Bureau of Meteorology provides a seasonal streamflow forecasting service, issuing on the 7th day of each month forecasts of flow volumes in the next three months at over 50 locations. The forecasts are produced using a Bayesian joint probability approach (Wang et al. 2009). The approach is based on two sources of predictability of streamflows: catchment wetness and future climate conditions. Most of forecast skill comes from knowledge of initial catchment wetness, with little contribution from climate information. This is also true for forecasting systems based on dynamical climate and hydrological modelling. This is because the skill of rainfall forecasts from general circulation models (GCMs) is still very modest at catchment scales. For this reason, improving rainfall forecasts is critical to improving streamflow forecast skill and to extending forecasts out to longer range.

In this study, we investigate methods for making the best use of GCM outputs for improving rainfall forecasts and thus seasonal streamflow forecasts. We compare three methods of statistically post-processing GCM output for forecasting Australian seasonal rainfall. We also report findings from our research on merging statistical and dynamical forecasts, merging forecasts from multiple international GCMs, and generating monthly rainfall forecasts to long lead times.

2. METHODS AND KEY FINDINGS

The GCM used in this study is the Predictive Ocean Atmosphere Model for Australia (POAMA), developed and operated by the Australian Bureau of Meteorology. To post-process the GCM outputs, we establish multiple single-predictor models to forecast seasonal rainfall. If the predictor variable is raw GCM rainfall, we refer to the model as a forecast calibration model. If the predictor variable is an SST-based climate index, we refer to the model as a forecast bridging model. Three calibration models are established using seasonal mean rainfall from three variants of POAMA. Six bridging models are established using POAMA forecasts of well known climate indices in the Pacific and Indian oceans. The Bayesian joint probability modelling approach is used to infer the parameters of each model and to produce probabilistic forecasts. Forecasts from individual models are then weighted and merged using a Bayesian model averaging method (Wang et al. 2012). Forecast skill and reliability are assessed using leave-one-out cross-validation for the period 1980-2010. Skill is also analysed in the short independent period 2011-2012.

We compare the forecasting skill of the calibration and bridging models separately, and also their combined skill. As separate groups, the calibration and bridging forecasts are skilful in certain seasons and locations. Whilst there are overlaps in skill, there are seasons and locations where the calibration or bridging forecasts are uniquely skilful. The merged calibration and bridging forecasts represent a significant improvement in spatial and temporal coverage of skilfulness. The left panel in Figure 1 provides a summary of the forecast skills from calibration, bridging and their combination, and the right panel in Figure 2 shows the skill of the merged seasonal rainfall forecasts across Australia in 12 overlapping seasons.

The merged forecast ensembles are shown to reliably represent forecast uncertainty and have climatologies aligned with the observed. They are therefore suitable for use in further modelling such as for

seasonal streamflow forecasting. The merged calibration and bridging forecasts are also shown to outperform the calibration forecasts in the short independent period (2011-2012).

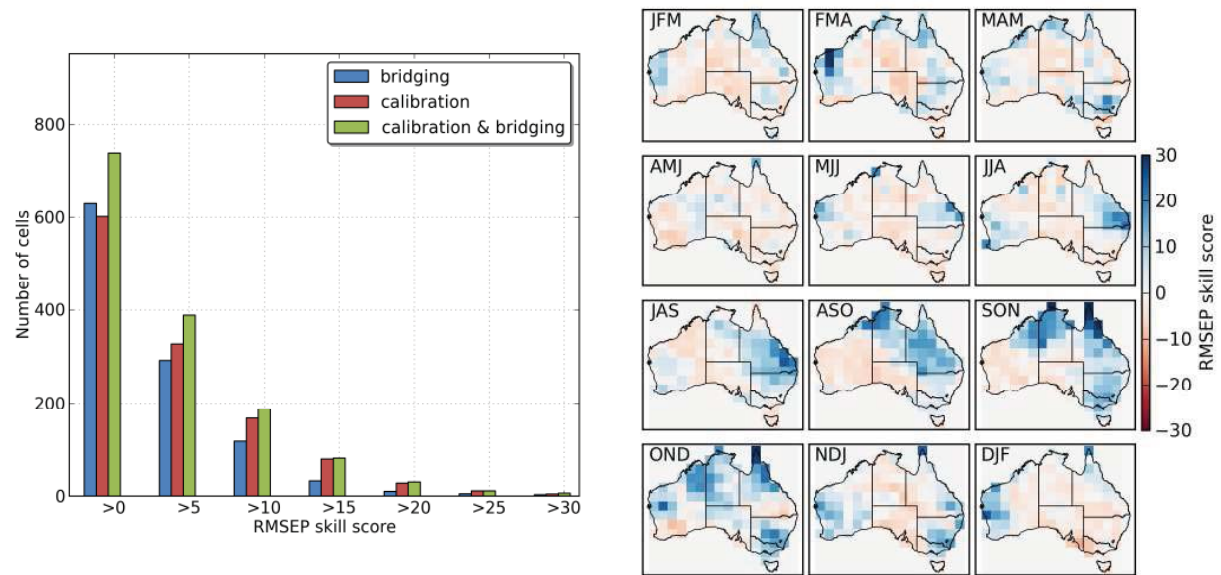


Figure 1. Skill of seasonal rainfall forecasts with 1 month lead time. Skill score expressed as percentage reduction in root mean squared error in probability (RMSEP) of forecast median from using climatology forecast median. Left: A comparison of calibration, bridging and their combination; Right: Skill distribution across Australia in 12 overlapping seasons.

3. DISCUSSIONS

The Bayesian joint probability and Bayesian model averaging methods are also used to establish statistical models for forecasting rainfall using monthly lagged observed climate indices as predictors, and to merge the forecasts with the POAMA calibration forecasts. The results are similar to merging POAMA calibration and bridging forecasts.

There are also forecasts from other international models that can be usefully merged with POAMA forecasts after appropriate calibration, because different models can have complementary skills for different regions and seasons. We apply the approach to three international models from the UK, ECMWF and Meteo-France modelling centres, all mapped to 2.5 degree resolution, and find that spatial and temporal coverage of positive forecast skill is much greater than using POAMA alone (Schepen and Wang, 2012).

Long lead rainfall and streamflow forecasts are highly valuable for planning and management of water resources. We establish multiple calibration and bridging models based on POAMA forecasts to produce monthly rainfall forecasts for Australia with lead times of up to 8 months. The skill of monthly rainfall forecasts is generally low. Compared to forecasting 3 month seasonal rainfall totals, it is more challenging to forecast monthly rainfall. However, there are regions and months for which forecasts are skilful. In particular, there are months of the year for which forecasts can be skilfully made at very long lead times.

Acknowledgement

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CASE STUDIES OF STREAMFLOW FORECASTING USING CLIMATE FORECASTING AND INFORMATION

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Abstract: It is widely acknowledged that climate variability modifies the spectrum of hydrologic events. Widespread research has demonstrated that these hydrologic events are often manifestations of climate anomalies, the most familiar of which is the El Nino/Southern Oscillation. In this regard, seasonal streamflow forecasts based on climate information can guide water managers toward superior reservoir operations, leading to improved water resources management efficiency. Uncertainty, however, is always present in seasonal streamflow forecasts, affecting the forecast value. Thus, a forecast should not be considered complete without a description of its uncertainty, which is critical for climate risk and water resources management. This paper explores the potential for seasonal prediction of hydrologic variables that are potentially useful for reservoir operations, and the associated uncertainties for Brazil, China, Taiwan and Korea.

Keywords: *Streamflow Forecasting, Climate Information, Bayesian Model, Nonstationarity*

1. INTRODUCTION

Water resources planning and management focuses on supplying a steady water supply amid hydrologic variability. Such variability occurs at many time scales, from hourly to daily and from seasonal to interannual and beyond. Engineering and management responses to hydrologic variability depend on the timeframe of the variability. Infrastructure, such as dams, typically responds to longer temporal variations. Seasonal forecasts of hydrologic variables potentially enable improved water management (Brown and Rogers, 2006). Reservoir operations, in particular, may benefit from a reduction in the uncertainty associated with future inflows (Kwon et al., 2012). Most studies of climate influence on hydrologic variables have focused on 3 month rainfall totals or streamflow (Kwon et al., 2008). As a result, their relative probability may be predictable. We investigate the climate teleconnections to the seasonal streamflow and the annual flood for China, Taiwan, USA and Korea. A prediction model for the streamflow is developed using a Hierarchical Bayesian Model (HBM) and climate indicators.

2. Methodology

A Hierarchical Bayesian based forecasting model is proposed to incorporate nonstationarity using time-dependent climate predictors. The objective of Bayesian inference is to compute the posterior distribution of the desired variables, in this case the parameters of the seasonal mean flow and the annual maximum flood distribution. Here, we present a method for incorporating climate information into updated estimates of the parameters for the distribution (e.g. Normal and Gumbel) used to represent the seasonal mean flow and annual maximum flood. The Bayesian Hierarchical regression is expressed in terms of both a location (mean) parameter $\mu(t)$ and a scale (standard deviation) parameter $\sigma(t)$, which both change with time, t . The parameters are hypothesized to be functions of climate indicators, such as SST and Snow Cover that are developed here and others, such as ENSO and PDO, that are generally recognized climate phenomena with expected local impacts. Using the Normal distribution, the distribution of seasonal mean flood $Y_{mean}(t)$ can be modeled as follows:

$$Y_{mean}(t) \sim Normal(\mu(t), \sigma(t)) \quad (1)$$

$$\mu(t) = \beta_0 + \beta_1 X_1(t) + \dots + \beta_K X_K(t) \quad (2)$$

Similarly, annual peak flow $Y_{peak}(t)$ can be modelled by using the Gumbel type extreme distribution ($Y_{peak}(t) \sim Gumbel(\mu(t), \sigma(t))$). where X_i , climate indices, are the i th rows of the known design matrices $\mathbf{X}$, and β is a vector of regression parameters which is normally distributed, $\beta \sim N(\mu_\beta, \Sigma_\beta)$. Similarly, the hyper-parameters μ_β and Σ_β are also assigned to a conjugate distribution.

3. Results and Discussion

This paper provides only one case study for China due to space limitations. A hierarchical Bayesian prediction model is developed for seasonal mean flow and annual peak flow at YHS using selected climate variables, specifically SSTs and snow cover. The best model for the peak flow as determined by the stepwise

regression procedure consisted of a quadratic model of the variables SST1, SST3, and SNOW. The strongest predictors were SST3 and the snow cover variable. These were retained for the final model of peak annual flow at YHS. The time series of observed peak flow and the values predicted with the Hierarchical Bayesian model with two predictors are shown in Figure 1. The model shows very good skill, with a correlation between observed and predicted peak annual flow of 0.73. The peak annual flood model was then used to estimate potential differences in a design flood based on the state of the predictor variables. Estimates of the annual flood value with 2% probability of occurring in a given year (50 year flood) were produced using the Bayesian model based on the predictors cited above. The time series shows nonstationarity in year to year flood risk. In other words, the volume of a 50 year design flood differs based on the state of the predictor variables. Each time series also includes the confidence interval based on the uncertainties associated with the parameter estimation. The figure also portrays the skill of the climate predictors in indicating the pronounced increases and decreases in flood risk inter-annually.

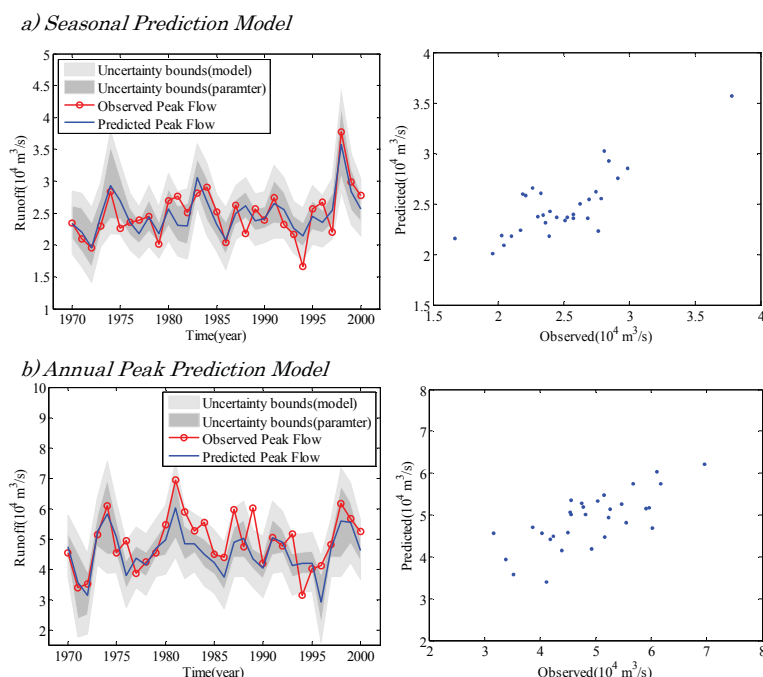


Figure 1. Time series of a) seasonal flow prediction results (solid line) and observed JJA streamflow (open circle), c) peak flow prediction results (solid line) and observed annual peak flow at Yichang Hydrologic Station using Hierarchical Bayesian regression with March-April-May values of SST1, SST2, SST3 and SNOW as predictors for 1970–2001. Scatter plot of b) seasonal flow prediction model and d) peak flow prediction model.

This study investigated the predictability of the seasonal mean flow and the peak annual flood. It also demonstrated the application of hierarchical Bayesian modelling for prediction of both peak annual and mean seasonal flow. The major advantage of the hierarchical Bayesian is that it allows an empirical estimation of the parameter uncertainty and higher confidence in the uncertainty bands accompanying the prediction. The model results show satisfactory predictive skill.

Acknowledgement:

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IMPACT OF MODEL IMPLEMENTATION AND NUMERICS ON THE RELIABILITY OF HYDROLOGICAL PREDICTIONS

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Abstract: Hydrological models, which route precipitation into streamflow, are a key component of the chain of models used to explore and estimate the impact of climate change and variability. They also form an integral part of general water resource modeling activities, including flood forecasting, water availability assessments, etc. The ability of hydrological models to produce useful predictions depends critically on their ability to approximate the dominant hydrological processes, whether explicitly (as in physically based models), conceptually (as in conceptual models) or using grey-/black-box models. This presentation focuses on a seldom recognized difficulty afflicting many current hydrological models, namely the robustness of their numerical implementation, in particular, of the time stepping schemes used to propagate storages from time step to time step. We review and summarize some recent findings along these research directions.

Keywords: Water, catchment hydrology, models, reliability

1. IMPACT OF TIME STEPPING SCHEMES ON MODEL PREDICTIONS

Conceptual hydrological models are popular in operations and research because, in many cases, they can provide adequate and relatively parsimonious descriptions of dominant catchment-scale processes at a low computational cost. As a result, these models are increasingly used as part of the chain of models used to evaluate environmental sustainability, estimate impacts of climate and land use changes, and plan for the future. As discussed in detail by Clark et al (2011) and others, in order for such models to produce useful predictions, especially in extrapolation, they must be physically realistic and computationally robust.

A key aspect of building and implementing a hydrological model, whether physical or conceptual, is the implementation of the storage equations using a numerical time stepping algorithm. Although implementation aspects have historically received little attention in the conceptual hydrological community (Kavetski and Clark, 2011), it is this step that is ultimately responsible for generating the model predictions.

Consider a simple bucket model $dS/dt = P - Q(S)$, where P is inflow and outflow Q is a function of the storage S at time t . When implementing the storage update over a time step Δt , the explicit Euler scheme is given by $S_{n+1} = S_n + \Delta t [P_n - Q(S_n)]$. This is computationally simple and is widely used in conceptual models (e.g., see review by Clark and Kavetski, 2010). The implicit Euler scheme differs from the explicit Euler scheme in using the solution at the end of the step to evaluate the outflow, and is given by $S_{n+1} = S_n + \Delta t [P_{n+1} - Q(S_{n+1})]$. Note that the implicit Euler solution requires iteration when the outflow Q is a nonlinear function of S . It hence requires more effort to implement and solve than the explicit scheme. However, the implicit Euler scheme is much more robust than the explicit Euler scheme, as evident from Figures 1 and 2 below.

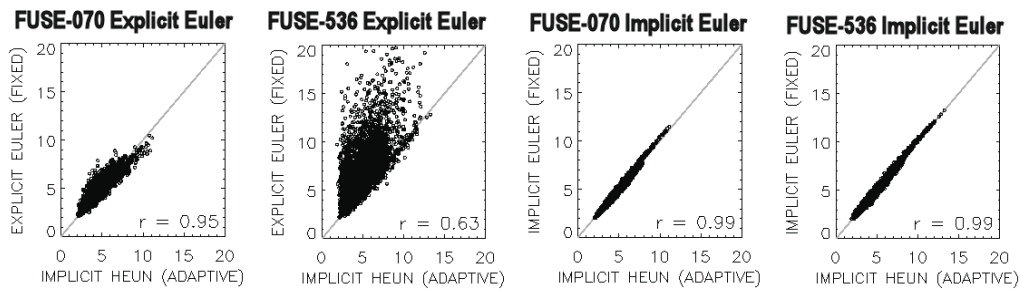


Figure 1. Numerical reliability of explicit Euler and implicit Euler time stepping schemes for conceptual hydrological models. Results shown for 2 hydrological models (FUSE-070 and FUSE-536, which differ in the number and connectivity of buckets, storage-discharge relationships, etc) applied to the Mahurangi catchment in New Zealand. The x-axes denote the root-mean-squared-error (RMSE) of an accurate solution of the conceptual model equations (obtained using adaptive substepping to satisfy a tight numerical error tolerance). The y-axes denote the RMSE of fixed-step time stepping schemes (with fixed daily steps). The dots represent 10,000 randomly-selected parameter sets (uncalibrated). It can be seen that using the explicit Euler scheme with fixed time steps (in this case, daily) can substantially increase the RMSE of conceptual hydrological models. This degradation is a spurious numerical artefact and can be avoided by solving the model equations using the implicit Euler scheme (still with daily steps). Figure adapted from Clark and Kavetski (2010).

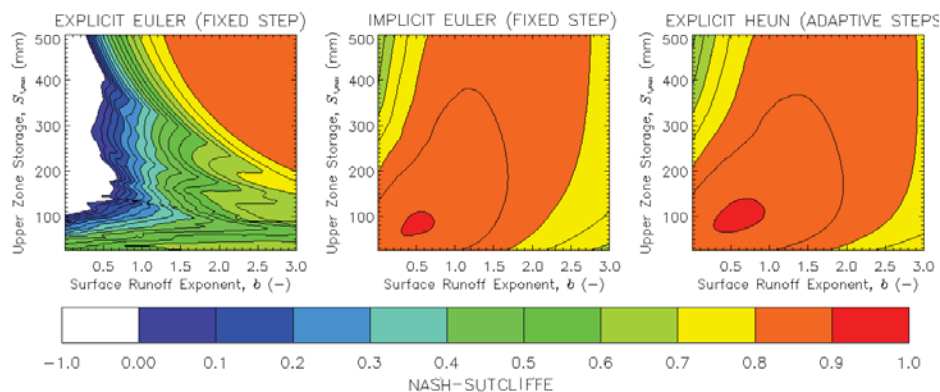


Figure 2. Numerical artefacts in the objective functions of hydrological models due to poor time stepping schemes. The panels above represent the objective function surface with respect to 2 model parameters (holding the remaining parameters fixed), based on the results of applying a hydrological model (FUSE-536) to the Mahurangi catchment in New Zealand. Exactly the same data, model equations and objective function were used – the difference is solely in the time stepping scheme used to implement the model equations. Massive distortions arising from using the explicit Euler scheme with fixed time steps (in this case, daily) can be seen. This will impact on parameter estimation, including determination of optimal parameter sets, and can be particularly problematic in extrapolation. Implementing the model equations using the implicit Euler scheme (still with daily steps) avoids these degeneracies and produces results of comparable quality to those obtained using an adaptive substepping scheme. Figure adapted from Kavetski and Clark (2010).

The significance of numerical artefacts should not be under-estimated. As found in studies based on several distinct hydrological models and several diverse catchments, numerical artefacts can produce staggering problems, most importantly (i) erroneous and/or misleading conclusions of sensitivity analysis, parameter inference and uncertainty estimation, and (ii) poor reliability of a calibrated model in predictive applications. (e.g., Kavetski and Clark, 2010, 2011). It is quite remarkable that such severe artefacts can arise literally depending on whether the start-of-step or end-of-step fluxes are used!

Switching to more robust time stepping schemes, in particular the implicit Euler scheme, notably reduces these problems. It is also possible to use higher order methods (e.g., the Heun scheme) and/or adaptive substepping (see Clark and Kavetski, 2010, for details). Our studies suggest that the implicit Euler scheme without substepping is adequate for typical conceptual hydrological models. Importantly from a practical perspective, it also tends to improve the performance of parameter optimization and uncertainty analysis algorithms. The more robust implicit Euler time stepping scheme is implemented in recent hydrological toolkits FUSE (e.g., Clark and Kavetski, 2010) and SUPERFLEX (e.g., Kavetski and Fenicia, 2011).

2. CONCLUSIONS AND RECOMMENDATIONS

The current generation of conceptual hydrological models, increasingly used in water planning studies and projections, climate impact assessments, etc, can suffer from severe weaknesses in numerical implementation. In particular, non-robust time stepping methods, such as the fixed-step explicit Euler scheme (widely used in conceptual hydrological models), can introduce severe overwhelming numerical artefacts into the model predictions. These artefacts can undermine the modelling conclusions, including sensitivities to changes in the forcings (e.g., rainfall), parameter values (e.g., representing land use changes), etc. In order to avoid these problems, it is necessary to use numerically robust time stepping schemes, such as the implicit Euler scheme. A number of hydrological toolkits such as FUSE and SUPERFLEX implement these robust solutions.

Acknowledgement

Portions of the figures presented in this work are adapted from referenced sources, including AGU publications.

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HYDROLOGICAL AND WATER ENVIRONMENTAL EFFECTS ON FUTURE CLIMATE CHANGE FOR NAKDONG RIVER BASIN IN SOUTH KOREA

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Abstract: This research introduced analysis techniques on water resources management affected by climate change in Nakdong river in South Korea. Hydrological and water environmental effects on future climate change are analyzed by elasticity method and SWAT model with future data from GCM-RCM.

Keywords: Climate Change, Elasticity Analysis Method, GCMs

1. INTRODUCTION

Climate change is now widely recognized as the major environmental and water resources problems facing the globe. Also, this is a significant and lasting change distribution of weather patterns over the periods from decades to millions of years. Serious problems in river, water resources, and water environment were caused by these phenomenon recognized as global matters in present. Effective plans coping actively with the changing circumstances are needed on sustainable development. For these reasons, GCM (General Circulation Model) being used around world is available to detect and forecast generating changes due to climate change. This research studied on the long term effects of climate change with elasticity analysis method and establishment of SWAT model with future precipitation and temperature data resulting in GCMs.

2. METHODOLOGY

Nakdong river on study area is one of the most important rivers in South Korea, which is 23,790 km² in watershed area and 510.36 km in stream length. This watershed has characteristics as follows: lots of mountain area, wide river width, flat area, as well as regular discharge. In the paper, two methods were used to analyze correlation between water quality and hydrological factors and forecast runoff over the future 90 years (2011-2100) divided into three periods as follows: F1 (2011-2040), F2 (2041-2070), F3 (2071-2100), which are elasticity analysis method being able to define the hydrological sensitivity of climate change and established SWAT model using GCMs as CNCM, CDMK, CT63, and MEPH based on A1B, A2, and B1 among the SRES scenarios.

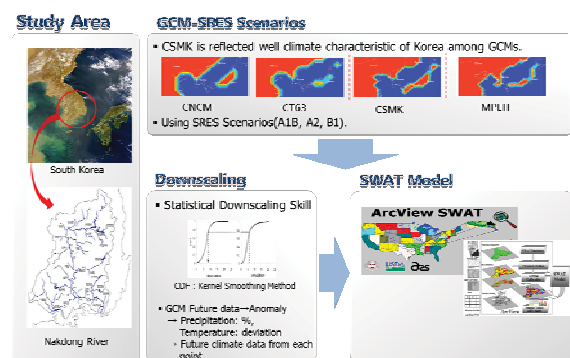


Figure 1. Flow chart for forecasting runoff of this study

3. RESULTS

Elasticity analysis method is compared with results of correlation among hydrological and water quality factors. The results showed that correlation analysis of air temperature-water temperature and water temperature-BOD was high level of elasticity in the summer and minus value of elasticity in the spring in most area except Nakdong river in the west. These phenomena were considered on account of an effect on the estuary in the river, in general, which were concluded by stagnation watershed not being smooth water current. Any other results, as relation to discharge-BOD and water temperature-BOD, were required most of the sites in the site are needed on the general plans of water quality management due to high level of elasticity in the winter. Figure 2 showed spatial distribution of air temperature elasticity on water temperature for each season at the site.

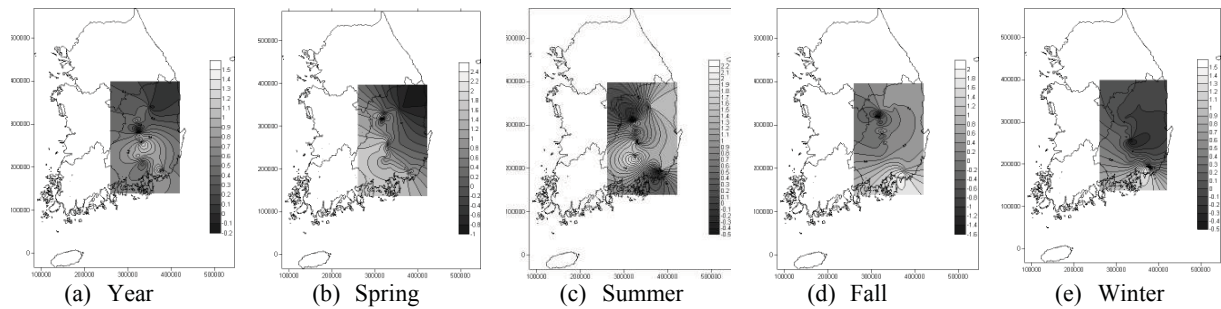


Figure 2. Spatial distribution of air temperature elasticity on water temperature at Nakdong river

The SWAT model established on Nakdong river resulted in forecasting discharge over the 90 years in the future as input data based on precipitation and air temperature from 2011 to 2100 produced by GCM-RCM. These results were obtained by four GCMs (CNCM, CDMK, CT63, MPEH) on the basis of A1B, A2, and B1 scenario in the present (1980-2009) and the future (2011-2100), especially future periods were divided into three periods as F1(2011-2040), F2(2041-2070), and F3(2071-2100). Figure 3 showed seasonal discharge at Jindong site in Nakdong river. This result is to assess effects on climate change in the far-off future for each season.

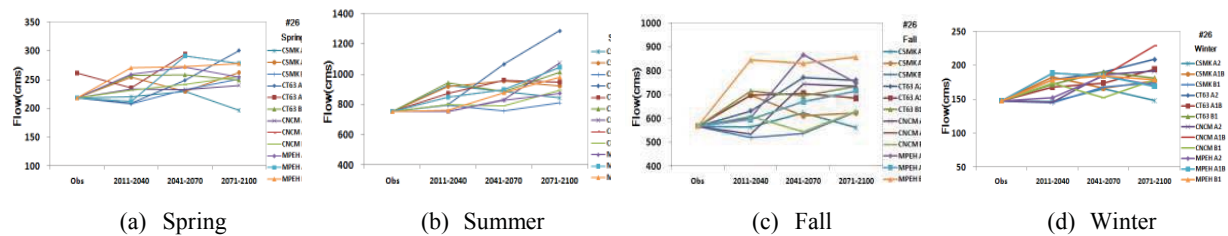


Figure 3. Climate change impacts on seasonal discharge at Jindong site based on various GCM scenarios.

In the following, application of the used methods for investigating the correlation between water quality and hydrological factors and climate change impact assessment is demonstrated using elasticity analysis method and GCM-SWAT model.

4. CONCLUSIONS

Overall, elasticity analysis method seems to be useful means for defining relation between hydrological and water quality factors. This study presents technical methodology for assessing influences on water environment and water resources. Also, this result expects to be quantitative and reliable data by applying to other rivers in studying climate change.

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EVALUATION OF THE AWS OBSERVED DATA APPLICATIONS FOR SHORT-RANGE STREAMFLOW FORECASTING

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Abstract: The objective of this study is to evaluate the valid forecast lead time and the accuracy when AWS observed rainfall data are used for real-time river flow forecast. For this, Namhan river basin is selected as study area and SURF model is constructed during flood seasons in 2006~2009. The simulated flow with and without the assimilation of the observed flow data are well fitted. Effectiveness index (EI) is used to evaluate amount of improvement for the assimilation. EI at Chungju, Dalcheon, Hoengsung and Yeosu sites as evaluation points show 32.08%, 51.53%, 39.70% and 18.23% improved, respectively. In the results of the forecasted values using the limited observed rainfall data in each forecast time before peak flow occur, the peak flow under the 20% tolerance range of relative error at Chungju, Dalcheon, Hoengsung and Yeosu sites can be simulated in forecast time - 11h, 2h, 3h and 5h and the flow volume in the same condition at those sites can be simulated in forecast time - 13h, 2h, 4h and 9h, respectively. From this results, observed rainfall data can be used for real-time peak flow forecast because of basin lag time.

Keywords: AWS observed rainfall, real-time river flow forecast, forecast lead time, SURF model

1. INTRODUCTION

When the forecast lead-time is greater than the sum of basin concentration time and flood propagation time on the channel system, rainfall observations are not sufficient for streamflow forecasting purposes since rain that has been transformed into runoff passes the basin outfall in the lead-time. Some estimate of future rainfall is therefore required if flow forecasts are issued up to the end of the lead-time. From this foundation, the rainfall observations are the key information for short-term flow forecasting in the mid-sized basin or more when the lead-time is shorter than the lag time. It's because the rainfall observations are more dominant to rainfall forecasts.

In this study, flows are forecasted by using the Sejong University River Forecast (SURF) model with the observed flow data assimilation (Lee and Bae, 2011). The runoff model is continuous rainfall-runoff model which is improved for estimating the hydrologic components such as potential evapotranspiration, surface flow, lateral flow and groundwater flow using physical foundations. The ensemble Kalman filtering (ENKF) (Evensen, 1994) technique is used for the observed data assimilation. This paper is going to assess a lower limit to the forecast flow given by setting all future rainfall equal to zero using observed rainfall and continuous rainfall-runoff model with observed flow assimilation using ENKF.

2. STUDY AREA

In this study, Namhan River basin is selected as the study area. This basin belongs to Han River basin that is the first major river in South Korea (Fig. 1). The basin area is 12,407 km², taking up 36.05% of the total basin area of Han river. Chungju dam, Goesan dam and Hoengsung dam are located in the basin. For discharge simulation, we divided the Namhan river basin into 17 sub-basins and collected the hourly rainfall data and the data on temperature, relative humidity, wind speed, and sunshine duration from the Korea Meteorological Administration for calculation of potential evapotranspiration.

3. APPLICATION AND RESULTS

Peak flow is important for river flood management, but peak flow and discharge volume are significant for dam. Therefore, we used both of the two indexes to evaluate the accuracy of measured streamflow. Fig. 2 shows the results of the relative errors in peak flow (RPE) and discharge volume (RVE). The forecast of streamflow is simulated by using only the measured rainfall until the current time assumed before the time of peak flow occurrence. In addition, if a dam existed in the upper stream, outflow was set at 0 m³/s for future period in the same way as the case with rainfall. In the figure, the value 0 on the X axis means the time of measured peak flow occurrence, and the value increasing in the left direction means the forecast lead time based on the time of peak flow occurrence.



Figure 1. Study Area

According to behavior of peak flow error at the forecast times for Chungju dam in Fig. 2 (a), the peak flow was underestimated for all periods in 2006. In 2007, it was found that the peak flow was overestimated until around 10 hours but was underestimated afterward. Furthermore, in 2008 and 2009, the peak flow was simulated well in general until 10 hours but simulated less afterward. Even though the measured rainfall for 10 hours before the time of peak flow occurrence was assumed to be 0 mm, the streamflow was simulated in a greater or similar level. The reason is believed to be that the lag time for Chungju dam was longer than around 10 hours. This means that the rainfall occurred in this period had little influence on peak flow. In addition, Fig. 2 (e) demonstrates that the error in discharge volume is within the range of 20% in the period of less than around 12 hours.

Fig. 2 (b) and (f) show the analysis results of peak flow error and discharge volume error in Dalcheon station. The forecast streamflow for all forecast lead times was simulated less than the measured streamflow. The results when only the discharge model was applied were estimated less than the measured values in all analysis periods. Therefore, it is believed that the forecast results after the assimilation were also underestimated. When the allowable error was assumed to be 20%, both of the indexes were found to be predictable within two hours on average.

The results from Hoengsung dam are shown in Fig. 2 (c) and (g). It was confirmed that when the streamflow forecast was performed only with measured rainfall, it was possible to precisely forecast peak flow and discharge volume within two hours. After the two hours, the error was found to increase significantly. The reason is believed that the basin area for Hoengsung dam was very small (209 km²) so that the lag time was less than three hours.

The results from Yeoju station are shown in Fig. 2 (d) and (h) with basin area in the upper stream of 11,104 km². Thanks to the continuous outflow from Chungju dam, Goesan dam and Hoengsung dam, the accuracy did not decrease dramatically. However, as the effect of outflow from dams in the upper stream was dominant, the valid forecast lead time was not as long as that of Chungju dam. When the allowable error was assumed to be 20%, it was possible to forecast that the peak flow was around five hours and the discharge volume was less than nine hours despite some differences according to type of discharge from dam in the upper stream.

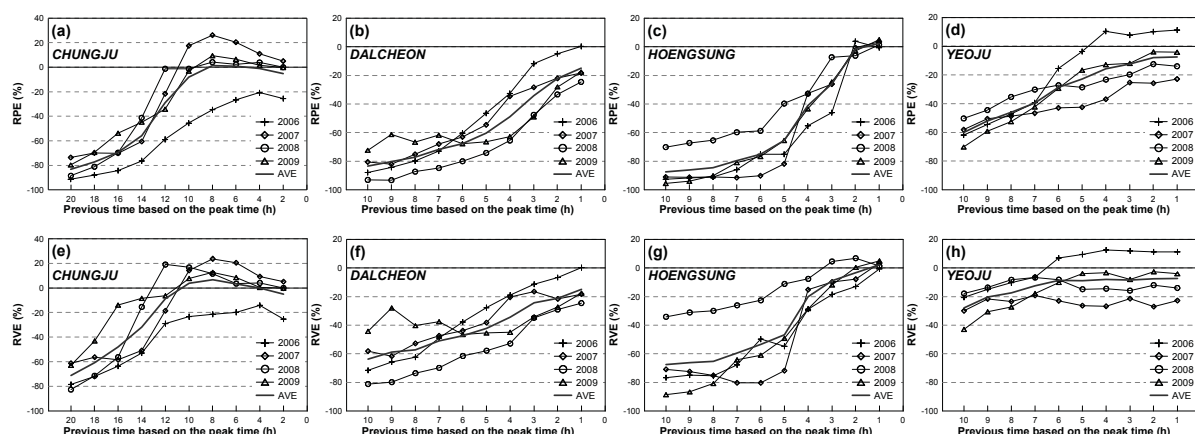


Figure 2. Relative peak flow error (RPE) and relative volume error (RVE) at the previous times based on the peak time on the 4 Sites

4. CONCLUSION

We evaluated the forecast possibility of peak flow and discharge volume by simulating streamflow based on the AWS real-time rainfall. The results showed that with the allowable error of 20%, the forecast was possible for the peak flow of 11 hours or less in Chungju dam, two hours or less in Dalcheon station, three hours or less in Hoengsung dam, and five hours or less in Yeoju station, and that the valid forecast was possible for discharge volume of 13 hours or less in Chungju dam, two hours or less in Dalcheon station, four hours or less in Hoengsung dam, and nine hours or less in Yeoju station. The aforementioned results verified that the forecast of peak flow and discharge volume was possible by using only the rainfall a few hours ago according to basin scale.

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EXPLORING CLIMATE RESEARCH APPLICATIONS OVER KOREA-JAPAN PENINSULA

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Abstract: While global models are nowadays extensively used for seasonal climate predictions by various international groups including the APEC Climate Center, some research results could be useful as guidance climate forecasts. A case is presented here to show possible benefits of research results for guidance climate forecasts. Recent studies by the authors (Kripalani et al. 2005, 2010) have shown that the extreme phase of the Indian Ocean Dipole Mode (IODM) during autumn (SON) could have an influence on the subsequent East Asian Summer (JJA+1) Monsoon (EASM) three seasons later. About 30 years (1975-2005) of data are used to draw these inferences. Based on this it is shown that the IODM could have been one of the factors responsible for the recent two extreme summer monsoons over Korea-Japan, drought during 2008 and floods during 2011. Possible mechanism for the delayed response three seasons later is suggested.

Keywords: *Indian Ocean, Dipole Mode, Climate, Korea-Japan*

1. INTRODUCTION

Studies have pointed out that a unique ocean-atmosphere mode exists in the Indian Ocean (IO), with anomalous warm SST over the western IO and anomalous cold SST over the eastern IO. This mode has been termed as the IODM (Saji et al. 1999). Most of the studies have focused on the simultaneous relationships between the IO and monsoon variability over the countries surrounding the rim of the IO. However Kripalani et al. (2005, 2010) proposed a delayed impact of the IODM on EASM as described below.

Analysis by the authors (Kripalani et al. 2005, 2010) suggests that the impact of the IODM is more on the remotely located EASM rather than the neighbouring South Asian Summer Monsoon. Results reveal that the peak positive phase of the IODM during autumn(SON) could suppress the following summer monsoon (JJA+1) activity over East Asia three seasons later, in particular over the Korea-Japan sector, South China and the adjacent West Pacific Region.

Composite and correlation analysis (Data 1975-2005) suggests that the autumn positive phase of the dipole could induce heavy snow over eastern Eurasia, just north of Korea-Japan during the following winter and spring seasons. This could transport cold and dry from north towards south over the warmer west Pacific region, weakening the low-level jet and displacing the North Pacific Sub-tropical High (NPSH) eastwards during summer. This could inhibit the moisture supply from the Pacific leading to subdued rainfall activity. The footprints of IODM could be carried by the snow distribution over eastern Eurasia.

2. FIGURES: EXTREME MONSOONS OVER KOREA-JAPAN

During autumn (SON) of the year 2007 a positive dipole prevailed over the IO with positive SST anomalies over the western IO and negative SST anomalies over the eastern IO (Fig.1a). Heavy snow over northern parts China during January was reported. This heavy snow could have been due to the positive dipole during the preceding autumn. During summer the NPSH weakened, leading to less moisture supply over the Korea-Japan sector. A severe drought prevailed over Korea-Japan and the adjoining regions (Fig. 1b)

On the other hand a negative phase of the dipole prevailed during SON 2010 with negative SST anomalies over western IO and positive SST anomalies over the eastern IO (Fig. 2a). NOAA satellite pictures indicated normal to below normal snow distribution over eastern Eurasia. The NPSH strengthened, leading to more moisture supply. There were unprecedented heavy rains over Korea-Japan during JJA 2011 (Fig.2b)

As seen in Fig.3 a positive dipole prevails over the India Ocean during SON 2011 and percentage of snow cover just north of Korea-Japan is in excess of 80% during Jan 2012. This probably suggests a subdued monsoon activity over Korea-Japan during JJA 2012. We need to wait and watch.

3. CONCLUSIONS

Though there cannot be one-to-one correspondence i.e. all positive dipoles need not necessarily result in drought over Korea-Japan since the correlation between these two indices is about -0.6 (variance explained 36%); nevertheless such information well in time may serve useful for water-resources managers.

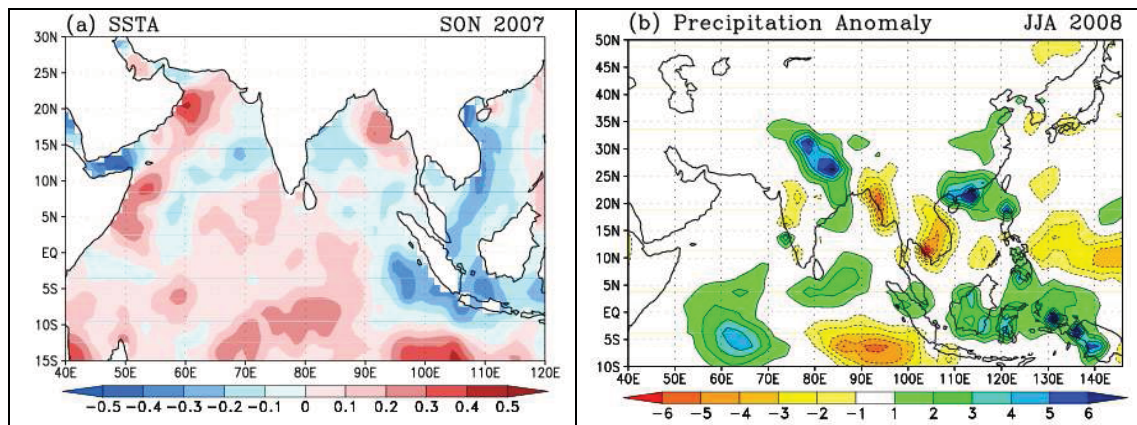


Figure 1. SST anomalies during SON 2007 (a) and precipitation anomalies during JJA 2008 (b)

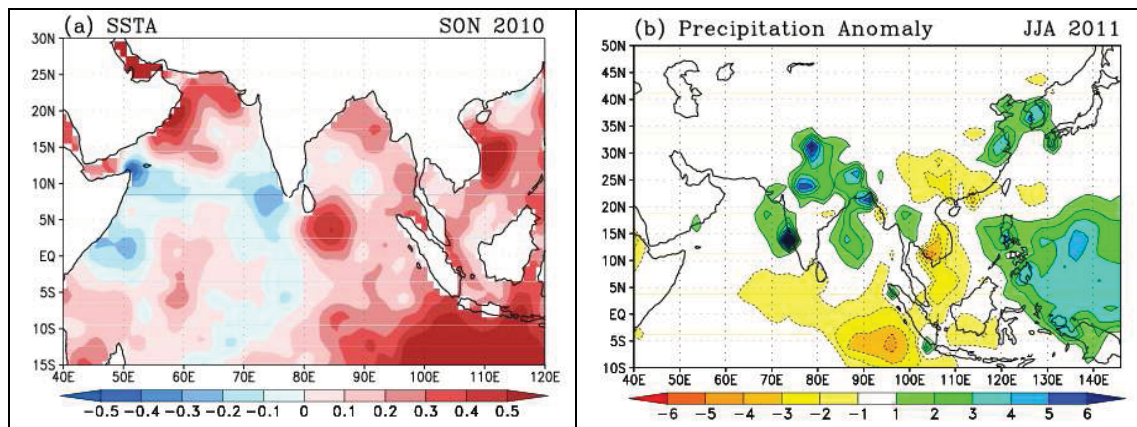


Figure 2. SST anomalies during SON 2010 (a) and precipitation anomalies during JJA 2011 (b)

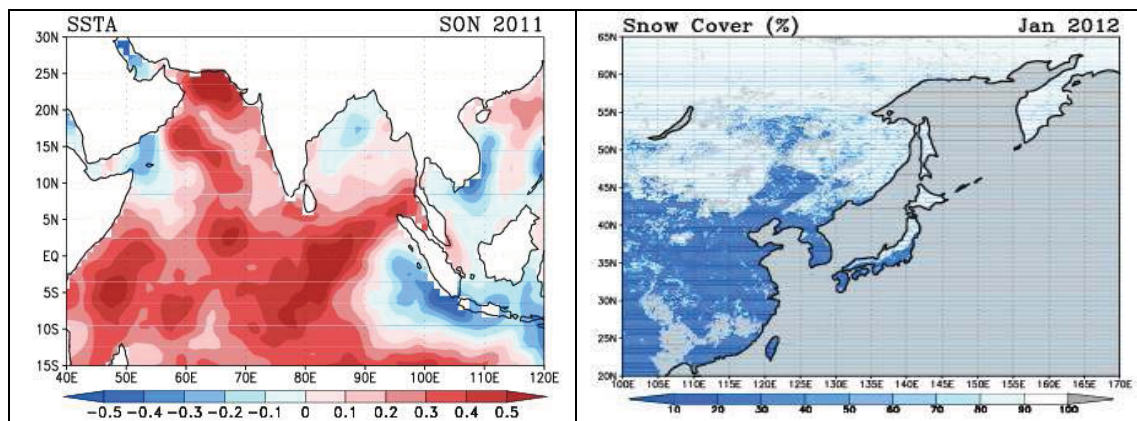


Figure 3. SST anomalies during SON 2011 and snow cover distribution in % for January 2012

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DEVELOPMENT OF A MULTIMODEL-BASED SEASONAL PREDICTION SYSTEM FOR EXTREME DROUGHTS AND FLOODS: A CASE STUDY FOR SOUTH KOREA

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Abstract: An experimental, district-level system was developed to forecast droughts and floods over South Korea to properly represent local precipitation extremes. The system is based on the Asia-Pacific Economic Cooperation (APEC) Climate Center (APCC) multimodel ensemble (MME) seasonal prediction products. Three-month lead precipitation forecasts for 60 stations in South Korea for the season of March to May are first obtained from the coarse-scale MME prediction using statistical downscaling. Owing to the relatively small variance of the MME and regression-based downscaling outputs, the downscaled MME (DMME) products need to be subsequently inflated. The final station-scale precipitation predictions are then used to produce droughts and flood forecasts on the basis of the Standardized Precipitation Index (SPI).

The performance of three different inflation schemes was also assessed. Of these three schemes, the method that simply rescales the variance of predicted rainfall to that based on climate records, irrespective of the prediction skill or the DMME variance itself at a particular station, gives the best overall improvement in the SPI predictions. However, systematic biases in the prediction system cannot be removed by variance inflation. This implies that DMME techniques must be further improved to correct the bias in extreme drought/flood predictions. Overall, it is seen that DMME, in conjunction with variance inflation, can predict hydrological extremes with reasonable skill. Our results could inform the development of a reliable early warning system for droughts and floods, which is invaluable to policy makers and stakeholders in agricultural and water management sectors, and so forth and is important for mitigation and adaptation measures.

Keywords: SPI, MME, statistical downscaling, variance inflation, seasonal prediction, extreme droughts and floods

1. INTRODUCTION

The recent global change occurring since late 1970s has resulted in changing frequencies and characteristics of the tropical Indo-Pacific phenomena such as El Niño and Southern Oscillation (ENSO), ENSO Modoki, and Indian Ocean Dipole (IOD), and consequently, their impacts globally. The changes have been associated with prolonged droughts and floods in many countries such as Australia, USA, Korea, etc. Droughts and floods result in tremendous economic, social, and environmental losses. Developing a good prediction system for the hydrological extremes is essential for minimizing such droughts and floods-related losses.

In this study, we seek to develop a reliable long lead, district-level MME-based prediction system for droughts and floods, using the downscaled MME (DMME) method and the inflation of the variance of the prediction products (Sohn et al. 2012). We implement a three-step procedure to produce a long lead, district-level MME-based prediction for extreme drought and flood events: The first step is spatial downscaling of precipitation data from multiple global models to stations across South Korea. Next, variance inflation is applied, as necessary, to calibrate the amplitude of the downscaling prediction. Three different approaches to correcting the variance of the Asia-Pacific Economic Cooperation (APEC) Climate Center (APCC) 3-month DMME precipitation forecasts (i.e., M1, M2, and M3; see Sohn et al. (2012) for more information) are evaluated. The final step is to produce drought and flood forecasts on the basis of the Standardized Precipitation Index (SPI) for each station location.

2. STATISTICAL DOWNSCALING

Figure 1 shows standard deviations of 3-month accumulated precipitation for March-April-May. The average accumulated spring rainfall in South Korea is approximately 80-440 mm, with some regional variation; the mean accumulated rainfall is about 300-400 mm on the southern coast, with Jeju Island receiving more than 400 mm in spring. Figure 3a shows that the largest variability is found in the southern coast locations, including Jeju Island, consistent with the mean rainfall distribution. The springtime precipitation is also influenced by the local terrain, resulting in large variability in the northeastern part of South Korea. Compared with observations, the MME average gives very low variance in precipitation (Figure 3b). Moreover, there is very little regional variation. For DMME, it gives larger variability in southern regions; nevertheless, the variance of the downscaling product is much less than the observed interannual variability. It is well known that the regression-based downscaling prediction tends to yield low variance, but this can be remedied by means of various inflation methods.

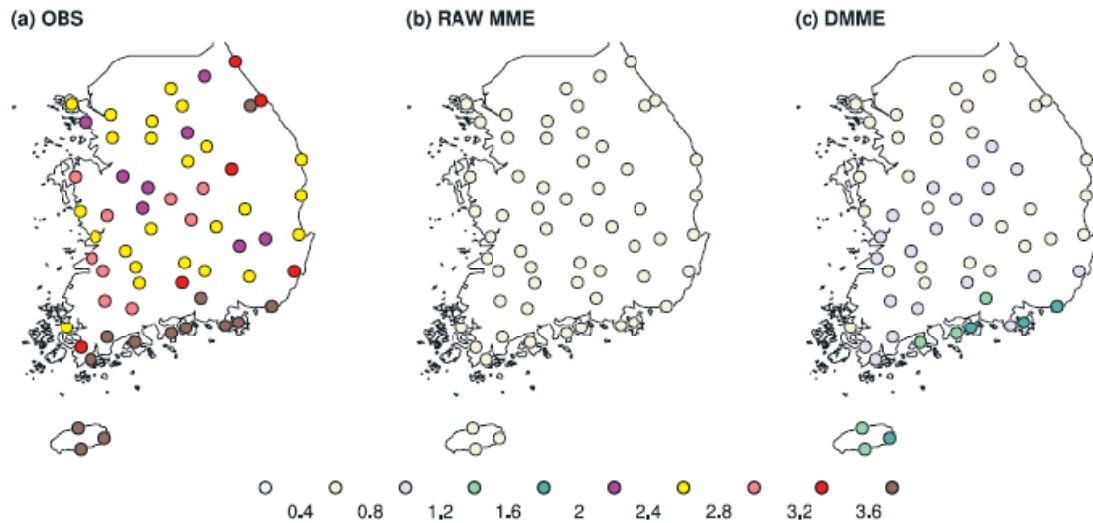


Figure 1. Interannual standard deviation for the March-April-May accumulated precipitation, based on (a) observations, (b) raw multimodel ensemble, and (c) downscaled MME predictions (units: mm/d).

3. EXTREME DROUGHT AND FLOOD PREDICTIONS

We now assess the impact of various calibrations of DMME precipitation forecasts on extreme drought and flood precipitation. Temporal correlation coefficients between the observed and predicted 3-month SPI (SPI3), ending in May, are given in Figure 2. SPI3 based on non-inflated DMME is moderately skilful in the northern part and the southern coastal region of South Korea. Due to its inflation method, SPI3 based on the M1 scheme actually shows a decrease in skill at some inland stations where there is a high correlation between observations and DMME. M2 gives the best overall skill of the three schemes, while the performance of M3 is almost the same as the non-inflated products. Overall, it appears that M2 is the best inflation method for predicting extreme drought and floods events. It is worth noting that all the schemes considered are also likely to inflate the accurate as well as inaccurate forecasts. Therefore, stations with low skill become more inaccurate when inflated by either M1, M2, or M3.

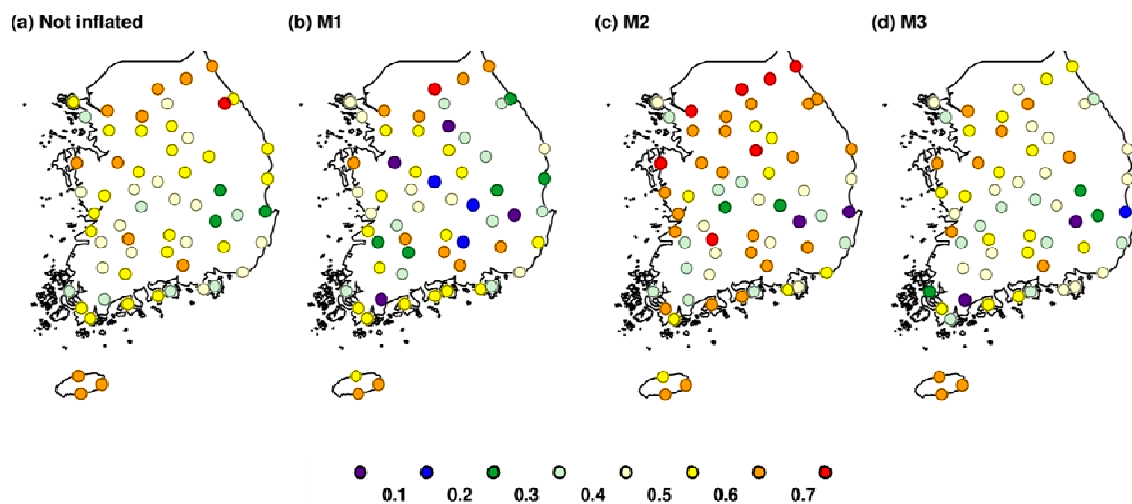


Figure 2. Temporal correlation coefficients of the SPIs calculated for 3 months ending in May during the period of 1983-2003 between observations and (a) non-inflated, (b) M1, (c) M2, and (d) M3-inflated DMME predictions.

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Session II

CLIMATE CHANGE STUDIES ON WATER RESOURCES IN KOREA

Deg-HyoBae, Moon-Hwan Lee

ECOSYSTEM PROCESSES AT THE WATERSHED SCALE: CLIMATE CHANGE, ECOSYSTEM FEEDBACKS AND IMPLICATIONS FOR WATER RESOURCES

Lawrence Band, Yuri Kim, Taehee Hwang

CLIMATE CHANGE IMPACT ASSESSMENT ON NATURAL DISASTER IN JAPAN UNDER THE KAKUSHIN PROGRAM

Eiichi Nakakita, Kyoto University's KAKUSHIN Group

WATER BUDGET PROJECTION AT THE MAJOR KOREAN MULTIPURPOSE DAMS BASED ON IPCC CLIMATE CHANGE SCENARIO

KANG Boosik, MOON Sujin, KIM Jungjoong

CLIMATE VARIABILITY AND CLIMATE CHANGE IMPACT ON WATER

Francis H.S. Chiew

DECADAL HYDROLOGIC FORECASTING - HOW VIABLE IS IT?

Ashish Sharma, Raj Mehrotra



A GRID-BASED MODELING FOR ASSESSING CLIMATE
CHANGE IMPACT ON WATERSHED HYDROLOGY

Seong-Joon Kim, Geun-Ae Park, Hyuk Jung

ESTIMATING THE SYSTEMATIC BIAS IN THE PRESENT
AND FUTURE PRECIPITATION OUTPUT OF AGCM60KM

Sunmin Kim, Eiichi Nakakita and Kakushin Team3 Modeling Group

A MULTI-INDEX MULTIVARIATE DROUGHT MONITORING
FRAMEWORK: APPLICATION TO CLIMATE CHANGE IMPACT
ASSESSMENT

Amir AghaKouchak, Zengchao Hao

STATISTICAL ASSESSMENT OF CHANGES IN DAILY
PRECIPITATION EXTREMES IN THE ASIA-PACIFIC REGION

Ok-Yeon Kim

POTENTIAL INCREASE OF HYDROCLIMATIC EXTREMES
IN KOREA DUE TO GLOBAL WARMING FROM A REGIONAL
CLIMATE SIMULATION

Eun-Soon Im

THE EFFECT OF UNIFORM AND NON-UNIFORM BIAS
CORRECTION METHODS ON IMPROVING NEXRAD
RAINFALL ACCURACY FOR DISTRIBUTED HYDROLOGIC
MODELLING

Kwangmin Kang



CLIMATE CHANGE STUDIES ON WATER RESOURCES IN KOREA

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Abstract: The objectives of this study are to provide the current status of climate change impact studies on water resources in Korea and to issue several important problems for the reliable climate change impact, vulnerability and adaptation studies in future. We will provide recent results for climate change impact assessment on water resources under Representative Concentration Pathways (RCP) AR5 scenario. For the better understanding and sharing ideas on climate change studies, Global Climate Model (GCM) and scenario selection problem, downscaling uncertainty problem, hydrologic model selection problem, global hydrological change problems in East Asia region and climate change adaptation strategies are discussed.

Keywords: *Climate change, RCP scenario, Impact assessment, Adaptation strategy, Water resources*

1. INTRODUCTION

According to the recent Korea Meteorological Administration (KMA) Report on 'Climate Change Scenario Report 2011', the increase of annual mean temperature in Korea is significant under RCP AR5 scenarios. This climate change directly impacts to the increase of evapotranspiration, changes of spatial and temporal precipitation patterns that cause the changes of river runoff. It also causes the increase of frequency of abnormal weather phenomena such as severe storms, drought, typhoon and heat waves. Therefore, the better understanding and corresponding adaptation strategy for climate change impacts on water resources are one of the most important and key issues on modern hydrology and water resources.

In Korea, as the first national level climate change impact assessment on water resources, Bae et al. (2008) provided the spatial and temporal changes of precipitation, evapotranspiration and river runoff on the 139 sub-basins that cover whole South Korea under A2 emission scenario. After this work, many Korean meteorologists and hydrologists have continued their climate change studies on water resources, especially focusing on water supply, flood and drought problems. The first part of this paper will deliver the current status of climate change studies in Korea. And then, we will introduce the national level ongoing projects for climate change impact assessment on water resources. In addition, we will issue several important problems for climate change studies including uncertainty problem and some limitations on climate change studies in Korean side. The last part of this paper will introduce near-future national level plan for climate change impact, vulnerability and adaptation studies.

2. RESULTS AND DISCUSSION

The general procedure for climate change impact assessment on water resources is categorized by the future climate change projection from GCM simulations, dynamic and statistical downscaling processes from global to regional-scale, hydrologic prediction by using hydrological models and climate change simulations (Fig. 1). Among many climate change impact studies (Bae et al., 2008; KICT, 2010; Bae et al., 2011; Kim et al., 2011; Jung et al., 2012), Fig. 2 is more recent result that represents the possible annual and seasonal changes of temperature, precipitation and runoff under RCP 4.5 scenario. The climate projections are obtained by using HadGEM2-AO with 135 km resolution and dynamically downscaled by HadGEM3-RA with 12.5 km resolution on Korean peninsula. The runoff changes are projected by using PRMS, SWAT and SLURP models. The study area covers the whole South Korea, which is made up of five large river (Han River, Nangdong River, Gum River, Sumjin River and Youngsan River) basins.

The temperature increase over South Korea is projected to 1.6°C for 2010-2039 (S1 period) and 3.2°C for 2070-2099 (S2 period) relative to 1980-2009 (reference period) under RCP 4.5, while 1.7°C and 5.6°C under RCP 8.5 (not shown). The temperature increase in Han River basin compared to other major river basins is dominant. In the case of precipitation, the increases for S1 and S2 periods relative to reference period are 11.7% and 30.2% under RCP 4.5 and 8.6% and 26.9% under RCP 8.5, respectively. Spatial changes of precipitation on south-western sub-basins are greater than those of north-eastern sub-basins, especially those of Sumjin River and Youngsan River basins are dominant and projected to 35.2% and 34.2% under RCP 4.5 and 37.0% and 37.2% under RCP 8.5. The rates of change in annual mean runoff are 16.2% and 42.1% under RCP 4.5, while 10.8% and 35.0% under RCP 8.5.

The right panel of Fig. 2 represents seasonal changes of precipitation and runoff. It is noted that SRES AR4 scenarios showed the increased runoff during fall and winter and decreased runoff during spring and summer in most basins. However, RCP AR5 scenario represents runoffs during winter, spring and summer are increased. It should be carefully reviewed the runoff trend in spring, which plays important role for agricultural water supply in this season.

3. CONCLUSION AND RECOMMENDATIONS

In addition to provide the climate change impact assessment results in Korea, we will also discuss about several important issues for climate change impact studies on water resources. They include GCM and scenario selection problem (Comparison of results between SRES AR4 and RCP AR5), downscaling uncertainty problem, hydrologic model selection problem, global water cycle change problems in East Asia region and climate change adaptation strategies.

Although we have had a great progress for climate change studies on water resources, there are still many problems that requires the better understanding of the impact scientifically and practically. We will introduce our future plan for climate change studies on water resources.

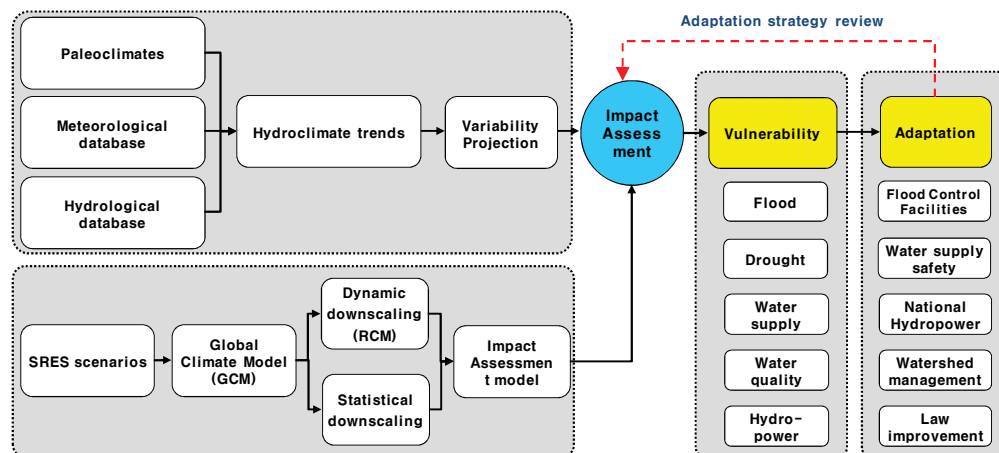


Figure 1. General procedures for climate change impact assessment, vulnerability and adaptation strategy

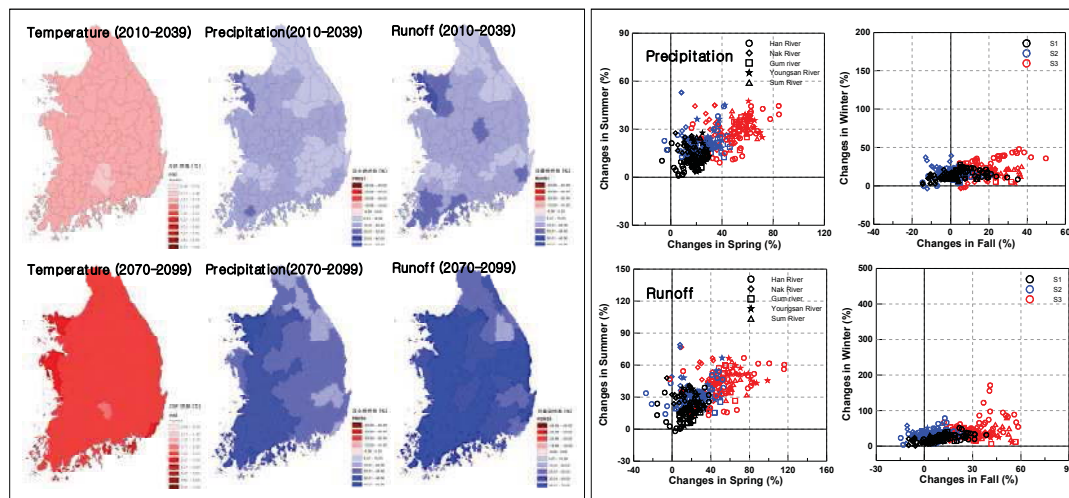


Figure 2. Annual and seasonal changes of temperature, precipitation and runoff under RCP 4.5 scenario

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ECOSYSTEM PROCESSES AT THE WATERSHED SCALE: CLIMATE CHANGE, ECOSYSTEM FEEDBACKS AND IMPLICATIONS FOR WATER RESOURCES

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Abstract: Future climate change may have significant impacts on the ecosystem services that provide freshwater for human societies and ecological systems. Forest ecosystems are both important consumers and sources of freshwater for many urban areas, and can be sensitive to interannual to long term hydroclimate variability. This provides nonstationarity in hydrologic systems and to model parameters for these systems if the dynamics are not endogenized or otherwise accounted for. These interactions can either exacerbate or mitigate different aspects of water resources vulnerability (e.g. annual yield, flood and low flow regimes) to climate and land use change, and can produce unintended consequences in other ecosystem services. In many climates, ecosystems will adjust leaf area and duration in response to water or nutrient availability (as well as species conversion). The change in leaf display can be remotely sensed, and can be used as an indicator of ecosystem adjustment to hydroclimate as well as water yield. We investigate nonstationarity and feedback of watershed runoff behavior with vegetation dynamics, and use a set of remote sensing methods and watershed models with varying levels of coupled ecohydrological processes to estimate freshwater and associated ecosystem service vulnerability to climate and policy scenarios in humid forest biomes.

Keywords: *Freshwater resources, ecosystem services, climate change*

1. INTRODUCTION

Future trends in local to regional water availability, along with related ecosystem services including carbon sequestration and the regulation of water quality will interact in manners that may provide strong feedbacks within the environment and with societal goals. Significant uncertainty in the reliability of freshwater supplies associated with long term climate scenarios are additionally confounded by interactions with population growth and related land use change scenarios, and with the dynamics of ecosystems responding to changing hydroclimate. Watershed management policy and investment in major water resources infrastructure and restoration strategies should require an integrated assessment of the dynamics of past, current and future hydrologic conditions, geared towards providing a predictive understanding of system dynamics. The assessment is necessarily subject to significant uncertainty due to sparseness of data, incomplete understanding of the dynamics and interactions of watersheds, ecosystems and human activities, and the potential for unintended, disruptive events. Non-stationarity in watershed system behavior, and in our analytical methods and models developed to understand and manage watersheds, can result from each of these sources of uncertainty and change. Therefore, the goals and benefits of an integrated assessment should include identification of potential vulnerabilities in watershed development with key observable metrics that can be used to test system understanding, screen for system behavioral changes, and provide support for adaptation in management.

2. METHODS

A set of major watershed research, management and restoration projects in the humid forest biome of the United States are indicative of the types and level of uncertainty in understanding ecosystem services interactions, and are used to illustrate both current capabilities and the potential to improve understanding and management of freshwater vulnerability. Major watershed management and restoration programs, geared towards water quality restoration and reduction of nutrient loading from regional water supply areas in North Carolina are sensitive to land use and the extent of forest cover. Water supply areas in this region have a dominant forest cover, even in urbanizing regions. Historical analysis and simulation of land use and forest change impacts on water resources are used to investigate long term trends and vulnerability in freshwater supplies. Results show sensitivity to forest ecosystem extent and response to hydroclimate change. We present additional research from Long Term Ecological Research (LTER) sites, which contribute greater process understanding, and key diagnostic metrics of watershed behavior developed from long term monitoring, and more comprehensive ecohydrological models (e.g. Hwang et al., 2012). These tools will benefit vulnerability assessment and the development of a predictive understanding in the larger ecosystems. The combination of simulation and remote sensing methods can extend the understanding and monitoring of forest impacts on larger water resources systems at seasonal, inter-annual and decadal time frames.

We use a set of water resources and ecohydrological models to assess long term behavior and trends in humid watersheds in the eastern United States. SWAT (is a widely used watershed model including land use and ecosystem heterogeneity as drivers of sub-basin scale hydrology, while RHESSys (Band et al 1993; Tague and

Band 2004; Hwang et al 2009) includes more explicit ecohydrological feedbacks between forest physiology and hydrologic flowpaths at the hillslope scale. Long term meteorological and discharge records provide signals to assess trends and potential future dynamics in freshwater resources, as well as sensitivity to forest dynamics. Historical information on land use, supplemented by more recent multi-scale remote sensing of forest type, extent and density are used to assess the interactions and controls of ecosystem patterns, hydrologic behavior and climate on coupled ecosystem services, including freshwater provisioning. Bias corrected regional climate change projections from the North American Regional Climate Change Assessment Program (NARCCAP – www.narccap.org), along with land use change models are used to evaluate scenarios for future freshwater resources.

3. DISCUSSION AND CONCLUSIONS

Analysis of mixed spatial and temporal resolution remote sensing of forest and land use cover is developed from IKONOS, Thematic Mapper and MODIS to develop metrics that can be widely developed and used with ecohydrologic models as indicators of forest ecosystem response to hydroclimate, and controls on freshwater availability. These metrics include information on forest physiology, growing season length (phenology), and adjustment of spatial forest patterns to hydrologic flowpaths and hydroclimate variability. The level of physiological and phenological dynamics and feedbacks incorporated into watershed models can produce significant impacts on forecast response of watershed freshwater availability to scenario climate and land use change. Incomplete specification of important feedbacks can result in bias not only to the magnitude of change in runoff projections, but also to the sign of changes (increases or decreases). It is recommended that a key set of diagnostic variables be developed from a combination of remote sensing, long term measurement and distributed simulation of watershed ecosystems to test and assess assumptions and goals of watershed planning and restoration as part of adaptive management frameworks.

Acknowledgement:

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CLIMATE CHANGE IMPACT ASSESSMENT ON NATURAL DISASTER IN JAPAN

UNDER THE KAKUSHIN PROGRAM

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Abstract: Disaster Prevention Research Institute has been performing “Prediction and evaluation of disaster environment in Japan” with the sub-project title of “Integrated assessment of climate change impacts on watersheds in a disaster environment” under the KAKUSHIN Program supported by Japanese government. Impacts on disasters by storm surge and strong wind are also one of the targets. It is the typhoon resolving output from the GCM and RCM that has realized the impact assessment on Japanese river regime. Base on the analysis on the projection, we have been addressing since 2009 that it is very important for climate change adaptation to discriminate more between planning with uncertain design level and risk management with the worst case scenario.

Keywords: Climate change Impact assessment, Natural disaster, Typhoon, River Regime, Storm surge

1. INTRODUCTION

Under the KAKUSHIN Program supported by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT), Meteorological Research Institute (MRI) of Japan Meteorological Agency, Disaster Prevention Research Institute (DPRI) of Kyoto University, and International Centre for Water Hazard and Risk Management (ICHARM) of Public Works Research Institute (PWRI) have been performing climate projections for the near future and for the end of the 21st century using atmospheric models of unprecedented super-high-resolution. The climate change studies have been based on a global 20-km mesh atmospheric general circulation model (GCM) and regional climate model (RCM) with higher spacio-temporal resolutions; emphasis has been placed on extreme events, including tropical cyclones and heavy precipitation during the East Asian summer monsoon season.

2. INTEGRATED ASSESSMENT OF CLIMATE CHANGE IMPACTS ON WATERSHEDS IN A DISASTER ENVIRONMENT

DPRI has been performing “Prediction and evaluation of disaster environment in Japan” with the sub-project title of “Integrated assessment of climate change impacts on watersheds in a disaster environment”. Impacts on disasters by storm surge and strong wind are also one of the targets. One of the important subjects in this sub-project is the interface between GCM and RCM, and various models on natural hazard. For example, MRI slightly changed its GCM and RCM so that they could output hourly rainfall from GCM. It is the typhoon resolving output from the GCM that has realized the impact assessment on Japanese river regime. Namely, GCM with the super-high spacio-temporal resolutions (20 km-1 hour) made it possible to evaluate extreme hazard (ex. Max. discharge) in Japan. (However, we must make sure that this does not mean that we can evaluate the changes in such a high spatial resolution.)

3. PROJECTED DISASTER ENVIRONMENT

It is projected that the number of typhoon which will approach to Japanese Archipelago will decrease in the end of century while chance of super typhoons will increase. It is also projected that the number of localized heavy rainfall in the Baiu season (a Japanese rainy season in June and July) increase as Figure 1

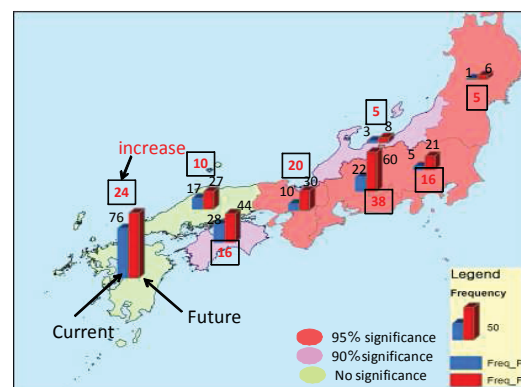


Figure 1. Increase in number of localized heavy rainfall during Baiu season in 25 years. (Nakakita et al., 2012)

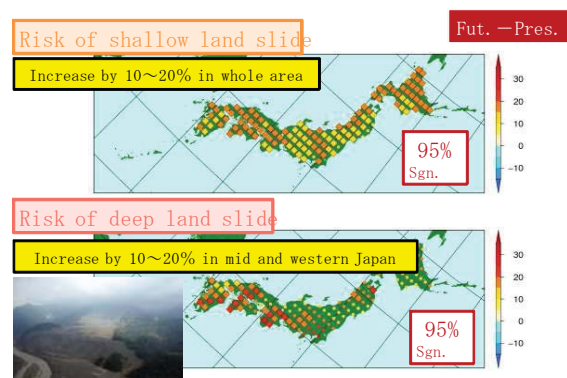


Figure 2. Change in risks of shallow landslide and deep seated land slide. (Oku et. al, 2011)

shows. As Figure 2 shows, due to those changes in meteorological feature, not only risk of the shallow land slide but also risk of the deep seated landslide is projected to increase by ten to twenty percentages, based on the analysis on changes in rainfall intensity and total amount of rainfall. Regarding the damage by strong wind by typhoon, it is projected

4. A WORST CASE SCENARIO ON DISASTER DUE TO TYPHOON

Results from typical climate change assessments on disaster environment in Japan will be shown as projections of change in design value. Most of the design value is expected to increase as expectation. This means that we can get approximate projection on changes in return period of extreme events. However, there is a risk that the return period does not have enough accuracy. Also, there is no guarantee that quite extreme events could be properly projected within the limited number of ensembles as GCM output with such a high resolution. On the other hand, the risk management deals with phenomena beyond design hazards. In this sense, it is very important to take into account the result from a worst case scenario, as one of the forcing for risk management on climate change. Taking into consideration above items, it is very important for climate change adaptation to discriminate more between planning with uncertain design level and risk management with the worst case scenario.

Figure 3 shows how to produce such a worst case typhoon scenario for a specific disaster and for a specific river basin. Once AGCM projects a typhoon candidate which may bring severe flood for a specific river basin, we can find a group of typhoon which will bring the severest flood, after virtually shifting course of typhoon based on vortugus method keeping potential vorticity same.

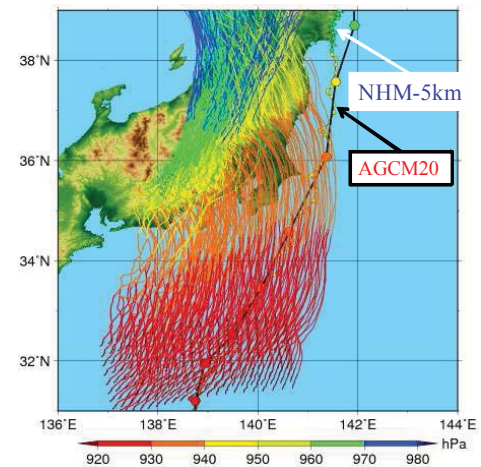


Figure 3. Schematic explanation of how to produce a worst case typhoon scenario. (Ishikawa et. al. 2012)

5. CONCLUSIONS

The AGCM and RCM with super-high spatio-temporal resolutions (20 km-1 hour) made it possible to evaluate extreme hazard (ex. Max. discharge). However, this does not mean that we can evaluate the changes in such a high spatial resolution.

We can get approximate projection on changes of return values of extreme events. However, there is a risk that the return period does not have enough accuracy because there is no guarantee that quite extreme events could be properly projected within the limited number of ensembles. (Single time series output from the AGCM20 and RCM). In this sense, it may be difficult to project correct design hazard for water management and flood control so on. On the other hand, the risk management deal with phenomena beyond design hazards. In this sense, it is very important to take into account the result from a worst case scenario as one of the forcing hazard for disaster risk management under climate change.

Taking into consideration above items, I think, it is very important for climate change adaptation to discriminate more between planning with an uncertain design level and risk management with a worst case scenario. Of cause, making the number of ensembles increase is essential for the Kakushin follow-up program.

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WATER BUDGET PROJECTION AT THE MAJOR KOREAN MULTIPURPOSE DAMS BASED ON IPCC CLIMATE CHANGE SCENARIO

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Abstract: The water budget projection corresponding to water resources availability in the major Korean multipurpose dams based on the IPCC climate change scenario(A1B) is suggested. The projection by 2040 for precipitation and dam inflow gives 7.8~13.1% and 6.7~24.6% increase for all dams. The dams (Soyanggang and Chungjudmas) in Han river basin shows relatively higher increasing trend than the dams in the other regions, Nakdong river basin in particular. As a result the availability of surface water resources can be expected to be improved, but, at the same time, the vulnerability against flood risk can be aggravated.

Keywords: Downscaling, Climate Change, Water Resources, Artificial Neural Network, SWAT

1. INTRODUCTION

The water resources depending largely on hydrologic components and cycle is one of the dimensions impacted directly by climate variability and change. Since the climate change has become one of the primary issues in water resources community, the global and regional projection of raw variables, e.g. precipitation and temperature, etc., computed by GCM(Global Climate Model) has been carried out, which have suggested quantitative and qualitative projection for near and long term periods. The regional projection using GCM accompanies significant amount of uncertainties which are propagated and amplified when the projection is extended to applied dimensions using impact models.

In this study, the water budget projection corresponding to water resources availability in the major Korean multipurpose dams based on the IPCC climate change scenario(A1B) will be suggested. The reliable projection in this case depends largely on the regional precipitation and temperature projection, which requires proper downscaling scheme reflecting not only global future trend but also regional dynamical and statistical behaviour. To this end the coupled downscaling scheme consisting of artificial neural network, dynamic quantile mapping, and stochastic typhoon simulation sub-modules was applied for the regional daily hydrologic projection. The basin inflow to the dam reservoir was computed using SWAT, the long-term continuous rainfall-runoff model which is one of most popular models used for climate change impact models.

2. REGIONAL DOWNSCALING FOR GCM OUTPUT

The RCM(Regional Climate Model) output for the future climate scenario was provided by KMA(Korea Meteorological Administration). It has 30km of spatial scale and provide daily scenarios to the public. The KMA's RCM was developed by calibrating NOAA's MM5 to Korean climate environment and coupled with ECHO-G model. It provides scenarios of 5 atmospheric variables; precipitable water, relative humidity, temperature (average, minimum, maximum). As the emission scenario for the projection in this study was SRES A1B of AR4.

The overall downscaling scheme is coupled with ANN (Artificial Neural Network), dynamic quantile mapping, and stochastic typhoon simulator and applied sequentially. Even though RCM provides the output with relatively small spatial scale (30km) but tend to show underestimation especially for precipitation. The ANN is one of the MOS (Model Output Statistics) tools for calibration of regional biases embedded in RCM or GCM (Kang and Lee, 2011; Kuligowski and Barros, 1998). The predictor variables for input to the ANN are precipitable water, relative humidity, temperature (average, minimum, maximum). Additional data fitting was implemented with DQM (Dynamic Quantile Mapping) which utilizes the dynamically variable statistical parameters reflecting the variable trend captured by the original RCM, thus more realistic projection with seamless connection with baseline scenario fitted to historical observation.

The typhoon is the typical meteorologic phenomenon occurred in monsoon climate region during flood season and occupies the 10-20% of annual precipitation in Korean peninsula. The GCM or RCM does not include the local heavy rainfall and typhoon generation mechanism, which can be a reason of underestimation for the summer precipitation (Cheng, et al., 2009). The uncouneted typhoon rainfall was simulated for the projection period using the STS (Stochastic Typhoon Simulator) which generates occurrence (and duration) and intensity of typhoon using the mixed Poisson and Gumbel distribution, respectively (Moon, et al., 2012). The projections of annual precipitation at multipurpose dam sites are suggested in Table 1.

Table 1. Most meaningful example of a brilliant table with columns and lines filled with a minimum of quantitative information (entries in 10pt; caption in 9pt).

unit : mm

Dam	Baseline(Obs) 1991~2010	Baseline(Sim) 1991~2010	2010~2040	2041~2070	2071~2100
Chungju	1445.4	1449.7(0.3% [*])	1651.1(13.9% ^{**})	1800.3(24.2% ^{**})	1998.3(37.8% ^{**})
Soyanggang	1459.0	1452.6(-0.4% [*])	1714.9(18.1% ^{**})	1900.5(30.8% ^{**})	2119.4(45.9% ^{**})
Andong	1245.2	1245.6(0.0% [*])	1379.9(10.8% ^{**})	1520.8(22.1% ^{**})	1720.0(38.1% ^{**})
Imha	1103.2	1105.1(0.2% [*])	1227.8(11.1% ^{**})	1393.2(26.1% ^{**})	1577.9(42.8% ^{**})
Hapcheon	1324.3	1349.9(1.9% [*])	1500.6(11.2% ^{**})	1747.3(29.4% ^{**})	1974.6(46.3% ^{**})
Namgang	1474.6	1481.7(0.5% [*])	1622.4(9.5% ^{**})	1811.3(22.2% ^{**})	2018.1(36.2% ^{**})
Juam	1501.6	1502.2(0.0% [*])	1619.6(7.8% ^{**})	1664.5(10.8% ^{**})	1788.1(19.0% ^{**})

^{*}Percentage of Baseline(Obs)

^{**}Percentage of Baseline(Sim) by periods

3. LONG TERM PROJECTION FOR INFLOW TO THE MULTIPURPOSE DAM SITES

The long term water budget was computed using SWAT, the continuous rainfall-runoff model. The HRU (Hydrologic Response Unit) was used for the sub-basin delineation. The simulation was carried out daily basis. The groundwater flow was analysed using hydrodynamic storage model and effective rainfall was estimated using SCS-CN method. The geographic digital information for terrain, soil, and landuse are constructed based on 1:5,000, 1:25,000 and 30m scales. The long-term inflow projection is suggested in Table 2.

Table 2. Most meaningful example of a brilliant table with columns and lines filled with a minimum of quantitative information (entries in 10pt; caption in 9pt).

unit : mm/yr

Dam	Baseline [†]	2011~2040	2041~2070	2071~2100
Chungju	852.2	1061.9 (24.6% [*])	1171.0 (37.4% [*])	1331.3 (56.2% [*])
Soyanggang	856.1	967.3 (13.0% [*])	1065.3 (24.4% [*])	1317.9 (54.0% [*])
Andong	868.5	971.2 (11.8% [*])	1075.8 (23.9% [*])	1211.0 (39.4% [*])
Imha	818.9	911.5 (11.3% [*])	1015.1 (24.0% [*])	1139.9 (39.2% [*])
Hapcheon	840.9	973.4 (15.8% [*])	1187.8 (41.3% [*])	1372.3 (63.2% [*])
Namgang	1037.7	1162.6 (12.0% [*])	1317.2 (26.9% [*])	1468.4 (43.2% [*])
Juam	1043.7	1113.8 (6.7% [*])	1158.7 (11.0% [*])	1270.5 (21.7% [*])

[†]simulated by SWAT

^{*}Percentage of Baseline(Sim) by periods

4. CONCLUSIONS

Due to the temperature increase, the weather in the region of Korea peninsula is likely to get into the sub-tropical band. The projection by 2040 for precipitation and dam inflow gives 7.8~13.1% and 6.7~24.6% increase for all dams. The dams (Soyanggang and Chungjudmas) in Han river basin shows relatively higher increasing trend than the dams in the other regions, Nakdong river basin in particular. Overall increasing trends of dam inflows are greater than those of precipitation. As a result the availability of surface water resources can be expected to be improved, but, at the same time, the vulnerability against flood risk can be aggravated. However, the risk of water shortage will exist always due to the increase of weather variability.

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CLIMATE VARIABILITY AND CLIMATE CHANGE IMPACT ON WATER

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Abstract: This paper provides an overview of the potential impact of climate change on water. It describes methods used to model climate change impact on water and highlights the considerable uncertainty in future water availability projections. Many governments and communities are starting to adapt to better cope with a changing climate, and some of the adaptation responses are described.

Keywords: *Climate variability, Climate change, Water, Projections, Adaptation*

1. INTRODUCTION

Climate influence on water is a significant cross-cutting issue affecting people, agriculture, industries and ecosystems. Water resources systems are managed to satisfy multiple demands and to cope with variability over a range of time scales. For example, the river flow in a wet year can be more than ten times greater than the flow in a dry year, floods tend to cluster in particular decades, and there are droughts of varying length and severity. The management of flood risk and water resources will be exacerbated by the non-linearities introduced by climate change and the amplification of regional climate change in the river flows. This paper (i) provides an overview of the potential impact of climate change on water, (ii) describes methods used to model climate change impact on water, and (iii) presents some of the water resources adaptation responses.

2. CLIMATE CHANGE IMPACT ON WATER

A warmer future climate will intensify the hydrological cycle and change large-scale atmosphere and ocean circulation. Observations show expansion in the Hadley circulation cell and poleward intensification of ocean gyre circulation in the Southern Ocean and the North Atlantic and North Pacific Oceans. This will result in a general pattern of equatorial regions and wet tropics becoming wetter and semi-arid and arid regions in the subtropics and low mid-latitudes becoming drier (Saeger et al. 2010).

The changes in precipitation will be amplified in the runoff and river flow, with a 1 percent change in average annual precipitation generally amplified as a 1 to 2 percent change in average annual runoff in cold regions and wet regions and 2 to 3 percent change runoff in drier regions. In cold regions and high elevations, more precipitation will fall as rain rather than snow and the snow will melt earlier, resulting in less spring and more winter flows. The seasonality of river flow will generally increase, with wetter wet season and drier dry season. The retreat of glaciers will increase flows in the short term, but the contribution of glacier melt will gradually fall as glaciers shrink. This enhanced hydrologic variability and decrease in snow and ice storage will reduce the reliability of water supply. The warmer climate will increase the potential for evaporation and hence increase the demand for water in irrigated agriculture, cities and water-dependent ecosystems, therefore increasing the gap between supply and demand in regions that become drier (Bates et al. 2008).

At the other extreme, heavy rainfall events are likely to become more intense because of the warmer and wetter atmosphere, increasing flood risks. Flooding in coastal areas may also be exacerbated by higher storm surge and sea levels. The higher rainfall intensity and peak flow will also increase erosion and sediment in waterways and exacerbate problems from aging stormwater and wastewater infrastructure in cities.

3. MODELLING CLIMATE CHANGE IMPACT ON STREAMFLOW

The three main modelling components are shown schematically in Figure 1. The global climate models (GCMs) simulate the large-scale atmosphere and ocean circulation and changes to the circulation in a warmer world. Statistical and dynamical downscaling models are used to downscale GCM outputs to catchment-scale climate to drive hydrological models. Statistical downscaling models relate catchment-scale climate variables to the large-scale drivers. Dynamical downscaling models are fine-scale climate models nested inside GCMs to represent the fine-scale topography, vegetation and weather patterns. In the near to medium-term, streamflow is influenced mainly by rainfall, and hydrological models calibrated against long historical data can generally be used to predict streamflow response to changes in the climate inputs (Vaze et al. 2010). However, for longer-term projections, the hydrological models must also consider potential changes in the rainfall-temperature-streamflow relationship and surface-atmosphere feedbacks in a warmer and enhanced CO₂ climate.

Figure 2 shows, as an example, the range of projected changes to average annual runoff across Australia for a 1°C global warming (median warming by 2030 relative to 1990), modelled using hydrological models informed by future climate projections from 15 GCMs. The considerable range in the runoff projections mainly reflects the uncertainty in the future rainfall projections. For example, there is little agreement between GCMs in the direction of rainfall and therefore runoff change in northern Australia. There is much stronger agreement in

southern Australia, where practically all the modelling results indicate a drier future. However, the range of projection is still very large, making planning and adapting to climate change difficult.

4. WATER RESOURCES ADAPTATION TO CLIMATE CHANGE

Most water resources adaptation response to climate change is driven by immediate stressors like the need to cope with existing water crisis, drought and/or increasing water demand. Adaptation in poorer countries mainly involves ‘no regrets’ options, where the cost of adaptation is relatively low and the adaptation actions provide immediate benefits regardless of climate change. Options include improving water management to better cope with hydrologic variability, capturing more rain water to increase water supply and improving agricultural practice. In richer countries, adaptation may involve increasing water supplies through enhancing existing storages, water transfers via pipelines or building new reservoirs. Some cities are diversifying to more secure supplies like desalinisation plants and stormwater and wastewater reuse systems. Many urban centres are attempting to reduce demand through water conservation measures and water sensitive urban design. In irrigation areas, adaptation options include upgrading infrastructures to reduce water losses, improving irrigation water use efficiency, establishing efficient water markets to allow water use patterns to adapt to shifting availability and move towards higher water value use, and developing flexible water sharing plans to cope with current and future climates. These options allow us to incrementally cope with a changing climate, although a more transformative adaption is probably required for the more extreme projections in the more distant future.

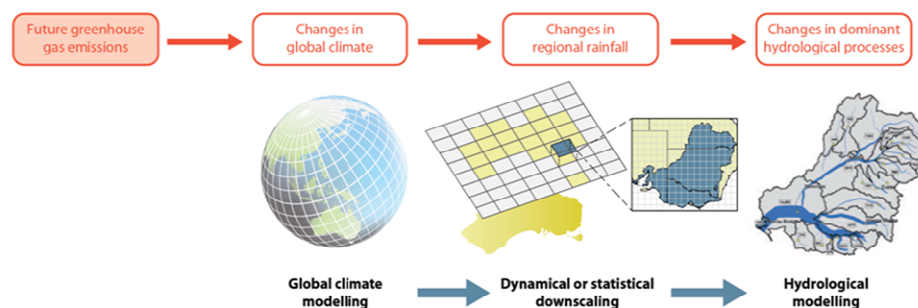


Figure 1. Modelling components for estimating future runoff with the main sources of uncertainty shown in red.

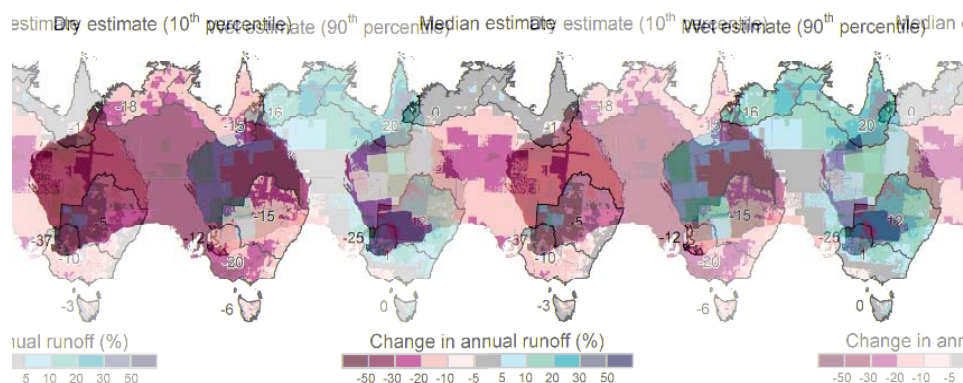


Figure 2. Modelled change in average annual runoff for a 1°C global warming with future climate informed by projections from 15 GCMs (Chiew et al. 2009 and Teng et al. 2012)

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DECADAL HYDROLOGIC FORECASTING - HOW VIABLE IS IT?

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Abstract: This talk assesses decadal hydrologic predictability, or, 1-30 year ahead climatic predictions issued using General Circulation Models (GCMs). This assessment is made using phase 5 of the Coupled Model Intercomparison Project (CMIP5), based on GCM hindcasts starting every 5 years, from 1960 onwards, using a total of 72 GCM/ensemble combinations. Issues related to predictability as a function of lead time, biases present in the predictions, and strategies on formulating the most meaningful forecasts for hydrologic applications, are discussed.

Keywords: Hydrologic prediction, Decadal Prediction, CMIP5

1. INTRODUCTION

One of the core objectives of phase five of the Coupled Model Intercomparison Project (CMIP5) is to provide a set of 10 year hindcasts or predictions initialized from common climate states every five years starting from 1960 (Figure 1). The decadal predictions explore the ability of the climate models to predict regional climate changes in the near future. The University of New South Wales is working in partnership with BoM, CAWCR and CSIRO to assess the viability of these decadal and inter-decadal forecasts, from a water management perspective. While the current phase of the study involves assessment of raw GCM simulations over Australia for the decadal time-frame under assessment, depending on the outcomes achieved, future phases will entail formulation of downscaling alternatives suitably tailored to take into consideration the changing accuracy of the simulation with increase in lead-time.

This talks presents the research till-date, outlining the viability of using raw GCM forecasts (with and without simplistic bias correction) for typical water resources planning applications. The talk goes ahead to also assess the predictability of other climate variables (near surface temperature, pressure, and others) with an intention of assessing the relative skill one can obtain for a range of climatic responses at decadal and inter-decadal time-scales. The talk concludes with a discussion of a range of options for decadal to interdecadal water forecasting, outlining a proposed methodology recommended for adoption in the second stage of this study.

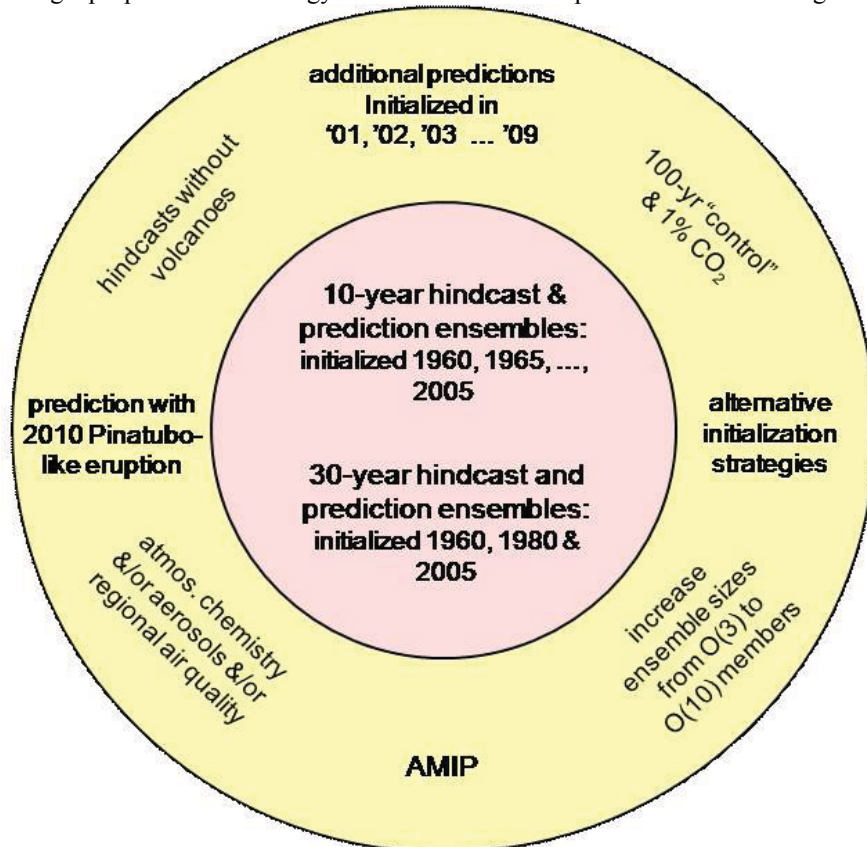


Figure 1. An assortment of climate model simulations available as part of CMIP5 (extracted from CMIP5 website - <http://cmip-pcmdi.llnl.gov/cmip5/>).

2. RESULTS

The presentation will include results from a total of 72 GCM/ensembles, assessed to answer several questions. Of the questions investigated, the key ones include: (a) whether predictability decreases with increase in lead time; (b) what is the highest lead time till which predictions are statistically better than climatology; (c) does this predictability change with space or with period of aggregation (month to year to multi-year); (d) what is the extent of “drift” in the precipitation simulations; € what is the effect of alternate bias correction strategies on the resulting rainfall.

3. CONCLUSIONS

CMIP5 decadal predictions are of significant use in hydrologic assessments, given the decadal time span associated with most hydrologic plans that are put into action. This is in contrast to the much longer (century) timescales usual climate change simulations are issued for. Decadal simulations are all the more interesting as the climate model outputs over the decadal time period are effected both by the assumed greenhouse gas emission regime considered in simulations, as well as the initial conditions used in initialising the model. The study reported here was amongst the first such studies that comprehensively assessed the viability of using GCM decadal predictions for hydrologic applications. The results obtained indicated that while there were several challenges that still need to be overcome, decadal predictions are viable and likely to be of considerable importance in future hydrologic action plans and policy development.

Acknowledgement:

This study was supported by the Australian Bureau of Meteorology and benefitted through considerable discussions with colleagues therein. Special thanks go to Mohammed Bari, Amir Amirthanathan and Narendra Tuteja for the extensive support throughout this work.

A GRID-BASED MODELING FOR ASSESSING CLIMATE CHANGE IMPACT ON WATERSHED HYDROLOGY

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Abstract: This study is to develop a grid-based hydrologic model for evaluating future climate change impact on watershed hydrology. The model is a typical distributed model, which divides the watershed into regular cell elements and calculates the daily water balance of each cell by constructing 3 vertical layers of surface, subsurface, and groundwater flow respectively. For a 930.4 km² Yongdam Dam watershed located in the middle of South Korea, the model with 1.0 km spatial resolution was calibrated and validated using 8 years (2002-2009) daily streamflow data at 3 locations with Nash-Sutcliffe model efficiency of 0.61~0.82. For the future climate change scenario, the HadGEM3-RA RCP 4.5 and 8.5 scenarios were prepared for 2040s (2020-2059) and 2080s (2060-2099) with 12.5 km spatial resolution. The future hydrologic components viz. evapotranspiration, soil water contents, surface runoff and streamflow were suggested as both integrated and spatially distributed results.

Keywords: *Grid-based, Modeling, Climate change, Watershed, Hydrology*

1. INTRODUCTION

A grid-based distributed hydrologic modeling can give us valuable information during the hydrological processes with both temporal and spatial aspects. We can look at the happenings of water cycle and extract some information at the level of a given cell dimension. When we try to assess the climate change impact on watershed hydrology, it is necessary to trace the responses of hydrologic behavior where they were occurred and how much were changed. This can help the establishment of water resources conservation and adaptation planning at the watershed scale. Thus, this study describes the development of a grid-based continuous hydrologic model for climate change assessment. Ultimately, the model will be extended to apply for 99,000 km² of South Korea.

2. STUDY AREA AND DATA

For model development, Yongdamdam watershed (930 km²) was adopted (Figure 1). Daily weather data for Penman-Monteith evapotranspiration were obtained from Korea Meteorological Administration. For model calibration and validation, the daily streamflow data were obtained from Water Management Information System (WAMIS). The data of elevation, soil type, land use, and the temporal data were prepared as a 1 km resolution grid with 46 rows and 55 columns.

3. MODEL DESCRIPTION

The model divides the watershed into rectangular cells, and the cell profile is divided into three layers: surface layer, subsurface unsaturated and saturated layers. The model performs the soil water routing in a daily base for each grid element. When it rains, the surface runoff is simulated by the available storage of soil moisture contents. Evapotranspiration is calculated by Penman-Monteith method considering Leaf Area Index (LAI) of vegetation canopy, and the percolation rate to deep groundwater layer is controlled depending on the soil field capacity and the saturated hydraulic conductivity. The model introduced six important parameters viz. surface lag coefficient, soil percolation ratio, lateral flow recession curve slope, lateral flow basin lag time, base flow recession curve slope, and base flow basin lag time for model calibration.

4. MODEL CALIBRATION AND VALIDATION

The model was calibrated for 5 years (2002-2006) and validated for 3 years (2007-2009) for daily streamflow data at 3 locations (Yongdam, Donghyang, and Cheoncheon) with Nash-Sutcliffe model efficiency of 0.61~0.82.

5. MODEL APPLICATION FOR CLIMATE CHANGE IMPACT ASSESSMENT

Table 1 shows the future temperature and precipitation scenarios and the projected 2040s and 2080s model results of evapotranspiration and streamflow, and figure 3 shows the spatial results of future seasonal surface runoff based on the baseline period (2002-2009).

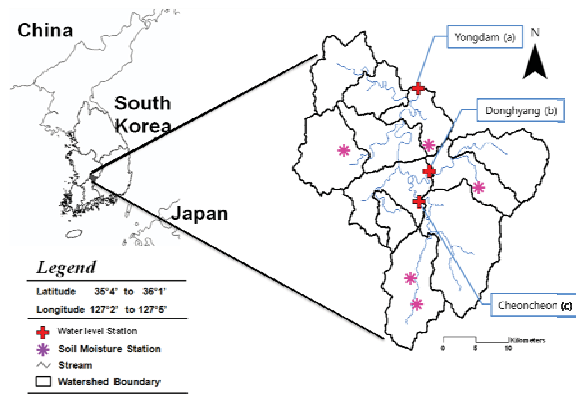


Figure 1. Yongdamdam watershed.

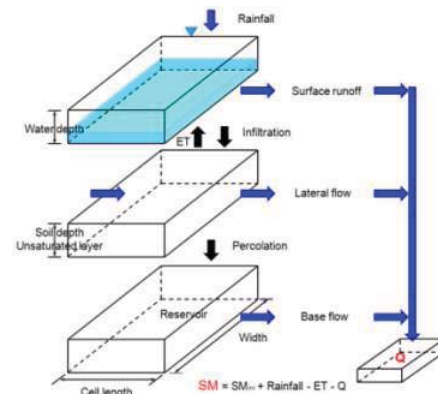


Figure 2. Schematic representation of the flow system (Kim et al., 2005).

Table 1. Summary of future predicted hydrologic components for HadGEM5-RA RCP 4.5 and 8.5 scenarios in 2040s and 2080s

Components	Baseline (2002-2009)	RCP 4.5		RCP 8.5	
		2040s	2080s	2040s	2080s
Temperature (°C)	6.24	7.09 (+0.85)	8.06 (+1.82)	7.79 (+1.55)	10.73 (+4.49)
Precipitation (mm)	1462.9	1550.4 (+6.0%)	1633.4 (+11.7%)	1660.2 (+13.5%)	1736.4 (+18.7%)
Evapotranspiration (mm)	520.8	462.7 (-11.2%)	492.4 (-5.5%)	455.6 (-12.5%)	533.9 (+2.5%)
Streamflow (mm)	892.4	1004.2 (+12.5%)	1057.8 (+18.5%)	1111.2 (+24.5%)	1116.4 (+25.1%)

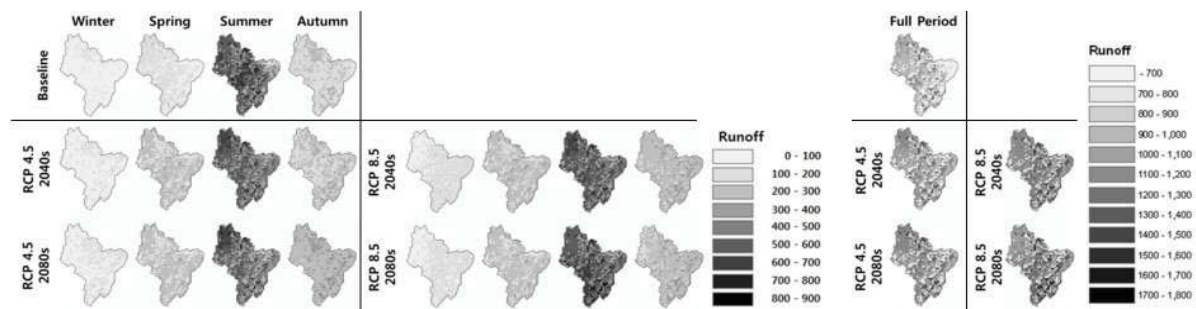


Figure 3. The 2040s and 2080s surface runoff based on baseline (2002-2009).

6. SUMMARY AND CONCLUSION

This study developed a grid-based hydrologic model for the purpose of assessing future climate change impact on watershed hydrology. For a 930.4 km² watershed, the model was calibrated and validated using 8 years daily streamflow data at 3 locations. For model application, the future climate data of HadGEM3-RA RCP 4.5 and 8.5 scenarios were prepared for 2040s (2020-2059) and 2080s (2060-2099) and the future hydrologic components were generated both integrated and spatially distributed results based on baseline period of 2002-2009.

Acknowledgement:

This study was supported by the Construction Technology Innovation Program (09-Tech-Innovation -C01) through the Climate Change Assessment and Projection for Hydrology (CCAPH-K) under Korea Institute of Construction & Transportation Technology Evaluation and Planning (KICTEP) of Ministry of Land, Transport and Maritime Affairs (MLTM).

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ESTIMATING THE SYSTEMATIC BIAS IN THE PRESENT AND FUTURE PRECIPITATION OUTPUT OF AGCM60KM

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Abstract: Precipitation output from a regionally-specified cloud resolving mode is assumed to be the true value for present and future climate conditions, and the systematic bias in the precipitation output from a GCM was evaluated. It was able to estimate the variation of model bias in the GCM precipitation output under different climate and boundary conditions. The validity of the bias correction concept is also examined, and it was revealed that the concept is prominent, even when the GCM runs on an incorrect boundary condition.

Keywords: *Bias correction, GCM precipitation output, Variant future climate conditions*

1. INTRODUCTION

Bias correction of GCM output is a widely utilized scheme in the field of climate change impact assessment research. The general concept of the bias correction is to remove the systematic bias from the GCM output by comparing the controlled simulation results with historic observations. It is assumed that this systematic bias from the controlled simulation will be the same for future climate simulations.

In this study, we have examined the validity of this important assumption underlying the basic concept of bias correction by comparing the precipitation output from two different types of climate models. By assuming the precipitation output from a regionally-specified climate model as a true value for the present and future climate conditions, it was able to estimate the variation of model bias in the GCM precipitation output under the two different climate conditions.

2. DATA AND METHODOLOGY

Under the Innovative Program of Climate Change Projection for the 21st Century (Kakushin Program, 2007–2011) of Japan, the Meteorological Research Institute of Japan developed several atmospheric GCMs. One of the developed AGCMs providing 20km of spatial resolution (hereafter AGCM20km) was mainly designed to simulate the Baiu front and Typhoon of East Asia (Kitoh and Kusunoki, 2007). AGCM20km uses the observed sea surface temperature (SST) of the HadISST1 dataset as a boundary condition for the controlled run (1979–2003). Future SSTs for the projection run (2075–2099) were estimated from the ensemble mean of GCM output, which adopts the A1B emission scenario, within the Coupled Model Inter-comparison Project phase 3 (CMIP3). Another AGCM providing 60km of spatial resolution (hereafter AGCM60km) was designed to estimate model sensitivity under different boundary and initial conditions. Based on the same model structure and parameterization scheme as AGCM20km, AGCM60km provides ensemble projection run output based on four different boundary conditions: future SST simulation results from CSIRO_MK3.0, MIROC3.2, and MRI-CGCM2.3.2, and the mean SST from the CMIP3 models (Kusunoki et al., 2011).

At the same time, MRI of Japan has developed a cloud system-resolving regional climate model with 5km of spatial resolution (hereafter RCM5km) based on the Japan Meteorological Agency's non-hydrostatic weather prediction model (JMA–NHM; Saito et al. 2007). The RCM5km runs using the boundary conditions from the AGCM20km (Nakano et al., 2012), and it simulates the atmospheric conditions of present and future summer seasons (June–October) of the region covering Japan and the Korean Peninsula (25°N–40°N and 125°E–145°E). Evaluation of the RCM5km output provides strong agreement with a rain gauge–based daily precipitation dataset for June–August, and the probability density distribution of daily precipitation amounts is also well matched to what is observed (Kanada et al., 2010).

In our experiment, the summer season precipitation output from the RCM5km is assumed to be the true value for the present and future climate conditions, and the systematic bias in the precipitation output from the AGCM60km was evaluated. This experimental design provides unique evaluating conditions, in that we can examine the systematic bias differences between the controlled run and the future projection. Both AGCM60km and AGCM20km, which provide the boundary conditions for the RCM5km, run with the same A1B emission scenario, yet AGCM60km runs on the variant SST boundary conditions. In the next section, we will illustrate the bias differences in the present and future climate conditions, and the conventional bias correction method will be applied to the AGCM60km precipitation output for evaluating the validity of the bias correction concept.

3. RESULTS AND DISCUSSION

Firstly, precipitation bias in the AGCM60km (mean SST) was examined by comparison with the output of the RCM5km, in terms of deviation and ratio for both present (1979–2003) and future (2075–2099) climate conditions (see Fig. 1). The deviation bias (d-bias) is the difference between the annual mean of summer season (June–October) precipitation amounts from the AGCM60km and the RCM5km. The ratio bias (r-bias) is the ratio of the d-bias to the annual mean of the RCM5km, which is assumed to be the true value in this experiment. The correlation coefficient of the d-bias between present and future climates is 0.872, and the correlation coefficient of the r-bias is 0.800, which show rather high resemblances in both cases.

Fig. 2 (Left) shows the effect of the bias correction, when the d-bias (and r-bias as well) from the present climate condition was corrected for the AGCM60km output in the future climate condition. Before the bias correction, the correlation coefficient of annual mean summer precipitation of AGCM60km to the RCM5km predictions was 0.781, and the correlation was improved up to 0.956, in the case of d-bias correction, and 0.954 in the case of r-bias correction. This improvement was also found when the d-bias and the r-bias were removed from the rest of the AGCM60km precipitation output using the different SST boundary condition (see Fig. 2, Right).

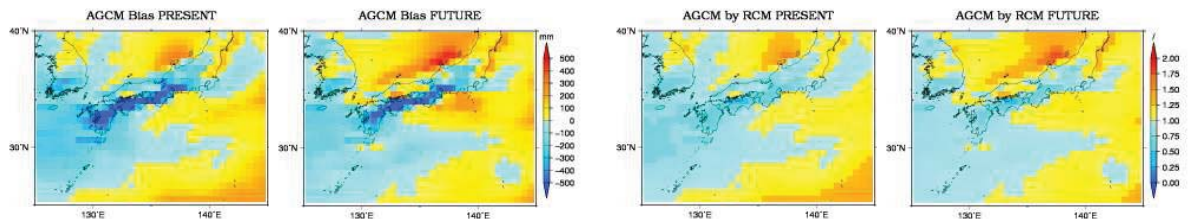


Figure 1. Precipitation bias in a sense of deviation (d-bias, left two figures) and ratio (r-bias, right two figures) during summer season (June–October) from the AGCM60km (mean SST) comparing to the RCM5km output.

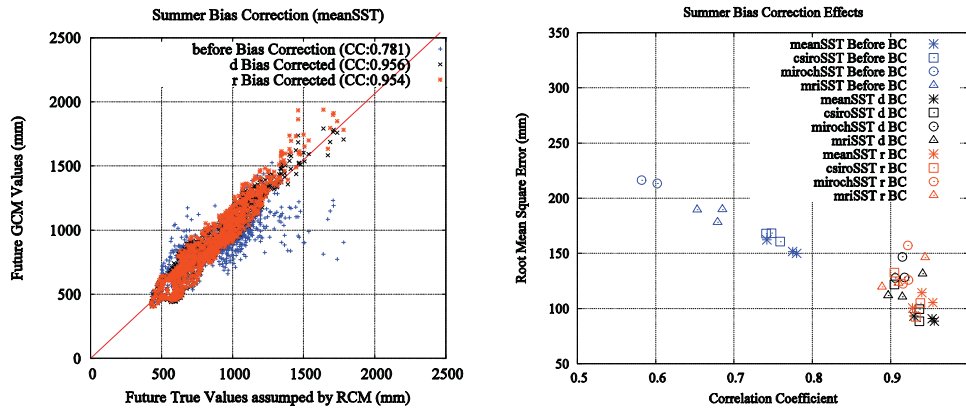


Figure 2. Effect of bias correction. Left: Annual mean summer precipitation of future before and after the bias correction, in the case of mean SST AGCM60km output. Right: Variation in correlation coefficients and root mean square errors before and after the bias correction for future summer precipitation.

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A MULTI-INDEX MULTIVARIATE DROUGHT MONITORING FRAMEWORK: APPLICATION TO CLIMATE CHANGE IMPACT ASSESSMENT

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Abstract: In this paper, a multi-index Multivariate Standardized Drought Index (MSDI) is introduced that can be used for drought monitoring based on multiple variables (e.g., precipitation, soil moisture, runoff). This index combines the states of multiple variables into one probabilistic measure of drought condition.

Keywords: Drought, Precipitation, Soil Moisture, Climate Change

1. INTRODUCTION

Improving our understanding of weather and climate, along with the development of reliable monitoring and prediction indices are essential for the proper assessment of droughts. Thus far, several indices have been developed for drought monitoring based on various indicator variables (precipitation, soil moisture, runoff; e.g., see Palmer (1965); McKee et al. (1993)). Defining droughts based on a single variable (e.g., precipitation, soil moisture or runoff) may not be sufficient for reliable risk assessment and decision making (Keyantash and Dracup, 2004). In this paper, a multivariate multi-index drought modeling approach is proposed using the concept of multivariate copulas. The suggested Multivariate Standardized Drought Index (MSDI; Hao and AghaKouchak, 2012) combines Standardized Precipitation Index (SPI) and Standardized Soil Moisture Index (SSI) probabilistically for drought characterization. In other words, MSDI incorporates the meteorological and agricultural drought conditions for overall characterization of drought.

2. METHODOLOGY

The suggested MSDI is developed through constructing the joint distribution function of two drought-related variables (here, precipitation and soil moisture). In this study, the joint distribution of precipitation and soil moisture is investigated for overall meteorological and agricultural drought characterization. Assuming precipitation and soil moisture as variables X and Y , the joint distribution can be expressed with a copula C as (Nelsen, 2006):

$$P(X \leq x, Y \leq y) = C(F(X), G(Y))$$

where C is the copula and $F(X)$ and $G(Y)$ are the marginal cumulative distribution functions of random variables X and Y , respectively.

3. RESULTS

MSDI is compared with SPI and SSI for characterizing drought condition over several locations across the State of California. Figure 1 displays SPI, SSI and the proposed Multivariate Standardized Drought Index (MSDI) for Climate Division 3 of California and using NOAA climate. The figure is generated using rainfall and soil moisture data obtained from the National Climatic Data Center (NCDC) and the Climate Prediction Center (CPC), respectively. The horizontal line refers to SPI and SSI equal to -1 (moderate drought). One can see that, while SPI and SSI are generally consistent, at several time steps the two indices show significant discrepancies. In a few time steps, even the wet and dry signals are different (e.g., $SPI > 0$ and $SSI < 0$). Such discrepancies could be due to abnormally high rainfall over a very short period of time while most of the month remains dry ($SPI > 0$ and $SSI < 0$). Alternatively, a below average rainfall distributed throughout a month such that the soil stays wet ($SPI < 0$ and $SSI > 0$) could lead to opposite signs of SPI and SSI and hence false or inaccurate drought signals. Figure 1 confirms that the two indices include discrepancies over several months, which leads to different risks and return periods depending on the choice of indicator variable. As an example, during 1976-1978, SPI and SSI both show two drought events with different durations, with the SSI-based drought being much longer than the SPI-based one (see Figure 1(top)). SSI starts later than SPI and ends later as well. Also, the levels of drought severity from SPI and SSI differ during the period of 1976-1978. MSDI, on the other hand, shows drought onset and termination based on the combination of SPI and SSI (starts with SPI and ends with SSI). Figure 1 highlights a property of MSDI: it does not change significantly if only one index changes for a very short period of time. This example demonstrates that MSDI can successfully combine the two datasets probabilistically and that it provides a basis for drought information based on multiple variables (here, precipitation and soil moisture).

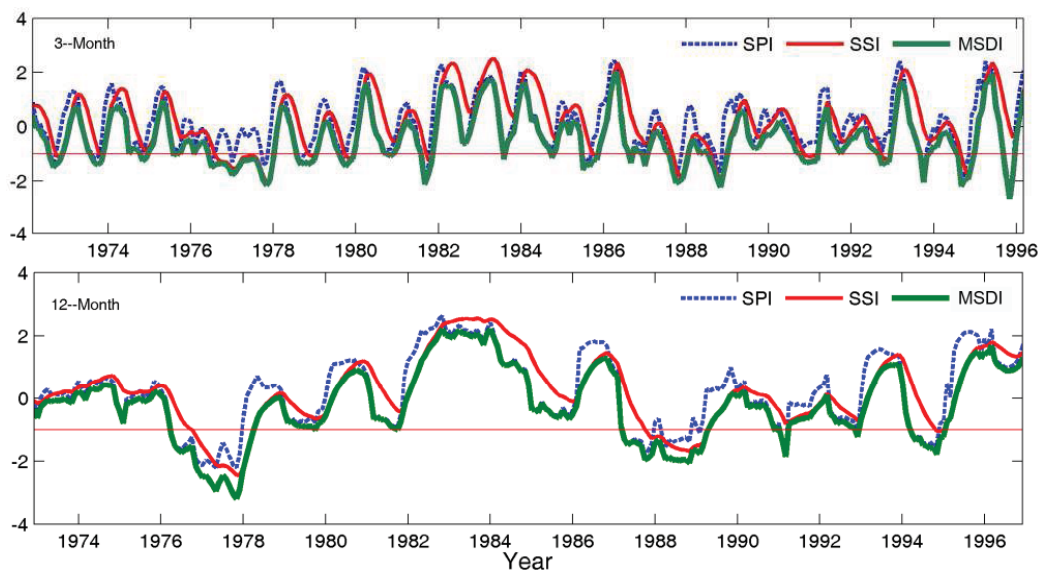


Figure 1. 3-month (upper panel) and 12-month (lower panel) Standardized Precipitation Index (SPI), Standardized Soil Moisture Index (SSI), and the suggested Multivariate Standardized Drought Index (MSDI).

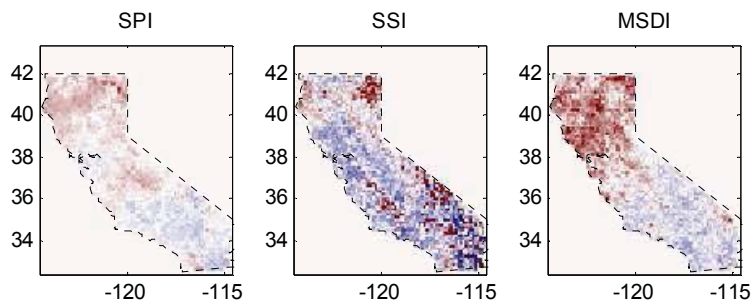


Figure 2. Changes (%) in the number of drought events across California for short-term duration (1- to 3-month) droughts based on 3-month SPI, SSI and MSDI.

projection (2040-2080) period compared to the baseline (1960-2000) period (i.e., 3-month SPI, SSI, MSDI below -1 for 1 to 3 consecutive months.)

In the following, application of the suggested MSDI for climate change impact assessment is demonstrated using phase 3 of the Coupled Model Intercomparison Project (CMIP3) bias-adjusted hydrology projections (Maurer et al., 2007). In this example, the baseline and projection periods are 1960-2000 and 2040-2080, respectively. Figure 2 shows changes in the number of drought events between 1 to 3 months based on a 3-month drought index below -1 for the

4. CONCLUSIONS

Overall, MSDI seems to be a reasonable model for combining multiple indices probabilistically. Evidently, reliable and more realistic probabilistic analysis of drought events plays a significant role in water resources management, agricultural production and disaster risk assessment. Efforts are underway by the authors to assess climate change and variability impacts on drought patterns and severity under different climate change scenarios using MSDI in a global scale.

Acknowledgement:

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STATISTICAL ASSESSMENT OF CHANGES IN DAILY PRECIPITATION EXTREMES IN THE ASIA-PACIFIC REGION

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Abstract: We applied a generalized extreme value (GEV) distribution to data on extreme precipitation events over 51 years (1960 to 2010) in the Asia-Pacific region. We demonstrated that trends (slope of the location parameter) in extreme precipitation events had not changed significantly at over 80 % of the observation stations analyzed; however, the linear trend suggests that changes in annual extreme precipitation events have occurred at smaller spatial scales as opposed to the entire Asia-Pacific region. Based on best-fit GEV distributions, return levels corresponding to various return periods were high in regions impacted by summer monsoons (including east Asia, south Asia, and northern Australia) or landfalling tropical cyclones. In addition, we found that 40-year return levels for extreme precipitation events for the most recent decade (2000 to 2010) have not changed significantly compared to the previous two decades (1980 to 2000) for 80% of the observation stations analyzed. We investigated the changes in extreme precipitation events for many stations in the Asia-Pacific region. And we also provided the return levels for various return periods there.

Keywords: *generalized extreme value distribution, return level, return period, extreme precipitation*

1. INTRODUCTION

Concerns regarding the changes in climate extremes are increasing, especially in the face of global climate change. In fact, historical data collected at local observation stations have been used to assess changes in climate extremes over the past several years. However, few systematic and extensive studies have been conducted on changes in extreme climate events because of the difficulties inherent in the collection of high-resolution spatial and temporal climatic data covering broad regions (Choi et al., 2009). Our objectives in this study were 1) to model annual extreme climate events, specifically relating to precipitation, in the Asia-Pacific region using historical precipitation observations and 2) to estimate the annual probabilities of extremely large daily precipitation amounts in this region. To accomplish this, we use extreme value analysis in which observed data extremes are analyzed, and the annual probabilities of those extremes are estimated.

2. DATA AND METHODS

We used GHCN-Daily data (Durre et al. 2010) from stations found within the Asia-Pacific region (including Australia, Japan, South Korea, Kazakhstan, New Caledonia, Philippines and Russia) only if those stations provided measurements consistently over the period between 1960 and 2010. We used the block maxima approach (Gumbel, 1958) to select a subset of extreme values from each station's dataset. We defined an extreme precipitation event as the highest precipitation amount that occurred in a single day within a year (denoted as AM1). In addition, we used 2-, 5-, and 10-day moving windows to sum the amount of precipitation that occurred at each observation point over the specified period in order to construct a time series of annual maxima in 2-, 5-, and 10-day precipitation (denoted as AM2, AM5, and AM10, respectively). We applied the generalized extreme value (GEV) distribution to the annual extreme precipitation data. We used GEV_C or Gum_C for the stationary distribution of the extreme precipitation data and GEV_L or Gum_L (GEV_Q or Gum_Q) for linear (quadratic) trends in the precipitation events.

3. RESULTS

In analysing the spatial distribution of the best statistical models fitted to the AM1, AM2, AM5 and AM10 datasets, we found that over 80% of the observation stations in the Asia-Pacific region exhibited insignificant trends in either the GEV_C or Gum_C distributions during the periods analysed from 1960 to 2100 (Fig.1). The 10.9 to 27.3% and 1.8 to 7.3% of the stations showed linear (GEV_L or Gum_L) and quadratic (GEV_Q or Gum_Q) trends, respectively. In addition, the GEV distribution models selected as best fits for the annual maximum precipitation data varied with the spatial location of observation stations. This is not surprising considering that precipitation has greater variability in space and time compared to, for example, temperature and that precipitation extremes could be affected by spatially isolated storm events or convections (Alexander and Arblaster 2009). In addition, we determined that the most appropriate model selected as the best fit for extreme precipitation events that occurred over varying lengths of time (e.g. AM1 compared to AM10) also varied depending on the location of the observation station (not shown). Given that trends in extreme precipitation events that occur over short periods of time (as in the AM1, AM2, and AM5 datasets) are primarily driven by local factors (e.g., typhoons or storms) while those that occur over longer periods of time (as in the

AM10 dataset) are influenced by large scale atmospheric circulation anomalies (Feng et al., 2007), it is expected that extreme precipitation trends would show different characteristics across the Asia-Pacific region at different time scales. We compared the spatial distribution of 20-year return levels with those of 5-year return levels (where an event has a 20% chance of occurring each year; Figure. 1). We found higher values for the 20-year return levels at all stations. Again, return values varied geographically such that larger increments occurred in the regions affected by seasonal summer monsoon systems and/or typhoons, such as Korea, Japan, the Philippines, and northern Australia. In addition, extreme precipitation events that lasted longer (as in the AM10 dataset) were recorded at the most stations showing considerably high differences between 20-year and 5-year return levels, suggesting that persistent large-scale atmospheric circulation anomalies during summer monsoon seasons have a disproportionately large influence on the changes in return levels over the Asia-Pacific region.

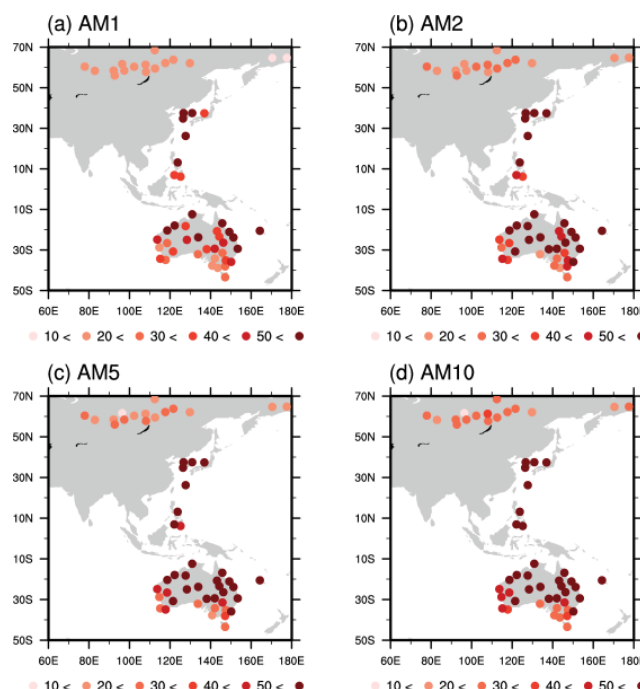


Figure 1. Differences in estimated 20-year return levels relative to 5-year return levels for (a) daily, (b)-(d) 2-, 5- and 10-day moving sums of precipitation

4. SUMMARY

Using a recently collected, comprehensive daily precipitation dataset, we performed an extreme value analysis using the GEV distribution of annual maximum precipitation events at around 50 observation stations in the Asia-Pacific region over daily, 2-, 5-, and 10-day scales spanning the years from 1960 to 2100. We did not find region-wide significant ($p < 0.10$) temporal trends in the extreme precipitation events at more than 80% of the observation stations analyzed. However, the estimated trend from location parameters suggests that the annual extreme precipitation events could be changing with time at smaller, more localized scales. Using the fitted GEV distributions for the datasets at each observation station, we also calculated the likely return levels over varying return periods for extreme precipitation events. We found that high return levels were linked to areas of high seasonal variability, usually associated with summer monsoons, including east Asia, south Asia, and parts of Australia.

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POTENTIAL INCREASE OF HYDROCLIMATIC EXTREMES IN KOREA DUE TO GLOBAL WARMING FROM A REGIONAL CLIMATE SIMULATION

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Abstract: The study investigates the changes in hydroclimatic extremes in Korea due to global warming. For a fine-scale (20 km) climate change projection focusing on the Korean peninsula, we performed dynamical downscaling of the IPCC AR4 participant climate scenario simulated by the ECHAM5 (Max-Planck-Institute global climate model) using the regional climate model, RegCM3. A 130-year long-term climatology (1971-2100) forced by A1B emission scenario is discussed with a focus on the flood and drought possibilities in response to global warming. Climate change projection based on the ECHAM5-RegCM3 model chain clearly shows the effect of global warming in increasing the intensity and frequency of extreme precipitation, even under the reduction of total precipitation, which implies an increased risk for flood hazards. The decreased relatively low intensity precipitation is responsible for the decreased total precipitation, so that the decreased total precipitation does not necessarily mean less heavy precipitation. Rather, a lower frequency of weak precipitation lengthens the dry spell while a significant warming induces a pronounced actual water stress. As a consequence, the combined effects of precipitation and temperature appear to provide a more favorable condition for dryness.

Keywords: *Hydroclimatic extremes, global warming, regional climate simulation, Korea*

1. INTRODUCTION

Given the scientific consensus of higher hydroclimatic intensity with global warming (Giorgi et al., 2011), recent studies reporting that Korea will be vulnerable to manage water resources under future climate have great implications (Im et al. 2012a,b). The modulation of the hydrological cycle due to enhanced water holding capacity in a warmer atmosphere can result in a complex and nonlinear response in terms of both mean and extreme precipitation changes. In particular, since the behavior of precipitation shows low predictability and strong regional-dependency with high frequency variability, it is difficult to derive reliable interpretation of its change feature. In order to reduce the possible uncertainty range and to understand the accurate characteristics of the hydroclimatic change, comprehensive investigations of precipitation with high resolution in terms of spatial and temporal scales are needed. Although there are several previous studies to deal with the future changes in precipitation over East Asia including the Korean peninsula from global and regional climate projections, our study could have the advantage beyond them in terms of spatial and temporal scales and integration length. Note that few studies have examined such a fine resolution in both spatial and temporal scales (20 km and 3-hour) from long-term climate projection (1971-2100, 130yr) over Korea.

2. DATA AND METHOD

A model chain composed of ECHAM5 and RegCM3 and the one-way double-nested technique applied to this work are based on the research by Im et al. (2011), and the references therein. In this study, we only focused on the temperature and precipitation from the inner nested domain of 20 km grid spacing for every 3-hour. In order to describe the statistical likelihood of extreme events, Intensity-duration-frequency (IDF) curves obtained by fitting the Generalized Extreme Value (GEV) distribution are applied. The GEV distributions are computed from the annual maxima values occurring within a certain duration (i.e. 3-, 6-, 9-, 12-, 15-, 18-, 21-, and 24-hour), and the return periods of extreme precipitation are estimated by the upper quantile of the fitted GEV distribution. For flood and drought analysis, this distribution has been widely used to fit to the annual maximum precipitation from observed data and model simulations.

3. RESULTS

Figure 1 presents the time series of annually averaged temperature and precipitation anomalies over Korea throughout the entire integration period. It provides useful insight into the trend and persistency in the long-term variability of the climate change signal in response to increasing GHG concentration. To validate the simulated results during the reference period (1971-2000), we also display the observed estimates archived at the Korean climate stations (averaged over 57 locations, 1975-2004). The mean, variability, and trends of the simulated temperature and precipitation demonstrate similarity with those of the observations. The temperature shows a gradually increasing pattern. The precipitation also exhibits an overall increase, but it has large interannual and interdecadal variability. According to the projection for the twenty-first century, the degree of warming is sharply accelerated, indicating a well-defined increasing trend. The increase of temperature enhances the evapotranspiration, and hence the actual water stress becomes more pronounced in the warmer climate. Im et

al. (2012b) demonstrates that the much faster future increasing rate of temperature is more responsible for the downward trend of the Palmer Drought Severity Index compared to the reference period. In case of precipitation, it is difficult to find any readily apparent trends when viewed in the context of the whole twenty-first century. However, since the trend depends on the selected period, for certain periods (e.g. 2031-2060) there is a visibly increasing trend while a decreasing pattern is discernible after the 2070s. Therefore, projections derived from a short certain period could produce erroneous interpretations of the results, highlighting the necessity of a multi-decadal length of simulation to consider both unforced variability and trends of the climate change signal.

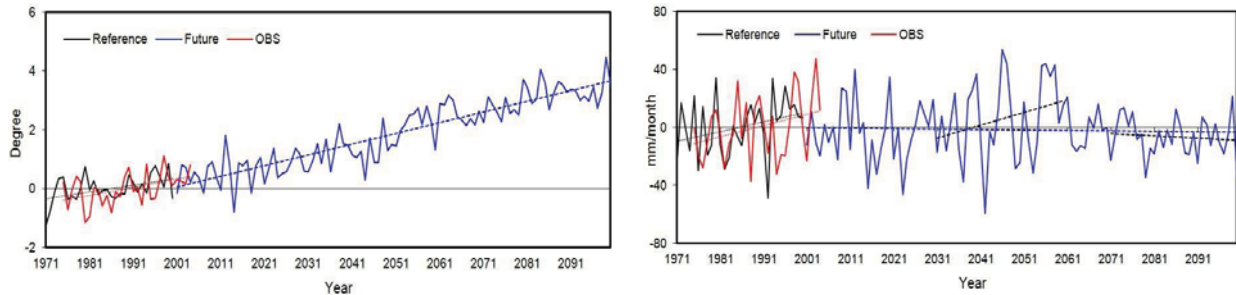


Figure 1. Time-series of annually averaged temperature (left) and precipitation (right) anomalies (solid line) with respect to the reference simulation and its trend (dotted line) during the reference (1971-2000) and future (2001-2100) period derived from observation (red) and simulation (black & blue) over Korea.

Figure 2 shows the IDF curves for the 3- and 24-hour precipitation. Despite the large differences in the 30-year temporal evolution of the annual mean, such as the increasing trend for 2031-2060 with large variability and the decreasing trend for 2071-2100 with relatively small variability, both change behaviors show consistent pattern. Significant reductions in the return period of extremes events are visible and the degrees of reduction become more pronounced in the late 21st century as the GHG concentration increased. The systematically higher future values compared to their corresponding values in the reference climate indicate a more intense heavy precipitation in the future warmer climate over Korea. In addition, the intensity enhancement is more pronounced in the 3-hour duration, which implies a greater vulnerability against flood hazards. Despite the same amount of precipitation, the precipitation event occurring relatively short period causes more damage and vulnerable situation. Therefore, the reduced total annual precipitation in the late 21st century shown in Figure 1 does not simply indicate a decrease of extreme precipitation. Rather, it reflects the intensified hydrologic cycle, implying more dryness due to reduced moderate precipitation in tandem with more floods due to increased high intensity precipitation.

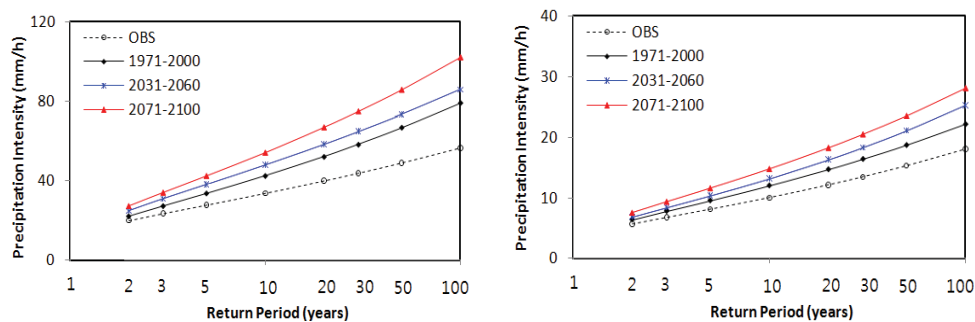


Figure 2. IDF curves derived from observation (black dashed line), the reference (black solid line) and the two future (2031-2060: blue solid line, 2071-2100: red solid line) simulations for 3-hour (left) and 24-hour (right) durations.

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THE EFFECT OF UNIFORM AND NON-UNIFORM BIAS CORRECTION METHODS ON IMPROVING NEXRAD RAINFALL ACCURACY FOR DISTRIBUTED HYDROLOGIC MODELLING

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Abstract: Next Generation Radar (NEXRAD) rainfall data are increasingly being used in hydrologic models to capture the spatio-temporal dynamics of rainfall in numerical simulations. Even though NEXRAD provides a better spatial representation of rainfall variability, it suffers from uncertainties and biases due to Z-R (reflectivity-rainfall) conversion method and limitation of available rain gauge information for NEXRAD bias correction in a particular river basin. In order to improve the accuracy of rainfall estimates from NEXRAD uncertainties, data assimilation technique is performed by considering NEXRAD and available rain gauges which can be used to assimilate spatially uniform (MPE scheme) and non-uniform (based on rainfall interpolation and bias interpolation) NEXRAD bias estimations during a storm event by Kalman filtering. Analysis of correcting NEXRAD bias rainfall with three different bias correction schemes is described in this study. The prediction accuracy of the STORE DHM (Storage Released based Distributed Hydrologic Model) simulations is also evaluated by using three different NEXRAD bias corrected rainfall inputs. The Upper Wabash River (17,907km²) and the Upper Cumberland River (38,160km²) basins are selected as the study areas to evaluate rainfall input sensitivity on different spatial characteristics. Use of spatially non-uniform NEXRAD bias correction schemes results in better rainfall and prediction accuracy compared to that from spatially uniform NEXRAD bias correction rainfall. In addition, the results show that spatially non-uniform NEXRAD bias correction schemes performs better in Upper Cumberland River that has greater rainfall variability compared to that with Upper Wabash River.

Keywords: NEXRAD; Kalman filter; bias correction; STORE DHM.

1. INTRODUCTION

Representation of rainfall dynamics is critical for making accurate hydrologic predictions. Numerous studies in the past decades have investigated the sensitivity of runoff hydrographs to rainfall data obtained from point gauges. In addition to the accuracy of gauged rainfall input, the predictability and sensitivity of hydrologic models is dependent on the spatio-temporal representation of rainfall (Faures et al. 1995; Wilson et al. 1979) which can be obtained from radar rainfall data (Smith et al., 2004). The next generation radar (NEXRAD) products available since 1992 provide high resolution rainfall information in space and time for the United States. Currently, the NEXRAD precipitation products are categorized into four levels based on the extent of preprocessing, calibration, and quality control performed. The *StageI* product is an hourly digital precipitation (HDP) directly derived from reflectivity measurements using a Z-R (reflectivity-rainfall) relationship after the application of several quality control algorithms (e.g. Fulton et al., 1998). *StageII* is the single radar site HDP product, which is merged with surface rain gauge observations to correct mean field bias using Kalman filtering (Smith and Krajewski, 1991; Anagnostou et al., 1999). In *StageIII*, the *StageII* rainfall data from multiple weather radars covering a River Forecast Center (RFC) region are combined (Fulton et al., 1998; Reed and Maidment, 1999). Finally, *StageIV* is the mosaicked *StageIII* rainfall product covering the entire Continental United States (CONUS).

Literature shows that the availability of high-resolution precipitation data from different weather radar platforms have led to improved understanding of rainfall uncertainty in hydrologic models, but few efforts have been directed towards understanding the influence of NEXRAD precipitation and its bias correction on rainfall-runoff simulations. This study presents three different NEXRAD rainfall bias correction schemes and their influence on sensitivity of grid based distributed hydrologic model simulations.

2. NEXRAD Bias Correction Methods

Spatially uniform NEXRAD Bias Correction using Kalman Filter

The logarithmic mean field bias between NEXRAD estimates at the rain gauge locations and the corresponding gauge rainfall amounts is computed by equation 1.

$$(t) = \frac{\frac{1}{n} \sum_{i=1}^n \log_{10}(G(t)_i)}{\frac{1}{n} \sum_{i=1}^n \log_{10}(R(t)_i)} \quad (1)$$

where $G(t)_i$ is hourly rain gauge rainfall at NEXRAD-gauge paired cell i for hour t , $R(t)_i$ is hourly NEXRAD rainfall at NEXRAD-gauge paired cell i for hour t , and n is the number of pairs of radar-gauge data. Spatially uniform bias corrected NEXRAD rainfall is then computed by using Eq. 2.

$$R^*(t)_j = B(t) R(t)_j \quad (2)$$

where $R^*(t)_j$ is bias corrected NEXRAD at j location at time t , and $R(t)_j$ is hourly NEXRAD rainfall at gauge cell j for hour t within the study area.

Spatially non-uniform NEXRAD Bias Correction using Kalman Filter

Unlike the MFB (Eq. 1), the spatially non-uniform biases vary from pixel to pixel across the NEXRAD domain. Corrected NEXRAD rainfall at an un-gauged NEXRAD pixel j for hour t , $R^*(t)_j$, is computed by multiplying spatially non-uniform bias correction factor ($B(t)_j$) at each un-gauged NEXRAD grid location j using Eq. 3.

$$R^*(t)_j = B(t)_j R(t)_j \quad (3)$$

3. CONCLUSIONS

Three different NEXRAD bias correction schemes are applied to two study basins (Upper Wabash River and Upper Cumberland River) to evaluate effects of each NEXRAD bias correction scheme on the representation of the rainfall, and its effect on hydrologic simulations. The following conclusions can be drawn from this study:

- 1) For the two basins used in this study, the cross-validation of rainfall estimates obtained by applying spatially non-uniform bias correction methods have better accuracy in terms of RMSE compared to spatially uniform bias correction method.
- 2) Among the two spatially non-uniform bias correction methods used in this study, the method that involves interpolation of rainfall before applying the bias correction (SNU-R) performed better than the method that involves interpolation of error (SNU-E).
- 3) Hydrologic simulations performed using a grid based distributed hydrologic model show that the input rainfall obtained by using spatially non-uniform bias correction method produced output hydrographs that are more comparable with the calibrated model output compared to the output from model with using spatially uniform bias corrected rainfall input. Among the two spatially non-uniform bias correction methods, the SNU-R method produced better runoff hydrographs compared to SNU-E method.
- 4) The improvement in rainfall estimates and hydrologic simulations from using spatially non-uniform bias correction methods is consistent for both watershed used in this study. The overall improvement is greater in the Upper Cumberland River (UCR) basin compared to the Upper Wabash River (UWR) basin. This shows that the application of spatially non-uniform bias correction for radar rainfall is more effective in larger areas with more variable rainfall (e.g. UCR) compared to smaller areas with less variable rainfall (e.g. UWR) basin. However, this conclusion is based on only two watersheds used in this study, and must be investigated further by including more watersheds to make it generally applicable.

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Session III

BEING PROACTIVE ABOUT DROUGHT: LONG-TERM RISKS AND EARLY WARNINGS

Roger S. Pulwarty PhD

DROUGHT INFORMATION SERVICES: BRIDGING THE SCIENCE/POLICY INTERFACE

Mark D. Svoboda

DEVELOPING EFFECTIVE COMMUNICATION CHANNELS AND TOOLKITS AMONG CLIMATE SCIENTISTS, WATER RESOURCE MANAGERS AND POLICY MAKERS

Mike Harrison

TOWARDS ROBUST PREDICTIONS OF THE HYDROLOGICAL IMPACTS OF CLIMATE CHANGE: THE BAYESIAN TOTAL ERROR APPROACH

Mark Thyer

MANAGING WATER RESOURCES UNDER GLOBAL CLIMATE VARIABILITY: RESPONSES OF WATER RESOURCE MANAGERS AND POLICYMAKERS IN NIGERIA

Andrew Onwuemele(PhD)



BEING PROACTIVE ABOUT DROUGHT: LONG-TERM RISKS AND EARLY WARNINGS

Roger S. Pulwarty PhD

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National Oceanic and Atmospheric Administration*

Abstract: Risk-based management approaches to drought planning at the national and regional levels have been recommended repeatedly over the years but their prototyping, testing and operational implementation have been limited. This presentation will outline two avenues for disaster risk reduction in the context of drought (1) integrated early warning information systems, and (2) linking disaster risk reduction to climate change adaptation strategies. Illustrative cases will be drawn from the IPCC Special Report on Managing the Risks of Extreme Events and Disasters (2011), the UN Global Assessment of Disaster Risk Reduction (2011) and implementation activities, such as the (US) National Integrated Drought Information System and assessments of international early warning systems, in which the author has been engaged

Keyword: *Climate, drought, early warning, risk, climate services*

1. INTRODUCTION

Drought has long been recognized as falling into the category of incremental but long-term and cumulative environmental changes, also termed slow-onset or creeping events. Climate scientists continue to struggle with recognizing the onset of drought and scientists and policy makers and communities continue to debate the basis (i.e., criteria) for declaring an end to a drought. Adaptation involves not only using operational facilities and infrastructure to cope with the immediate problems but also leaving slack or reserve for coping with multiple stress problems that produce extreme impacts and surprise. Most drought early warning systems have tended to focus on the development and use of physical system indicators and forecasts of trends and thresholds. Risk-based management approaches to drought planning at the national and regional levels have been recommended repeatedly over the years but their prototyping, testing and operational implementation have been limited. As the experience of US National Integrated Drought Information System, the Famine Early Warning System Network and other knowledge management systems illustrate, “early warning” represents a proactive social and political process whereby actor-networks integrate diverse knowledge systems and engage in collaborative risk management. The process of communication is increasingly recognized to be complex, transactional, and heavily dependent on the potential user's pre-existing knowledge, beliefs and experiences and limited for producing transformational change. It is not surprising, that many policy-makers and operations managers believe that the information provided is, for the most part, insensitive to the unique situations in which they must act. Illustrative cases will be drawn a broad array of international studies of early warning systems and services implementation efforts in which the author has been engaged.

2. DISCUSSION

Early Warning Systems (EWS) aim to reduce vulnerability and improve response capacities of people, economies and ecosystems at risk. The UN International Strategy for Disaster Reduction (UNISDR) defines early warning as “the provision of timely and effective information, through identified institutions, that allows individuals exposed to a hazard to take action to avoid or reduce their risk and prepare for effective response”. There are multiple factors that limit current drought EWS capabilities and the operational application of data in preparedness, mitigation, and response globally (Wilhite, 2006): inadequate density and data quality of meteorological and hydrological data and the lack of data networks on all major climate and water supply parameters; inadequate data sharing-between government agencies and the high cost of data; user accessibility and training in applications; and inadequate indices for detecting the early onset and end of drought. The lack of specificity of information provided by forecasts, especially during non-ENSO years, limit the use of this information by farmers and others.

For the most part, EWS have been interpreted narrowly as technological instruments for detecting and forecasting impending hazard events and for issuing alerts. This interpretation, however, does not clarify whether information about impending events is actually communicated and used to reduce risks (UNISDR, 2011; IPCC 2012). Much decision support research, at present, focus on infrastructure and efficiency and fit the mould of “applications” with the next step being “communication”. While existing decision support activities can be identified in many disparate settings (e.g. federal, academic, private), the challenge of changing environments (coupled physical and social) is actually one of crafting implementation strategies for improving decision quality (not just meeting “user needs”), coordinating innovation mapping and diffusion, and providing fora and visualization tools (sometimes termed “discussion-support”) to identify common interests and differences in the way risks are perceived and managed among the affected groups. There is thus a difference between applications research and that done for effecting adaptation ((just as there is for basic research). The disaster research and

emergency management communities have shown that warnings of impending hazards need to be complemented by information on the risks actually posed by the hazards and likely strategies and pathways to mitigate the damage in the particular context in which they arise. We show that successful early warning systems that meet expectations of risk management also have explicit foci on (1) integrating physical and social vulnerability indicators across timescales, (2) analytical capacity to generate local scenarios of risk using both analogs and projections, (3) the communication of risk-based information, and (4) the support and governance of a collaborative framework for early warning structures across spatial scales.

The U.S. National Integrated Drought Information System and the FEWSnet experience will be used to illustrate that successful drought early warning information systems have explicit foci on (1) integrating social vulnerability indicators with physical variables across timescales, (2) embracing risk communication as an interactive social process and, (3) supporting governance of a collaborative framework for early warning across spatial scales (Pulwarty and Verdin, 2012). This experience shows that effecting anticipatory change in managing climate-related risks, requires more than communication. It is most readily accomplished when: (1) a focusing event (climatic, legal, or social) occurs and creates widespread public awareness; (2) leadership and the public are engaged; and (3) a basis for integrating monitoring, research, and management is established. We examine cases from around the world to illustrate governing criteria for defining and conducting “decision support” which entails: interactive learning, anticipatory coordination, communication and evaluation. Forecasts need not be perfect to make early warning useful. In such settings the timing and form of climatic information (including forecasts and projections), and access to trusted guidance to help interpret and implement the information and projections in decision-making processes may be more important to individual users than improved reliability and forecast skill. The term “*risk communication*” as used here, refers to intentional efforts on the part of one or more sources (e.g., international agencies, local government, communities) to provide information about hazards and hazard adjustments through a variety of channels among themselves or to different audiences (e.g., the general public, specific at-risk communities) and of local communities to characterize and communicate their risk-based experience. Internet based tools, such as Google maps, and graphical tools are already being used for participatory, large-scale information development. However, these tools are inherently limited in communicating the relevant local context and the consequences (positive and negative of information use). There is no prescriptive substitute for local monitoring, knowledge and trust

3. CONCLUSIONS: LINKING DISASTER RISK REDUCTION AND CLIMATE ADAPTATION

There is a critical need to approach and support early warning through both Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) (UNISDR, 2011; IPCC, 2011). This requires a framework that uses climate change scenarios not above but within risk and vulnerability profiles that capture the nature of capabilities and decision-making networks. These form the basis for effective early warning systems design and implementation. The cases above, and other efforts, have demonstrated that social protection and early warning information interventions can provide disaster risk reduction while helping to meet the goals of adaptation to changes in extreme events. For most locations, the governance context in which EWSs are embedded is key. The links between the community-based approach and the national and global EWSs are weak at present (Birkmann et al 2011). Improving the complementarity and legitimacy of both approaches is a new challenge to address especially in developing the institutional foundations for global climate early warning information systems envisioned by the Global Framework on Climate Services. One goal is to be prepared to use windows of opportunity for engaging and providing leadership, legitimizing drought risk management and successful communities of practice that have arisen during but also between events. We show that successful early warning “information” systems that meet expectations of risk management also have explicit foci on (1) integrating physical and social vulnerability indicators across timescales, (2) analytical capacity to generate local scenarios of risk using both analogs and projections, (3) the communication of risk-based information, and (4) the support and governance of a collaborative framework for early warning structures across spatial scales.

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DROUGHT INFORMATION SERVICES: BRIDGING THE SCIENCE/POLICY INTERFACE

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Abstract: As a boundary organization, the National Drought Mitigation Center (NDMC) works to achieve its mission of helping society reduce its risk to drought through activities and services that help to bridge the gap between science and policy. This is achieved through an end-to-end continuum process of research, applications, operations and outreach. The NDMC works with international, state, federal, tribal, individuals and academic partners around the world as well as networks of citizens and decision makers to produce and enhance state-of-the-art drought monitoring, early warning and planning products. The NDMC has conducted activities and partnered with groups (including many agencies of the United Nations) on six of the world's seven continents. A sample of some of these activities is highlighted below.

Keywords: *Drought, Drought Planning, Drought Atlas, Drought Early Warning and Information Services (DEWIS), Drought Impacts*

1. INTRODUCTION

Perhaps no other hazard lends itself as well to helping stand up climate services than does drought. Unlike most hazards, the fact that droughts typically evolve slowly, last for months or years and can cover millions of square kilometres. The fact that it commonly crosses over multiple political boundaries and economic sectors can make it a daunting task to monitor, mitigate and plan for. The fact that it is a normal, recurring part of the climate cycle means we should plan for it. Many forces are working together via the National Integrated Drought Information System (NIDIS) (<http://drought.gov>), the National Drought Mitigation Center (NDMC) (<http://drought.unl.edu>), tribes, states, state and federal agencies, regional and state climate offices, river basin authorities and various communities across the United States and globally (including the World Meteorological Organization, Group on Earth Observations, the Food and Agriculture Organization and others) in the formation of a collaboration and coordination nexus with an ultimate goal of building comprehensive national and global drought early warning and information systems (GDEWIS).

The NDMC works to reduce societal vulnerability to drought by helping decision makers at all levels to: implement drought early warning systems, understand and prevent drought impacts and increase long-term resilience to drought through proactive risk management planning. The NDMC is a national center founded in 1995 at the University of Nebraska-Lincoln in the United States. The program objectives of the NDMC revolve around: 1) **Improving the science** of drought monitoring, planning, and mitigation; 2) **Building awareness** of drought and its **impacts** on society and the environment, and how human actions affect our **vulnerability** to drought; and 3) Focusing the attention of policy makers on the importance of **drought policy and planning** in the wise stewardship of natural resources. The NDMC conducts basic and applied research along with the maintaining of a number of operational drought-related activities, including the U.S. Drought Monitor (USDM), North American Drought Monitor (NADM), Drought Impact Reporter (DIR) and the Vegetation Drought Response Index (VegDRI) (<http://vegdiri.unl.edu/>).

2. APPLICATIONS AND SERVICES

The U.S. Drought Monitor (Svoboda et al., 2002) (<http://droughtmonitor.unl.edu>) (Fig. 1) has been produced since 1999 and has become the state-of-the-science in monitoring drought in the United States. A partnership between the NDMC at the University of Nebraska-Lincoln, U.S. Department of Agriculture (World Agricultural Outlook Board) and the National Oceanic and Atmospheric Administration (NOAA) produces the Drought Monitor. However, advice from many other sources is incorporated in the product, including virtually every government agency dealing with drought. The USDM is based on a ranking percentile approach and uses a convergence of evidence approach in order to blend various indicators and impacts, which are then combined with local expert feedback. The USDM has become widely used in policy as the U.S. Farm Bill, Internal Revenue Service, U.S. Department of Agriculture, U.S. Department of Commerce, Environmental Protection Agency and several states are using the USDM as a trigger tied to policy and relief efforts. The monthly North American Drought Monitor (NADM) (<http://www.ncdc.noaa.gov/temp-and-precip/drought/nadm/index.html>) effort followed shortly thereafter and brings together scientists in Canada, Mexico and the United States using the same percentile ranking approach.

The NDMC launched the Drought Impact Reporter (DIR) (<http://droughtreporter.unl.edu>) (Fig. 2) in July 2005 as the nation's first comprehensive database of drought impacts and has logged and archived more than 14,000 reports/impacts since that time. This update, released in fall 2011, collects and displays more types of information, providing researchers and interested members of the public with more context and detail, as well as more readily summarized information. Drought impact collection is a critical effort needed to build a baseline as well as identify and address vulnerability to the hazard.

The idea of building an enhanced on-line GIS-based Drought Risk Atlas (DRA) interface was based on updating and expanding on the original National Electronic Drought Atlas (NEDA) developed in the early 1990s by the U.S. Army Corps of Engineers and IBM. The original NEDA contained those stations found at the time within the Historical Climate Network (HCN), numbering approximately 1,000. In the new web-based Drought Risk Atlas interface, we have expanded the data to include all of the most complete long-term stations from a variety of sources, using a *weekly* time-step to calculate multiple drought indices at each point from which multiple derivative analyses and products are made available to the user along with the data. The SPI, SPEI, PDSI, sc-PDSI, Deciles and other hydrological-based drought indices are included in the new DRA with the total number of stations nearly tripling to 3,000 along with a doubling of the period of record as well for most sites.

The National Integrated Drought Information System (NIDIS) (<http://drought.gov>) was signed into U.S. Public Law in December of 2006. It is a National Oceanic and Atmospheric Administration led federal, state, tribal and local partnership. The goal of NIDIS is to improve the nation's capacity to proactively manage drought-related risks by providing decision makers with the best available information and tools to assess the impact of drought and to better prepare for and mitigate the effects of drought. NIDIS has three general tasks:

- 1) Provide an effective drought early warning system that:
 - a. Collects and integrates information on the key indicators of drought and drought severity; and
 - b. Provides timely information that reflects state and regional differences in drought conditions
- 2) Coordinate federal research in support of a drought early warning system; and
- 3) Build upon existing forecasting and assessment.

3. CONCLUSIONS

This paper has provided a brief overview and description of various drought resources, tools, services and collaborations already being provided by the NDMC and its partners along with a look at what is in the development pipeline for the future in helping others toward developing drought early warning and information systems along with drought practices and policy in the U.S. and around the world.

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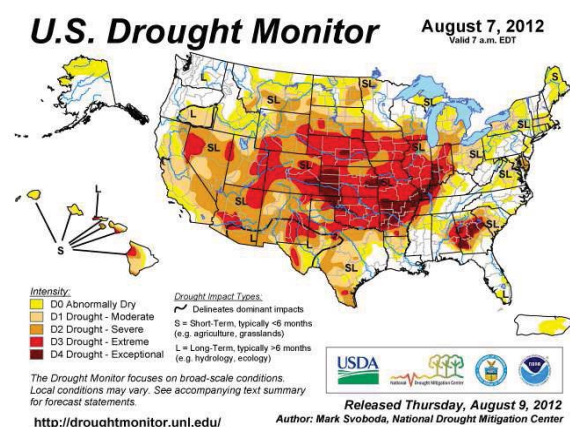


Figure 1. The weekly U.S. Drought Monitor map dated August 7, 2012.



Figure 2. The NDMC's Drought Impact Reporter web interface showing impacts and reports logged during the period July 13 – August 13, 2012.

DEVELOPING EFFECTIVE COMMUNICATION CHANNELS AND TOOLKITS AMONG CLIMATE SCIENTISTS, WATER RESOURCE MANAGERS AND POLICY MAKERS

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Abstract: Effective communication relies upon provision of all aspects of available information as required in decision making, included in which are details of uncertainties involved. This requirement is considered under three headings: best available climate information, best available potential error information and best attainable blending into decision processes. Limitations under all three headings are identified that together result in the full set of information not reaching the decision maker in many instances. No process has yet been defined that ensures that the best possible climate and water resource information, complete with all uncertainties, reaches the decision level, and that would be a key step towards optimal decision making.

Keywords: *Climate, Water, Information, Communication, Decision Making*

1. INTRODUCTION

There are perhaps three major objectives in transferring information from the climate community to the water community and to policy makers. Although the principles remain the same, differences need to be recognised should the final recipient/decision maker be a water resource manager or a policy maker, differences that reflect both the likely technical backgrounds and the decision making priorities of the two groups. The three objectives, each discussed below in greater detail, are:

- ♦ To deliver the best attainable climate information
- ♦ To deliver climate (or water resource) information complete with the best attainable potential error information
- ♦ To deliver information in the form most suitable for users (water resource managers/policy makers) to blend into their decision making processes

2. OBJECTIVE 1: BEST ATTAINABLE CLIMATE INFORMATION

Climate information comes in two forms: a) historical and present; b) future. Often historical information is provided from observations, but increasingly modelling approaches, such as reanalyses, are being used to fill in missing historical information. Future information is sometimes generated through statistical means but normally is produced from one or more dynamical models; the model(s) may include embedded water resource components, or separate assessment models for water resources may be run independently based on first stage climate inputs.

Any statistical or modelling approach used is almost certain to be created through the finest tools available, such that from that perspective the 'best attainable climate information' is provided. However the resulting information is frequently presented in deterministic manner and, as discussed in the next sections, unless full error information is added the information can be misleading to lesser or greater extent, and any decisions based thereupon may be inappropriate as they are not produced using the possible full range of knowledge concerning the climate.

3. OBJECTIVE 2: BEST ATTAINABLE POTENTIAL ERROR INFORMATION

Error information should play a full role in any decision making process and should be sufficient to facilitate a complete sensitivity assessment to all errors in that decision. Typically standard deviations or similar are attached when providing statistically-generated information, but these are normally conditioned on the statistical methodology used and thus, even when a Gaussian assumption is valid, may under-represent potential errors. When reanalyses are used to recreate historical information full details of cross-comparisons of modelled/observed information are required such that a best-possible estimate of potential errors is provided, not least for data-scarce areas where reanalysis estimates, especially for rainfall and any derived values, may be substantially inaccurate.

The only valid approach for constructing future climate information is to begin with an ensemble; the same applies with any follow-through use of water-related models. It is unlikely that any single-model ensemble

is capable of providing the error information supplied by a multi-model ensemble. That said, it is also likely that any climate time scale multi-model ensemble is likely to underestimate the range of errors. No presentation of potential error information is complete unless a full assessment has been made of the capability of any ensemble structure to reproduce errors, and the limitations of the ensemble to provide a full error estimate has been provided.

4. OBJECTIVE 3: BEST ATTAINABLE BLENDING INTO DECISION PROCESSES

Once the first two objectives have been achieved then the information is ready for transfer towards the decision making stage, and it needs to be provided in a form suitable within that context. There are two aspects discussed below regarding the necessary communication channels, the development of confidence by those making decisions with the information being supplied and the manner in which the information itself is provided.

Creation of confidence is a complex area of perceptions, politics, and personalities, and is too extensive for detailed discussion here. From the side of the climate scientist the optimal approach is as outlined in the two previous sections. However scientists, alongside most others, may be overconfident in their interpretation of information and may transfer this simply as confidence to a policy maker not possessing the technical insight to make a judgement. Even the best climate information may result in inappropriate decisions if information is presented with overconfidence.

Changes are frequently applied to formats emerging from the models when supplying the information, in order that the information becomes more accessible to the end user and does not require that individual to possess detailed technical knowledge. Producing that format change normally requires interpretation of the climate information, and in making that interpretation new errors can be created. These new errors are not necessarily technical with some cognitive in nature, and again include overconfidence in the interpretation. There are various additional interpretative issues that can occur, and any may result in a change of decision when compared with that that might be made given the un-interpreted information alone.

As a straightforward example, one common cognitive issue is called ‘framing’. For instance, information framed one way – “there is a 20% probability that water stress will increase by 2030” – might produce a different decision than were that same information framed a different way – “there is an 80% probability that there will be no increase, or even a decrease, in water stress by 2030”.

5. CONCLUSIONS

All tools we possess for producing climate information are imperfect, and it is almost certain that any decisions based on climate information must also be imperfect. However the process of information delivery is often such that the best possible information is not delivered to the decision maker; there are numerous examples within the climate community itself whereby information is interpreted in a manner that does not take recognition of the full ranges of errors and uncertainties involved in that interpretation. At times it seems that the inevitability of uncertainty runs at odds to the perception, or expectation, that it should be possible to produce precise descriptions of the past or the future. Neither is the case, yet decisions are often made under the implicit assumption that such descriptions are not only possible, but are being made. In fact the decision maker often appears to expect his burden to be lightened through the removal of as much uncertainty as possible from information. The issues are not only technical, issues that might be eliminated through creation of the ‘perfect ensemble’, but also are cognitive, issues that are inherent within the presentation of information, issues often not recognised even to exist. Given the objective of optimal decision making, then it is the responsibility of the information provider, the climate or the water scientist, to ensure that the channel of communication to the decision maker is created in such a manner that all uncertainties are revealed in a manner that can inform fully the decision process. If that ideal is to be achieved then the first thing to establish is the approach to presentation of information complete with all uncertainties, technical and cognitive; once that has been achieved then approaches to decision making themselves might be considered.

***Acknowledgement:** My thanks to Neville Nicholls who first introduced me to the complex psychological issues that are inherent, but often ignored, in the delivery of climate information, but which are so critical in supporting optimal decision making.*

TOWARDS ROBUST PREDICTIONS OF THE HYDROLOGICAL IMPACTS OF CLIMATE CHANGE: THE BAYESIAN TOTAL ERROR APPROACH

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Abstract: Hydrological models play a vital role in transforming projections of changes in meteorological forcings (rainfall and temperature) due to climate variability and change into water-related societal impacts such as projected changes in floods and droughts. Typically, hydrological models require calibration of their parameters using observed data. However, these models are then applied to provide climate change projections which are often “outside the envelope” of the data to which they are calibrated. Furthermore, the calibration process often has several key assumptions, which are rarely scrutinized. These assumptions impact on the reliability and robustness of hydrological model predictions. This paper, provides an overview of the Bayesian Total Error Analysis (BATEA) approach to model calibration and prediction. The main aim of this framework is to provide a calibration and prediction tool to improve the reliability of the parameter and model predictions and develop a better understanding of predictive uncertainty by decomposing the multiple error sources of a model. A series of case studies will be presented that highlight the role of data errors and the assumptions of the model calibration process in inducing parameter biases and unreliable model predictions. These case studies highlight the role of the BATEA approach in improving the parameter estimates and the reliability of model predictions.

Keywords: *Hydrological Modelling, Predictive Uncertainty, Model Calibration,*

1. INTRODUCTION

Hydrological models simulate water balance dynamics at the catchment scale. Given the significance of water in human society, and in aquatic and terrestrial ecosystems, catchment models are an integral part of environmental science, engineering and management, including water resources planning, flood risk prediction, as well as assessing the impact of climate variability and change on floods and droughts. The nonlinearities and thresholds in the hydrological process mean the rainfall to runoff transformation often amplifies the impacts of climate changes in meteorological forcings - typically, the rainfall elasticity of streamflow is of the order of 2.0 – 3.5 [Chiew, 2006]. Given, the vital role that hydrological models play in assessing societal impacts of climate change on droughts and floods, it is of key importance that the hydrological predictions are robust and reliable.

Robust and reliable hydrological model predictions requires an assessment of the key assumptions in the modelling process. Constructing such models generally consists of several steps [Beven, 2001]: (1) Develop a qualitative “perceptual” model that broadly describes “how the system works” and which processes are dominant; (2) Develop quantitative “conceptual” model equations that reflect the perceptual model. These will be referred to the “governing model equations”, and to the approximations made at this stage as “model approximations”, which yield “model structural errors”; (3) Solve the governing model equations, using a numerical algorithm if an exact solution is impossible. Approximations made at this stage are “numerical approximations” that cause “numerical errors”; (4) Infer (“calibrate”) the system parameters from observed data; and (5) Evaluate the model predictions and associated uncertainties, and scrutinize the assumptions of both the conceptual model and the inference/prediction methodology. In practice, it is the exception rather than the rule that these five steps are undertaken. This paper will focus on the role of steps 4 and 5 - the role of data errors and model calibration assumptions on parameter inference and predictive uncertainty. The Bayesian Total Error Analysis Framework (BATEA) provides a rigorous approach to scrutinize the calibration and error modelling assumptions. Several case studies illustrate how the BATEA approach has improved the reliability of parameters and predictions.

2. THE BAYESIAN TOTAL ERROR ANALYSIS APPROACH

The hydrological modelling process has several sources of errors (Figure 1). The differences between the models and reality is characterised by data and structural errors. Figure 2 provides an overview of the BATEA framework developed by Kavetski *et al.* [2006]. The aim of this framework is to provide a calibration and prediction tool to improve reliability of the parameters and model predictions, and develop better understanding of predictive uncertainty by decomposing the multiple error sources of a model. Its core ideas are to: (1) specify explicit probability models for each source of uncertainty (input, output and model structural errors); (2) where necessary, use hierarchical techniques to implement these probability models within a Bayesian inference framework; (3) where available, include a priori information about the catchment behaviour and data

uncertainty; (4) jointly infer the parameters of the hydrological model and the error models; and (5) examine posterior diagnostics to check the assumptions of the error models made in step 1.

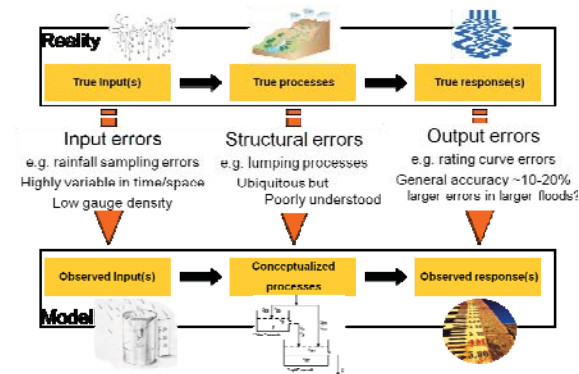


Figure 1 – Sources of Errors

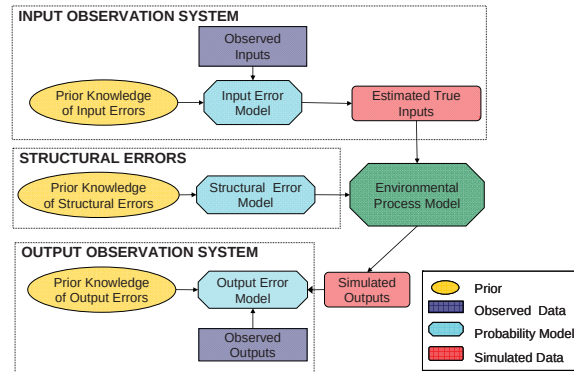


Figure 2 – BATEA Framework

3. CASE STUDIES

Several studies have shown that BATEA offers significant improvements over traditional approaches to model calibration and prediction:

- Due to the sparsity of rainfall gauges, catchment rainfall has significant “noise”. *Thyer et al.* [2009] illustrated that standard calibration approaches, produce parameter biases and unreliable predictions, because they are calibrating to “noise” in the rainfall data.
- Quantifying the relative contribution of data and structural errors to the total predictive uncertainty is of significant benefit, because it guides investments to reduce predictive uncertainty. [*Renard et al.*, 2011] showed that by incorporating errors model for rainfall and runoff error, enabled the identification of structural errors. This provided a significant improvement in the reliability of model predictions, and enabled the identification of the key contributions to the total predictive uncertainty.
- Robustness of hydrological model predictions under climate change is a key issue. Using a case study from a key water supply catchment it was demonstrated that hydrological model calibration using standard least squares calibration approaches over-estimated annual runoff in a drier climate by 45-62%. In comparison, using weighted least squares, which was verified in the BATEA approach as providing better residual error model, reduced this bias to 20-25%.

4. CONCLUSIONS

Hydrological models play a key role in providing predictions of the impacts of climate change on key water-related societal impacts such as projected changes in floods and droughts. A key question is whether, these hydrological models provide robust predictions under a changing climate. The Bayesian total error analysis framework provides a rigorous framework to assess the impacts of the assumptions of the modeling process. Several case studies highlighted the value of the BATEA approach in improving parameter inferences and providing more reliable predictions.

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MANAGING WATER RESOURCES UNDER GLOBAL CLIMATE VARIABILITY: RESPONSES OF WATER RESOURCE MANAGERS AND POLICYMAKERS IN NIGERIA

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Abstract : Water is essential for the sustenance and health of all living species. It provides fundamental inputs for developmental activities. Despite these functions, there is a persistent and systemic water crisis in many countries. Nigeria has an abundance of water but it is not evenly distributed. This scenario is exacerbated by climate change as Nigeria is highly vulnerable due to its geographic location. Consequently, the north and southern part of Nigeria are experiencing either droughts or floods. Tackling this problem demands new approaches to water resources planning and management. This paper assesses responses of water resources managers to challenges posed by climate variability to water resources. Key stakeholders and documentations in the water sector were interviewed and content analysed respectively. Results reveal little or no considerations of climate change in the planning and management of water resources. It reveals strong linkages among climate change scientists; however, research outcomes are hardly utilized in the management of water resources due to poor dissemination of results among stakeholders. The paper suggests stakeholder participation, collaboration and review of water policies with a view to incorporating climate change considerations in the planning for water resources in Nigeria.

Keywords: *Water Resources, Global Climate variability, Resource Managers, Policymakers, Nigeria*

1. INTRODUCTION

Water is essential for the sustenance and health of all living species. It provides fundamental inputs for human needs and economic development activities. Despite these functions, there is a persistent and systemic water crisis in many countries including Nigeria. Nigeria has a relative abundance of water with surface water resources potential estimated at 267.3 billion cubic meters per annum, while groundwater resources are estimated to total 51.9 billion m³ per annum. Despite these abundant resources, a large percentage of the country does not have access to potable water (Okoye and Achakpa, 2007). This scenario is exacerbated by climate change as Nigeria is highly vulnerable due to its geographic location.

In Nigeria, available meteorological data shows evidence of declining rainfall in magnitude and temporal distribution in northern Nigeria resulting to reduction of water levels and total drying up of Lake Chad (Chindo and Nyelong, 2005; Odjugo 2007). Contrastingly, in southern Nigeria, several studies (Nkomo *et al.*, 2006 and Nnodu *et al.*, 2007) confirm the existence of extreme weather related events such as erratic rainfall pattern, floods and sea level rise in coastal cities of Warri, Lagos and Port Harcourt. Tackling this problem demands new approaches to water resources planning and management. Water resource planning and management acknowledge the natural variability of water, creating a need to develop contingency plans. The Intergovernmental Panel on Climate Change (1996) noted that "water resources in many regions of the world will be significantly affected by climate change and that many current freshwater problems will be made worse by the greenhouse effect. This report urges water managers to begin "a systematic reexamination of engineering design criteria, operating rules, contingency plans, and water allocation policies" and noted with "high confidence" that "water demand management and institutional adaptation are the primary components for increasing system flexibility to meet uncertainties of climate change. It is in this context that this paper assesses the responses of water resources managers to challenges posed by climate variability in the planning and management of water resources in Nigeria.

2. MATERIALS AND METHODS

The paper combines literature review with empirical data from interviews of various actors in the Nigerian water sector including water planning and management officers, climate change scientist and policymakers. Also relevant documentation on the water sector in Nigeria such as the National Water Supply and Sanitation Policies, the Water Resources Act 1993 among others were content analysed.

3. DISCUSSIONS

The paper first examines the responses in terms of institutional framework and policies for water resources management. From the results, the three tiers of government in Nigeria are involved in the planning and management of water resources. At the Federal level, there is the Federal Ministry of Water Resources with plethora of parastatals such as the River Basin Development Authorities, the National Integrated Water Resources Management Commission, among others. At the State level, management of water resources is undertaken by various state ministries such as Agriculture, Natural Resources, Works and Public Utilities. There

are currently 37 State Water Agencies (SWAs). From the analysis, the existing federal and state frameworks relating to water resources management are not specific as to where final control of water resources resides.

At the policy level, numerous policy guidelines for water resource management exist at the federal level. Some of these policies include the 1989 National Policy on Environment, the National Water Supply and Sanitation Policy 2000, the National Water Resources Management Policy 2003, among others. The 36 States of Nigeria including the Federal Capital Territory (FCT) have additional separate policies designed for the management of water resources in their jurisdictions leading to duplication and lack of intersectoral coordination with each state and levels of government pursuing its own independent water agenda. A content analysis of the various policy documents indicates that it focuses on the need for a comprehensive development of the country's water resources to provide safe drinking water for the populace, make water available for agricultural as well as the generation of electricity. However, the impacts of climate change on water resources were hardly considered in the various water policy documents. The implication of this is that the new policies, governance framework and emerging planning and management strategies can hardly cope with ensuing challenges occasioned by climate change in the water sector. Currently, in most cities in Nigeria as noted by one of the respondents, the provision of water for both domestic and industrial uses is left at the discretion and ability of individual households or organizations. One of the corollaries of this is plethora of private bore holes in every nook and cranny of most cities. This scenario poses a serious threat to groundwater replenishment due to high rate of withdrawal and the phenomenal of climate variability which is now a reality in Nigeria.

The paper further assesses the channels of communication among water managers, policymakers and climate change scientist. The analysis reveals high level of interaction among climate change scientists. For instance, research outcomes from the Nigerian Meteorological Agency (NIMET) are widely disseminated among climate change scientists. Water managers hardly have access to climate change scientific research outcomes due to poor dissemination and communication among stakeholders. This hinders its application for the purpose of water planning as observed by one respondent. Water planners and managers also noted their poor involvement in the design of the studies and hence the difficulties in accepting the results for the purpose of water planning. The paper further assesses the planning and management approach of water resources in Nigeria using the seven elements of integrated water resources management (IWRM) (public involvement, water demand forecasting, water supply forecasting, reliability evaluation, source strategies, financial planning and drought contingency planning) as the basic parameters. The assessment indicates that six out of the seven elements of IWRM were lacking. While there is poor public involvement and financial planning, there is the complete absence of water demand forecasting, water supply forecasting, reliability evaluation, source strategies and contingency planning in their water resources management framework.

4. CONCLUSIONS

There is poor response of policymakers and water resources planners and managers with respect to climate change in Nigeria. The contemporary responses of policymakers and water resources managers cannot cope with the ensuing challenges pose by climate variability in Nigeria. The current policy and institutional responses relating to water resources management are to a large extent not specific as to where final control of water resources resides. Governments at all levels should review all water resources policy documents as well as the institutional framework to provide for a robust policy and institutional frameworks without duplication and overlapping of responsibilities. All decisions about long-term water planning should take into considerations changing climatic conditions. Cooperation and collaborations of water agencies with leading climate change scientific organizations is vital to facilitate the exchange of information on the state-of-the-art thinking about climate change and its impacts on water resources.

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Session IV

MAKING AN INFORMED DECISION ON FRESHWATER
RESOURCE MANAGEMENT BY INTEGRATING REMOTE
SENSING DATA WITH TRADITIONAL DATA

Jason J Hyon

LESSONS FOR CLIMATE ADAPTATION POLICY FROM
WATER REFORM EXPERIENCE IN AUSTRALIA

Tony Slatyer

ADAPTATION CHALLENGES IN INTERNATIONAL
(AND TRANSBOUNDARY) RIVER BASINS

Roger S. Pulwarty PhD

THAILAND GREAT FLOOD 2011: LOOKING BACK AND
LOOKING FORWARD

Seree Supratid

STRENGTHENING OF CLIMATE INFORMATION
SERVICES CONCERNING WATER AVAILABILITY TO
SUPPORT FOOD SECURITY PROGRAM IN INDONESIA

Nelly Florida Riama, Andhika Hermawanto

A POLYCENTRIC APPROACH TO DEAL WITH
UNCERTAINTY AND CLIMATE CHANGE ADAPTATION A
CASE STUDY OF TRANS-BOUNDARY WATER
GOVERNANCE IN VOLTA RIVER BASIN IN WEST AFRICA

Sam Wong



MAKING AN INFORMED DECISION ON FRESHWATER RESOURCE MANAGEMENT BY INTEGRATING REMOTE SENSING DATA WITH TRADITIONAL DATA

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Abstract: The US National Research Council (NRC) recommended that: “The U.S. government, working in concert with the private sector, academe, the public, and its international partners, should renew its investment in Earth-observing systems and restore its leadership in Earth science and applications.” in response to the NASA Earth Science Division’s request to prioritize research areas, observations, and notional missions to make those objectives. [NRC, 2007] In this presentation, we will discuss our approach to connect remote sensing science to decision support applications by establishing a framework to integrate direct measurements, earth system models, inventories, and other information to accurately estimate fresh water resources in global, regional, and local scales. We will discuss our demonstration projects and lessons learned from the experience. Deploying a monitoring system that offers sustained, accurate, transparent and relevant information represents a challenge and opportunity to a broad community spanning earth science, water resource accounting and public policy. An introduction to some of the scientific and technical infrastructure issues associated with monitoring systems is offered here to encourage future treatment of these topics by other contributors as a concluding remark.

Keywords: *Climate, Water resource management, Remote Sensing, Decision support framework*

1. INTRODUCTION

NASA with a partnership with international space agencies has flown satellites to understand hydrological cycle since 1980’s; they consist of SeaSAT, QuikSCAT, Jason-1, GRACE, OSTM, EOS (Aura and Aqua), TRIMM, CloudSat, and Aquarius to provide measurements of sea level, ice in land and ocean, salinity, sea surface winds, sea surface temperature, sub surface water, rain, and clouds. In coming years, more satellite and airborne instruments will be deployed to provide measurements of soil moisture, water level in rivers and lakes, snow covers, and water vapour. In developing capability to connect remote sensing measurements to decision support applications such as green house gas monitoring [Duren, 2011] and fresh water resource management, we have established a framework to integrate heterogeneous sources of information in order to establish a validated information source which estimates water resource in a statistically robust fashion with quantified uncertainties.

Adaptation to and mitigation of climate change impacts in the western United States are becoming increasingly important considerations for planning and policy development. However, an integrated, multi-disciplinary framework that enables trust-worthy, scientifically informed decisions is lacking. In conceptualizing this framework, we have studied current practices by decision makers and identified key gaps. One of the key gaps is reconciling between ‘top-down’ estimates of water resources in the earth atmosphere, land, and ocean, and ‘bottom-up’ estimates of water inventories in an iterative synthesis assessment of the amount, location, and trends from in situ statistics and analysis.[Duren, 2011] Another key component of the effort is to build on established relationships with local, regional and state level water managers to develop and refine requirements for information products and the IT infrastructure. Here are three key objectives in establishing the goal:

- ♦ **Understand stakeholder information needs by building** on relationships with local, regional and state agencies (LADWP, MWD, DOI/USGS) to provide decision relevant information products through active engagement of the end users.
- ♦ **Integrate multi-disciplinary science and technology to enable informed decisions** through **synthesis** of Earth science mission and *in situ* observations to create relevant information products and services. Specifically:
 - Range-scale Snow Water Equivalent products derived from integrated MODIS, airborne instruments, and USDA SNOTEL observations with emphasis on effects of dust on snow [Painter, 2010].
 - Near real-time flood inundation information products for the Sacramento and San Joaquin Valleys derived from multiple microwave sensors and integrated with USGS river gauge measurements.
 - Multi-scale surface water and vegetated wetlands GIS based maps for the Sacramento-San Joaquin Delta derived from AMSR-E, MODIS, QuikSCAT, Palsar and Landsat.
- ♦ **Facilitate the flow of information to managers and stakeholders** by **developing** the IT infrastructure to provide integrated information products that will improve monitoring and data collection.

According to the Colorado river basin forecast system [Werner, 2012], models validated by observed data are critical in estimating water resources. Climate change and dust deposition from disturbed lands have

already begun the encroachment on this precious resource. As a proof concept for a forecast system, JPL is establishing an airborne snow observatory (ASO) to provide snow water equivalence in the Sierra Nevada and the mountains of the Upper Colorado River Basin. For ASO, data sources of dust accumulation and snow water equivalence are the airborne instrument suite of radar, radiometer, hyperspectral imager, and lidar. (Fig. 1 & 2) [Painter 2010] The key role for remote sensing data is to provide timely coverage of snow and to validate models used in the river forecast system, which consists of weather and climate forecasts, hydrologic model analysis, observed data, and calibration. JPL also hosted a workshop to address key observed data requirements in estimating water resource in this changing climate; they included measurements of precipitation, snow, evapotranspiration, soil moisture, ground water, surface water and runoff, and integration and modeling. [Fisher, 2012] The biggest unknown identified in the workshop was a quantification of evapotranspiration. Additionally, fusion of complex heterogeneous data sources in a timely manner will require GIS based infrastructure to handle multiple data formats and quality of service that a decision support system requires.

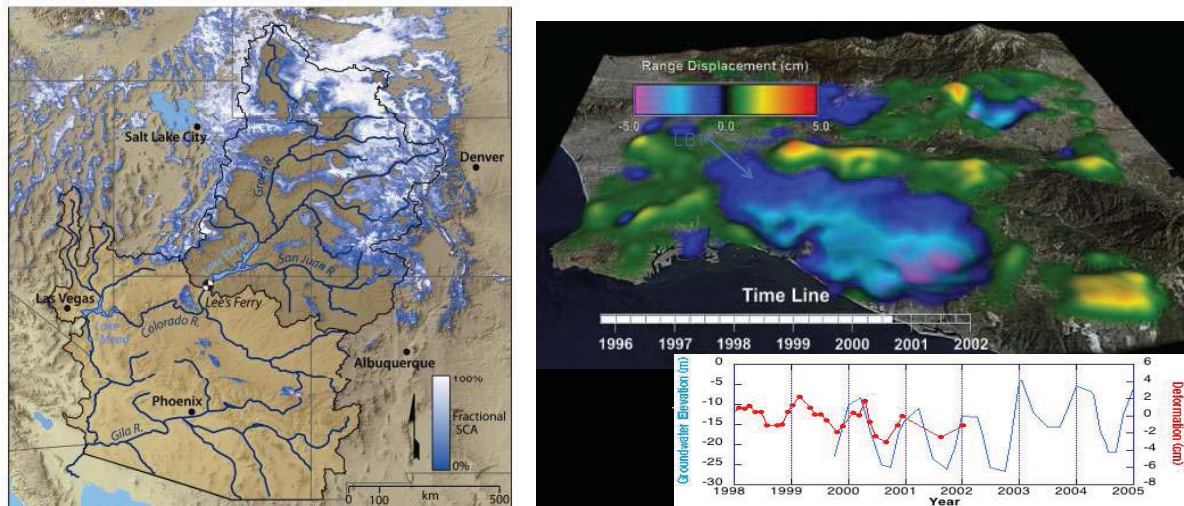


Figure 1. Snow Cover map of Upper Colorado River Basin **Figure 2.** Aquifer discharge compared with radar and in situ data

4. CONCLUSIONS

The challenges are to connect global and regional scale models and data product to local scale. Furthermore, there is growing recognition of the potential of applying improved top-down methods in synthesis with bottom-up methods to the challenge of monitoring and forecasting water resources across the coupled earth system. Independent of supporting verification efforts or enabling improvements in accuracy, a system like ASO would offer relevant information in order to quantitatively assess the ultimate effects of mitigation actions on policy-relevant space-time scales and provide rigorous guidance for future policy formulation. The best approach might be to prototype systems to build a capability one step at a time and understand the impact to decision process. Remote sensing plays an important role; however, it is only relevant if the existing forecasting systems incorporate these new data and clearly understand caveats associated with these data.

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LESSONS FOR CLIMATE ADAPTATION POLICY FROM WATER REFORM EXPERIENCE IN AUSTRALIA

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Abstract: This presentation discusses the relevance of water reform experience in Australia for climate adaption policy settings. It provides evidence that the adaptation by individuals, firms and communities to increasingly uncertain future water availability can be assisted and supported by governments, by establishing and regulating markets in water access rights, undertaking long term forward planning and collecting, disseminating relevant information and the application of risk-management principles .

Keywords: *Adaptation, Water, Markets, Planning, Risk*

1. INTRODUCTION

In Australia, water resources are unevenly distributed, water flows in major rivers are highly episodic and average annual flows are unpredictable. In the most water-dependent regions, the best climate science shows high degrees of uncertainty about future flows.

Australian governments responded initially with infrastructure to enhance storage and control of water and in recent decades with policy measures, including long term water use plans and the creation of water access rights, the water assigned to which varies according to current water availability.

In the past decade, Australian governments have gone much further, with the National Water Initiative strengthening the legal protection associated with water access rights, and freeing up trade in such instruments. Most recently Australian governments have embarked on further reforms aimed at improving long term planning and regulation in the Murray-Darling Basin, where about fifty per cent of Australia's irrigation production occurs, restoring water to the environment, improving public information about water availability, and improving governance arrangements.

Australia experienced particularly severe drought in the decade to 2008-09. By this time, water markets and inter-government cooperative decision-making processes in the Murray-Darling Basin were relatively well developed. Despite dramatic reductions in water availability for agricultural uses, the value of agricultural production was largely maintained.

These experiences provide potentially valuable lessons for policy making in regard to climate adaptation.

2. DISCUSSION

Water access rights in Australia are generally equivalent to percentage shares of the available resource. In wetter years, more water is allocated to the right-holder. In drier years less water is allocated. Different classes of right are established by state governments to suit different water use types. For example, some rights allocate more water in drier years than others. These 'high security' rights have a much higher value than rights which only receive water in wet years. Trading in these rights (known as permanent trades), and in the annual allocations to these rights (known as temporary trades) give water users high levels of flexibility and incentive to use water efficiently.

Australia's National Water Commission has reported (National Water Commission 2012) that during the last four years of the extended drought in southern Australia, water availability in the Murray-Darling Basin fell by 53 per cent. However the gross value of irrigated agricultural production fell by 27 per cent, about half this amount. In response to uncertainty about the cause and effect of this result, the Commission also undertook modelling which showed that in the southern Murray-Darling Basin, production was \$3.4 billion higher over five years from 2006-07 than would have been the case without intra-regional trade. This provides evidence that governments can enhance the resilience of water dependent industries to major changes in water availability by creating water access rights and enabling trade in these.

Australian governments have sought to reduce uncertainty associated with holding water access rights by setting down clear rules for bearing risk associated with changes in water availability. In the National Water

Initiative policy adopted by all Australian Governments in 2004, it was agreed that water right holders should bear all the costs of reduced water availability as the result of climate change and natural weather events such as droughts and that government should bear all the costs associated with policy changes they make, such as to re-allocate water away from rights holders for other purposes. Costs associated with government decisions to reduce water availability as the result of improved knowledge about the capacity of a system to sustain extraction levels is apportioned between government and industry according to a clear formula. These arrangements provide assurance to water access right holders that their rights will not be diminished arbitrarily by governments without some form of compensation. Providing such security ultimately reduces the cost of making long term investment in water use efficiency and like technologies and in achieving the most efficient use of water resources.

Australia has invested heavily in improving water data to ensure water users have reliable information on which to base water use and trading decisions. The Bureau of Meteorology has been tasked to report annually on the state of Australia's water resources nationally, through National Water Account, which is set up more or less like a financial balance sheet and operating statement.

Water planning in Australia is governed by principles set out in the National Water Initiative, requiring expected climate change impacts to be planned for well in advance. Commonwealth Government led reforms now being implemented in the Murray-Darling Basin are seeking to re-set water use onto a more sustainable footing, by requiring an independent body to propose new diversion limits based on sustainability principles. When these limits are incorporated in the Commonwealth's Murray-Darling Basin Plan, all State water resource plans will need to adhere to them. Based on the draft Plan now under consideration, around 25 per cent of water currently available for consumption would be returned to the environment. This aims to improve the productive base of the Basin hydrology for the long term benefit of all water users, and enhance the resilience of the Basin environment and water allocation system to future climate change.

A further lesson Australia experienced in the recent drought was the importance of applying risk management principles in an unfolding climate crisis. For example, in the Murray-Darling Basin, governments had to make choices about how much water to hold back in storage and how much to allow for production and environmental protection purposes, and for what priorities, while being bound by inter-jurisdictional water sharing agreements. Through cooperative inter-government processes, these discussions were managed so as to avoid as much as possible premature economic and environmental harm while making due provision for the risk of continuing drought. Much was learned about the practice of 'cooperative risk management' during this period, which will serve Australia well in future droughts which may well become more prevalent with climate change.

3. CONCLUSIONS

Australia's experience in water resource management provides evidence that the adaptation by individuals, firms and communities to reducing and uncertain future water availability can be assisted and supported by governments by establishing and regulating markets in water access rights, undertaking long term forward planning and collecting and disseminating relevant information. It is also important that risk management approaches are taken to minimise the current costs entailed in securing future benefits.

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ADAPTATION CHALLENGES IN INTERNATIONAL (AND TRANSBOUNDARY) RIVER BASINS

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Abstract: Climate variations affect the function and operation of existing water infrastructure – including hydropower, structural flood defenses, drainage and irrigation systems – as well as water management practices in support of economic security and environmental needs. As is well documented by several international assessments including those by the IPCC, MEA and World Water Forum, climate change challenges the traditional assumption that past hydrological experience provides a reasonable guide to future conditions. In this presentation we will compare the challenges and lessons provided in drought and water resources management optimization in the context of climate variability and projected change in selected international watersheds. Adaptive management has been repeatedly articulated as an important governance framework to achieve resilience. However, especially in the transboundary setting, several paradoxes in water management and governance militate against the effectiveness of adaptive management strategies. Consequently a complete analysis of the effects of climate change on transboundary water uses intended to inform decision-making would consider cross-sector and cross-scale interactions and networks, values being pursued including competing demands, and barriers and opportunities for putting learning into practice over the long term.

Keywords: *Transboundary, international, watersheds, climate adaptation*

1. INTRODUCTION

Transboundary fluctuations and changes in river flow can be attributed to (1) climate variations and change, and, (2) physical and biological transformations of basin hydrology including increased storage, diversions, and landscape changes. In such settings climate variations can affect the function and operation of existing water infrastructure – including hydropower, structural flood defenses, drainage and irrigation systems – as well as water management practices in support of efficiency and environmental needs. In many parts of the world, climate change is anticipated to result in greater water scarcity. As is well documented climate change challenges the traditional assumption that past hydrological experience provides a reasonable guide to future conditions. Adverse effects of climate variability and change on freshwater systems aggravate the impacts of other stresses, such as population growth, changing economic activity, land-use change and urbanization and most importantly upstream-downstream winners and losers. Thus current water management practices may not be robust enough to cope with the impacts of climate change on water supply reliability. In many locations, water management does not even satisfactorily cope with current climate variability, resulting in large flood and drought-related environmental and economic damages occurring on seasonal to decadal timescales.

2. DISCUSSION

Long -term cumulative environmental problems can seldom be dealt with by single discrete actions or policies but respond only to researchers with in-depth knowledge of the system, building networks and collaborative frameworks between research and management and continuing, sustained efforts at learning, supported by steady public attention and visibility. Climate adaptation is primarily a local and regional scale activity, undertaken within a national or international discourse that provides the necessary background for such initiatives to be undertaken. Several international assessments (IPCC, Millennium Ecosystem Assessment World Water Forum etc.) outline the projected impacts and recommended adaptations in for water resources management in several countries. These reports note that adaptation procedures and risk management practices that incorporate projected hydrological changes with related uncertainties are being developed in some countries and regions. Supply-side strategies to address these effects generally involve increases in storage capacity, abstraction from watercourses, and water transfers. Other adaptations may include technical changes that improve water use efficiency, demand management (e.g. through metering and pricing), and institutional changes that improve the tradability of water rights. The availability of water for each type of use may be affected by other competing uses of the resource. Consequently a complete analysis of the effects of climate change on human water uses would consider cross-sector interactions, including the impacts of changes in water use efficiency and intentional transfers of the use of water from one sector to another.

The international and transboundary setting however introduces additional complexities beyond the variability and uncertainty of supply. Many researchers have highlighted factors underlying international disputes involving river flows, including: interdependencies among users, increasing water scarcity, over-allocation and rising costs, the increasing vulnerability of water quality and aquatic ecosystems to human activities, ways and means of supplying safe water facilities, and the mobilization of financial resources for water development and management making restraint in using scarce water resources unlikely especially when the forces of global economic competition reinforce the focus on opportunities for immediate economic uses. In

addition, they note that national and state policies are usually at odds with border needs and priorities. In most such settings, the complications of changes in the spatial and temporal distribution of rainfall, soil moisture, runoff, frequency and magnitudes of droughts and floods have not been explicitly included in response planning. Systems design, operational inflexibility, and legal and institutional constraints reduce the adaptability of water systems to respond to changing climate.

In this presentation we will review the challenges and lessons provided in drought and water resources management and optimization in the context of climate variability and projected change in transboundary watersheds. As is evident in Basins such as the Colorado, Columbia, the Rio Grande, the Nile, Guadiana and elsewhere, early “winners” are unlikely to be willing to alter earlier terms of agreement even when changes in climate conditions are well documented. The barriers to implementing adaptation measures include the inability of some natural systems to adapt at the rate of combined demographic pressures and climate, incomplete understanding and quantifying of water demands, and impediments to the flow of timely and reliable knowledge and information relevant for decision makers. Many adaptation measures are technology and efficiency based. These problems are further complicated by the unique context imposed by transboundary resources at the borders themselves. These physical and social conditioning factors result in several paradoxes in water management and governance mitigate against the effectiveness of scientific information for meeting short term needs in the context of reducing longer-term vulnerabilities and for providing water to meet environmental needs. Practice thus becomes largely issue-specific and incremental with the focus on “winners” and “losers” rather than on the development of a consensual vision of a preferred future. There is, in addition, limited experience for managing impacts of severe events, such as persistent drought, in the context of projected rates of development or in the context of closed international water systems. In meeting new challenges and tradeoffs brought by a changing and variable environment and societal changes, we simply do not know how (precisely) we must plan. The end result is that in the absence of explicit discussion of conflict the policy process is pushed toward the “technological fix”; and, time and resources are allocated to achieve near-term tangible results, rather than long term solutions.

3. CONCLUSION: CREATING A FRAMEWORK FOR ADAPTING TO CLIMATE CHANGE IN TRANSBOUNDARY WATERSHEDS

A major challenge in the coming decades, given committed cross-timescale climate variability and climate change already in the system, will be maintaining water supplies for environmental services, which support economies across international and multiple use watersheds. Even where information on thresholds is available, usable and can produce positive results, the value of such information may still be overwhelmed by rates and magnitudes of social, economic and environmental changes.

The management of the cumulative impacts of extremes (droughts, floods, hurricanes etc.) usually occurs through reactive, crisis-driven approaches. The watershed experience shows that change in managing climate-related risks (in this drought) may be most readily accomplished when: (1) a focusing event (climatic, legal, or social) occurs and creates widespread public awareness; (2) leadership and the public are engaged; and (3) a basis for integrating research and management is established. As the cases show, a key component in developing such an integrated framework is the creating the capacity and ability of practitioners themselves to manipulate data and to reconcile scientific claims with their own knowledge. This plays important roles in their choices. Lessons from the basins explored in this presentation include, an expanded use of incentives for improving water-use efficiency, including metering and pricing, to encourage water conservation and development of water markets and implementation of virtual water trade, These hold considerable promise for water savings and the reallocation of water to highly valued uses. Early warning information, as well as decision support tools for long range planning, but should be based on a mixed portfolio of experimental and scenario-based approaches for shared learning by researchers and practitioners. Integrated water resources management provides an important governance framework to achieve adaptation measures across socio-economic, environmental and administrative systems but has proven elusive in practice.

Mainstreaming climate change adaptation into existing water management systems is being considered in several case studies, but barriers have been encountered, such as a) gaps in stakeholder participation during key phases of project design and implementation, and b) post-disaster pressures to quickly return a system or place to pre-disaster conditions rather than incorporate longer-term development policies. If lessons learned are to be actually applied, then a large part of the scientific adaptation goal should be to inform processes that can decrease impediments to the flow of information, identifying and supporting leadership at different nodes in the management system and a deliberate effort at testing and applying innovations. Future needs include greater exploration of alternate integration models and overlying policy structures that could, together, facilitate and sustain shared learning of climate change adaptation. This would ultimately transform such one-off studies or a project-based activity into a long-term service. A complementary need would be for better understanding of communication for cross-scale adaptation decisions that may emerge within one level of government, multi-levels of government, and at the watershed scale with its mix of governments and utilities.

THAILAND GREAT FLOOD 2011: LOOKING BACK AND LOOKING FORWARD

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Abstract: The 2011 great flood causes tremendous damages to all business sectors including livelihood of Thai people. Official report from the World Bank reveals a figure of 1.440 billion Baht (US\$ 45 billion) which ranks forth as the world's costliest disaster. Looking back of the disaster history (EM-DAT International Disaster Database), flood is the dominant natural disaster in the last fifty years for Thailand. Between 1995-2006, 54 flooding events were reported accounting for 55% of all natural disasters, resulting in US\$ 4.5 billion damage, 2,682 people killed and 30 millions affected. Thailand (in the Chao Phraya river basin) was regularly flooded every 2 years during the last 10-year records. They are in 2002, 2004, 2006, 2010, and 2011, respectively. In this study, we apply a flood simulation model (Mike 11, Mike 21) to investigate the 2011 flood behavior including conceptual measures for flood prevention and mitigation. Four case studies are investigated. The 1st case study is the base case of the 2011 flood (Do nothing). The inundation area was found approximately 8.8 million Rais. The use of 2 million Rais as retention basin (Case study 2) can reduce the inundation area by 18% or 7.2 million Rais. The 3rd case study is the use of east floodway of 1,000 cms capacity. This can reduce the inundation area by 35% or 5.7 million Rais. The 4th case study is the use of both floodways (East and west of 1,000 cms per each). This can reduce the inundation area by 42% from the 2011 flood event.

Keywords: Flood simulation model(Mike 11, Mike 21), flood prevention and mitigation, inundation area

1. INTRODUCTION

Bangkok covers an area of 1,569 km² located in the delta of the Chao Phraya River Basin, which is the largest basin in the country, covering an area of 159,000 km² or about 35% of the total land area of the country. There are two main rivers bisecting the delta area: the Tha Chin River on the west and the Chao Phraya River (the main stream) on the east. The basin forms up by 4 large tributaries: the Ping, Wang, Yom, and Nan originate from the mountainous terrain in the northern part of the country. These four tributaries flow southward to join each other in Nakhon Sawan to become the Chao Phraya River.

The basin area is flat at an average elevation of 1 to 2 m from the mean sea level (m.MSL), with certain spots where the elevation is lowered down to the sea level due to land subsidence. There are a number of canals crisscrossing the whole basin. Bangkok straddles the Chao Phraya River 33 km north of the Gulf of Thailand. Due to the flatness of the area and close proximity to the seashore, the area annually faces the problems of floods from rivers from the north and inundation due to the high tide from the sea.

Though, efforts have been made to mitigate the flood damage in the Chao Phraya river basin through several structural measures (construction of dams, reservoirs, dikes, and pumping stations), flooding still cause much more impact as a result of deforestation, farmland expansion, and urban development. The flood damage potential is increasing due to rapid urbanization and land development in downstream areas, particularly, the Bangkok metropolitan area and other municipalities along the Chao Phraya river.

2. MODEL SET-UP

This study covers the flood areas of the BMA (Bangkok Metropolitan Administration) and surrounding provinces (Samut Sakhon, Samut Prakan, Nakhon Pathom, and Nonthaburi). These areas are located in Chao Phraya-Tha Chin river Basin (about 31,885 km²). The downstream boundary of the computational domain was setup along the coastline from Thachin river to the Bangpakong river(80 km long) and 50 km offshore. The model was setup using the 1-D Hydrodynamic model (Mike11) of the river network in the Chao Phraya-Tha Chin basin. These are simulated by 2 dimensional flow using Mike21. The computational grid size is 400 x 400 m. The above two models were integrated to be a single model by using the MIKE FLOOD module. The model configuration is shown Fig. 1 (World Bank, 2008).

The discharge data of the Chao Phraya river and the discharge release from the Rama IV Dam of the Pa Sak river were used as the upstream boundary conditions. The tidal level was input as the downstream boundary for the coastal area. The measured rainfall was also input at each gauging station for rainfall-runoff computation in the sub-catchment. The model was calibrated and verified by the flood event of the year 2002 and 1995, respectively.

3. RESULT DISCUSSIONS

The 2011 rainy season was influenced by both the North-west monsoon and the tropical storm, starting from Nock-Ten that made a landfall at Vietnam and became tropical depression before moving to Thailand at the end of July (Nan province). In addition, there are 4 storms (Haima, Haitan, Nesat, and Nalgae) that caused

medium to heavy rainfall from June to October in the north and north-east of Thailand. The continuous rainfall in the north are accumulated nearly 1,675 mm which is 42% more than the 30-year averaged value (TMD, 2011). This causes significant accumulated run-off volume passing Nakornsawan province more than 30,000 mcm. Due to limited capacity of the Chao Phraya river and also Pasak river, several overbank flows occurred and also dikes along the river were broken causing excessive flow to many communities beside the river and downstream. The inundation area was estimated 14,000 km² with the flood volume of approximately 10,000 mcm in the floodplain from Nakornsawan to Ayuthaya.

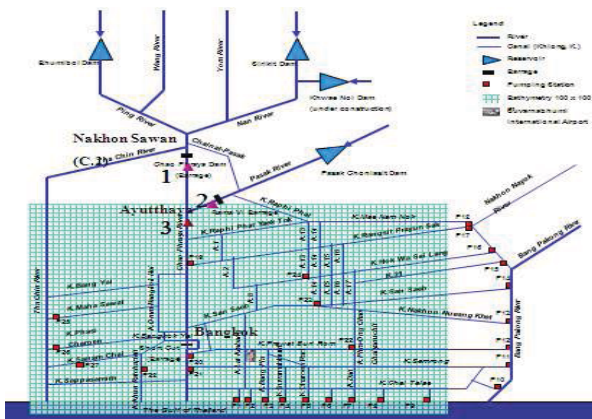


Fig. 1 Model configuration

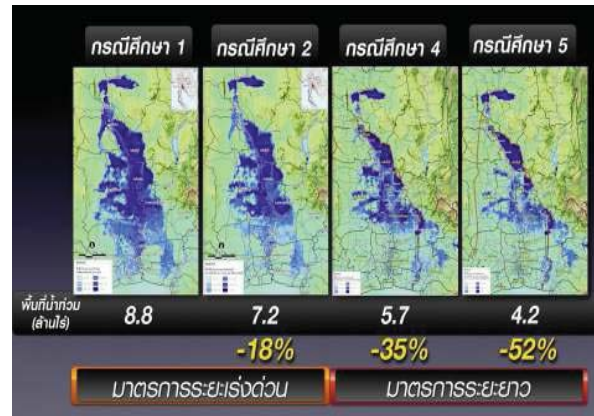


Fig. 2 Flood prevention and mitigation measures

Four case studies are investigated (see Fig. 2). The 1st case study is the base case of the 2011 flood (Do nothing). The inundation area was found approximately 8.8 million Rais. The use of 2 million Rais as retention basin (Case study 2) can reduce the inundation area by 18% or 7.2 million Rais. The 3rd case study is the use of east floodway of 1,000 cms capacity. This can reduce the inundation area by 35% or 5.7 million Rais. The 4th case study is the use of both floodways (East and west of 1,000 cms per each). This can reduce the inundation area by 42% from the 2011 flood event.

4. CONCLUSIONS

This study was aimed to assess conceptually the prevention and mitigation measures for the 2011 flood events. The Mike11 and Mike21 models were used to calculate the flood depth and flood inundation area. Four case studies were investigated. The 1st case study is the base case of the 2011 flood (Do nothing). The inundation area was found approximately 8.8 million Rais. The use of 2 million Rais as retention basin (Case study 2) can reduce the inundation area by 18% or 7.2 million Rais. The 3rd case study is the use of east floodway of 1,000 cms capacity. This can reduce the inundation area by 35% or 5.7 million Rais. The 4th case study is the use of both floodways (East and west of 1,000 cms per each). This can reduce the inundation area by 42% from the 2011 flood event. However, in order to obtain flexible and sustainable solutions in the future, impact of climate change (Sea level rise, heavy rainfall) including internal drivers (Land use planning, Land subsidence) has to be considered.

In the middle of December 2011, the Thai Government established the Strategic Committee for Water Resources Management (SCWRM). The SCWRM releases 6 immediate plans to mitigate the possible 2012 flood that is very much concern for the people. They are 1) Reservoir operation rule improvement 2) Recovery of the damaged infrastructures 3) Improvement of flood forecasting and warning systems 4) Emergency management plan 5) Define floodways and retention basins and 6) Line of organization review. Finally, the best practice for the Integrated Flood Management in the Chao phraya considering climate change and climate variability has to be adopted for sustainable future. The government is now inviting Thai and Foreign firms to join the Thailand's overall water management in proposing a conceptual plan. The project cost is about 300 billion Bahts.

Acknowledgement:

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STRENGTHENING OF CLIMATE INFORMATION SERVICES CONCERNING WATER AVAILABILITY TO SUPPORT FOOD SECURITY PROGRAM IN INDONESIA

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Abstract : Indonesia as a country with large population stipulates that food security program becoming a top priority program which is very prone to climate variability and climate change. Therefore Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) as a government agency who responsible to provide climate must strengthen the capabilities to produce the information. BMKG consists of 178 stations and operates 155 Automatic Rain Gauges and 176 Automatic Weather Stations throughout the country. BMKG has also developed 79 Agro Automatic Stations and 21 automatic soil moisture which focus to support food security program. Establishing of the automatic equipments and sensors is a need to have better monitoring and prediction capabilities especially for drought event due to water availability that very crucial to support food security program. Special for water catchment area, BMKG has established Rainfall Monitoring System in Kedungombo and Mrican Dam in Central Java, one of our food production centers. This system can give automatic rainfall monitoring in water catchment area for dam operation. By all of the activities BMKG optimize that climate information will be applied widely not just for policy maker but also for end users in various sector including in the water management context.

Keywords : *Food security , climate, water availability*

1. INTRODUCTION

Indonesia is a country with population of around 230 million, it is the forth in the world. With this fact, it is firmed that food security program is one the top priorities of the Government policy. In national level, Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) has task to provide of climate information. At special case to food security program, BMKG has a mandate to provide analysis of events and to disseminate of climate extreme which stated in the Presidential Instruction No. 5 / 2011 on rice production security to anticipate the climate extreme events.

2. OBSERVATIONAL NETWORKS

BMKG operates 120 Meteorological Stations, 21 Climatological Stations, 31 Geophysical Stations, 155 Automatic Rain Gauge and 176 automatic weather stations. Since 2011, BMKG has developed 79 Agro Automatic Stations which focus to support food security program. For dam operation, BMKG also installed 10 ARG's in water catchment area for two dams namely Mrican and Kedungombo. These dams are used for irrigation purposes and electric generation. In future time, BMKG plans to install more automatic equipment to accelerate data collection and information dissemination.

3. CLIMATE INFORMATION PRODUCTS

BMKG releases regular and specific climate information products. Regular information products consist of seasonal prediction, monthly rainfall prediction, drought monitoring using SPI method and soil water availability. Specific climate information products include Drought Potential Analysis, Suitability Agroclimate Map and Climate Classification Analysis.

Soil water availability is calculated based on soil water balance which from the difference between the amounts of water fall the surface and the water that loss by evapotranspiration or in other words refers to the amount of water held in the soil at any particular time. It is assumed that the water that receives by the surface is primarily from precipitation and the depth of soil is 1 meter. In the future BMKG will plan to use the data measured by soil moisture sensor. This information is disseminated in the website and also in a printing bulletin. The users are from agriculture department, university and disaster management agency both in national and regional level.

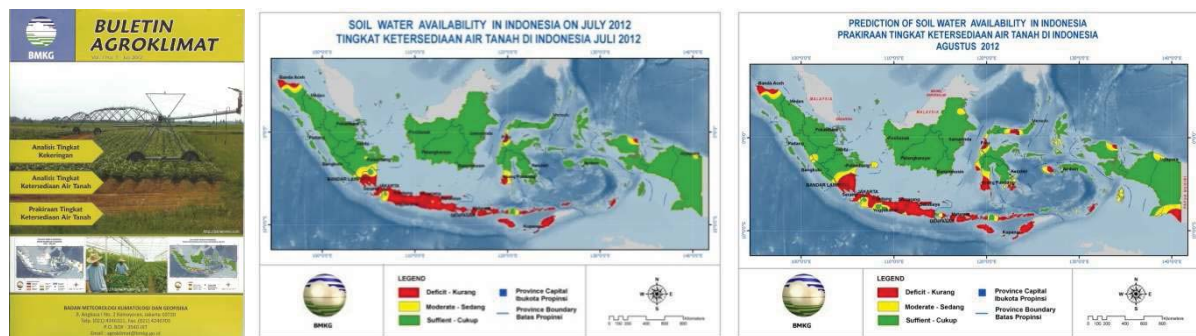


Figure 1. Left : Bulletin of Agroclimate- June 2012; Middle: Information of Soil Water Availability on July 2012; Right: Prediction of Soil Water Availability on August 2012

4. RAINFALL MONITORING FOR DAM

For specific users in water management sector, BMKG has installed 10 ARG's to monitor rainfall amount in the water catchment area for two dams, Mrican and Kedungombo in Central Java Province. This province is also known as one of the national centers of rice production center. The rainfall information is used by the dam manager to analyze the amount of water storage in catchment area as will be affected to the dam.

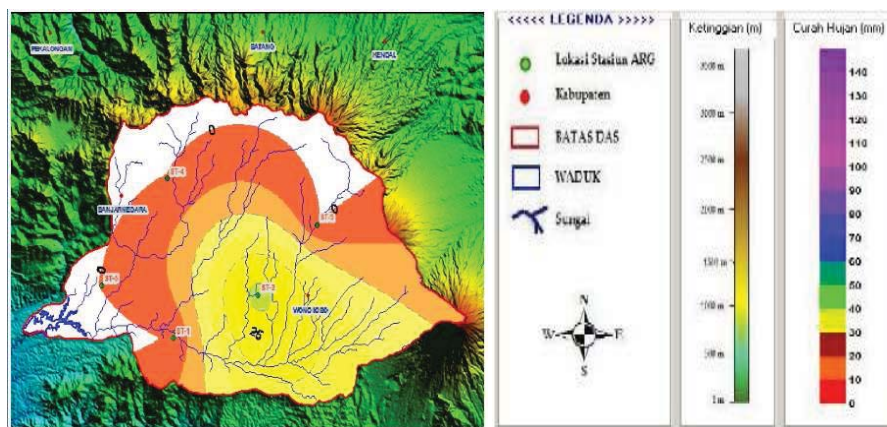


Figure 2. Monitoring of rainfall amount (mm) in catchment area of Mrican Dam, Central Java, Indonesia.

5. CONCLUSIONS

Many activities have been done by BMKG in order to strengthen climate information services for various users. Start from strengthening of network observations, increase the variety of climate information and also speed up the dissemination to user. It is obvious that the information has been used widely for various users, not only for policy maker but also for end user in the field. All the activities should intend to support the food security program in Indonesia.

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A POLYCENTRIC APPROACH TO DEAL WITH UNCERTAINTY AND CLIMATE CHANGE ADAPTATION – A CASE STUDY OF TRANS-BOUNDARY WATER GOVERNANCE IN VOLTA RIVER BASIN IN WEST AFRICA

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Abstract: By drawing on an innovative trans-boundary water governance project in West Africa as a case study, this paper is intended to highlight the strengths and limitations of the polycentric approach, especially shedding light into the power dynamics of working with different scale of governance. This paper particularly examines the power asymmetries between the regional and the local governance in the trans-boundary water governance arrangements. Drawing on the case study of White Volta River Basin in West Africa, it raises concerns about the implicit preference of the regional water committee for long-term ecological sustainability over the short-term livelihood interests of poor people. No matter how well-intended the adaptation policies might be, a focus on long-term ecological sustainability could pose a real threat to the livelihoods of poor people, and worsened poverty. It concludes by developing a 'pro-poor' polycentric approach. It suggests that finding alternative sustainable livelihoods in order to meet poor people's current needs and to protect long-term ecological sustainability is of equally importance and urgency.

Keywords: *trans-boundary, polycentric, Ostrom, gender, power, Ghana, Burkina Faso*

1. INTRODUCTION

Elinor Ostrom (2009) suggests that climate change is a classic collective action problem that is best addressed at multiple scales and levels. She argues that a polycentric approach to linking small- and medium-scale governance units to a higher level is crucial for addressing climate change. While the notion of polycentricity has been gaining momentum in the institutional literature, how effective is it to deal with vulnerability, degradation and climate change? To answer this question, this paper draws on a case study of trans-boundary water governance project in Ghana and Burkina Faso.

In this paper, I will argue that the polycentric approach can create a common vision between communities and help local people be more aware of the cross-border impact of climate change. I will suggest that, under the right institutional arrangements and support, the trans-boundary water structures can effectively challenge social inequalities along lines of gender, language and faith. This paper will, however, show some of the limitations of the policy implementation of the polycentric approach. It calls for a more poverty-sensitive approach by making poor people's existing livelihoods as equally importantly as the needs of future generations.

2. CASE STUDY: TRANSBOUNDARY WATER GOVERNANCE IN GHANA AND BURKINA FASO

Ghana and Burkina Faso share 85% of the Volta River Basin. How they manage water is crucial to the development of the region. With the support of SIDA and IUCN, a Regional Trans-boundary Water Committee was set up. This 14-member committee comprised regional ministers, district chief executives, civil servants from forestry, agriculture and water ministries, NGOs, and two community representatives. It provided visions for better coordination of water sharing between countries. Another committee, called Country Committee, was set up. This 60-member country committee was composed of eight regional coordinators, six district coordinators, fourteen technical service staff (in charge of Food and Agriculture, Forestry, and Water), eight NGO representatives, and 24 local representatives. It linked the Regional Trans-boundary Water Committee and local communities.

Amongst the 24 local representatives, there were eight female and sixteen male chosen from eight communities located in Upper North Region of Ghana and Southern part of Burkina Faso. These eight communities were chosen because they were located along the White Volta River and they had previously worked with the NGOs in other projects. Furthermore, they represented communities of different religions (Christian, Muslim and Pagan) and of different languages. Each chosen community selected three villagers to participate in the country committee. In order to promote gender equality, at least one out of the three local representatives must be female. A series of climate change adaptation policies were adopted. A 10-metre wide buffer zone was formed and trees were planted to stabilise the river bank. Farmers were 'persuaded' to stop farming within the buffer zone. Free mango seedlings were offered to compensate for their loss.

3. SUCCESS OF POLYCENTRIC APPROACH

This project is effective in making villagers aware that water-related problems in their communities were neither unique nor isolated cases. The sense of 'togetherness' was also generated by a constant comparison between communities over the progress of the project. During the country meetings, the chairperson would report how many new trees have been planted in the buffer zone of each community. In order not to be seen as 'lazy' or 'not progressive enough', a female representative said she would ensure that her community did not lag behind other communities. This gave a strong sense of self-motivation for rule enforcement. Project coordinators have highlighted the role of women in water management because women are responsible for fetching water and collecting firewood in most communities. The success of the adaptation policies, therefore, lies in the recognition of their contribution to, and involvement in, the decision-making process. To ensure fair gender representation, each community needed to select at least one woman as their representative. The female representatives felt empowered in the process of participation. They raised questions during the meetings and challenged the decisions that they thought unfavourable to their own communities.

4. LIMITATIONS

The creation of the buffer zone along the river banks aimed to reduce soil erosion and strengthen flood protection. Farmers were asked to stop cultivation within the buffer zone. This policy hit poor farmers disproportionately. Lands along the river bank were usually fertile, and the availability of river water made free irrigation possible. The confiscation of the farmlands, for the sake of creating the buffer zone, had become a blow to the livelihoods of very poor farmers. To compensate for their losses, the project organisers provided pumping facilities to make long-distance irrigation possible. However, poor farmers were often excluded from the pumping groups because they thought they could not afford the fuel costs. In addition, free mango seedlings were distributed to provide an alternative farming practice. The idea was that cash crops, such as mangoes, had high market values, and that would boost farmers' incomes. The farmers, however, complained in interviews that it would take them three years to get the first harvest. They were also worried that when everyone switched to grow mangoes, the price level of mangoes would drop and they would not make much profit out of it. Although they had expressed these concerns to their community representatives, they complained that their representatives had turned a blind eye. As a result, some farmers stopped participating in local meetings because they did not see they could get any benefits from the project. The project organisers worked closely with local chieftains and *Tindana* since the inception of the project. However, to safeguard their interests in the trans-boundary water project, the chiefs and *Tindana* made influence in the process of selecting community representatives and made sure that their family members and relatives were chosen. All these have demonstrated that this project has helped consolidate, rather than challenge, their authorities (Wong, 2008).

5. CONCLUSIONS

Climate change affects people both locally and regionally. The polycentric approach provides better coordination between communities. This paper has, however, argued that the over-emphasis of the polycentric approach on climate change cannot, and should not, be isolated from a deeper analysis of power and poverty. No matter how well-intended it may be, the long-term ecological sustainability, such as creating the buffer zone along the river banks, can pose a real threat to the livelihoods of poor people, and that can worsen poverty. This, therefore, calls for an intricate balance of the interests of the current and future generations. In addition, if adaptation policies build on, and help to reinforce, existing unequal social structures, poor people will finally become the victims, rather than the beneficiaries, of the climate change-sensitive initiatives.

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Poster Session

PREDICTION OF DROUGHT INDICES OVER INDIA USING MULTI- MODEL ENSEMBLE

Nachiketa Acharya and U.C. Mohanty

CAN MODELS HELP TO FORECAST RAINWATER DYNAMICS FOR RAINFED ECOSYSTEM?

M. AHMED and F.F. van Ogtrop

SEASONAL RAINFALL VARIABILITY AND ITS IMPACT ON VEGETATION DYNAMICS IN THE SOUTHWESTERN UNITED STATES: AN OUTLOOK ON FUTURE WATER BUDGET ISSUE

Clement Sohoulade, Vijay Singh

CLIMATE PREDICTIONS AND GRASS ROOT ADAPTATIONS: WILL THEY REMAIN PARALLEL OR CONVERGE: FIELD OBSERVATIONS FROM SOUTHERN INDIA

K. Lenin Babu

CLIMATE VARIABILITY AND ITS IMPACTS ON WATER RESOURCES IN OTI PLAIN

Badjana Heou Maleki, Hounkpe Koffi, Abalo-Sama Abide, Wala Kperkouma, Edjame S. Kodjovi

VULNERABILITY OF COASTAL WETLAND TO CLIMATE CHANGE AND SEA LEVEL RISE OF BANGLADESH: ISSUES AND CHALLENGES

Abu Hena M K

RAINFALL VARIABILITY AND ITS IMPACT ON WATER RESOURCES IN HIMALAYAN HEADWATERS: NEED FOR LONG-TERM ADAPTIVE AND INTEGRATED WATER RESOURCE MANAGEMENT AND GOVERNANCE POLICY

Prakash C Tiwari, Bhagwati Joshi.

IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES AND RICE PRODUCTIVITY IN DROUGHT PRONE AREA OF BANGLADESH

Md. Abiar RAHMAN1

International Conference on Climate, Water and Policy (ICCWP) 2012:

Exploring Climate Application Series I

COMMUNITY FOREST OF NEPAL: HOW IT MAINTAINS ECOSYSTEM SERVICES AND COPES WITH GLOBAL WARMING?

Bidur Khadka, Masters Student

APPLICATION OF CLIMATE INFORMATION ON IMPACT ASSESSMENT OF STREAM FLOW

Jung-Lien Chu, Yun-Ju Chen, Yuan-Fong Su,

Jun-Jih Liou, Yung-Ming Chen

CLIMATE VARIABILITY AND CHANGE IN BANGLADESH: A SPATIO-TEMPORAL ANALYSIS OF RAINFALL AND TEMPERATURE USING HISTORICAL DATA AND GIS

Md. Rejaur Rahman

ASSESSMENT OF CHANGES OF ANOMALY TEMPERATURE AND EXTREME PRECIPITATION IN THE MIDLATITUDE ASIA-PACIFIC REGION

V. Platonova

WATER RESOURCES MANAGEMENT IN INDIA UNDER A CHANGING CLIMATE

Shadananan Nair

CLIMATE CHANGE IMPACTS ON GROUNDWATER- DEPENDENT IRRIGATION SYSTEM IN NORTHWEST BANGLADESH

Shamsuddin Shahid

NATURAL FACTORS AND ANTHROPOGENIC IMPACT OF THE ESTUARIAL AREA OF THE AMUR RIVER RUNOFF FORMATION

Polina A. Sokolova, Tamara G. Ponomareva

THE APPLICATION OF CATASTROPHE THEORY TO THE POSSITIVE CLIMATIC TRENDS

Talgat R. Kilmatov, Olga I. Trinko

EVALUATION OF WATER DEMAND-SUPPLY RELIABILITY BASED ON CLIMATE CHANGE SCENARIO IN HAN RIVER BASIN

Jang-Won Moon, Dong-Ryul Lee, Si-Jung Choi

ASSESSMENT OF HISTORICAL RIVER FLOWS AND CLIMATOLOGY OF UPPER INDUS BASIN (UIB) AND TO DEVELOP RELATIONSHIPS BETWEEN RIVER FLOWS AND CLIMATIC VARIABLES IN UIB

Engr. Amjad Masood, Qurat Ul Ain Ahmad

ADAPTATION STRATEGIES FOR SAFE WATER SUPPLY IN THE DELTAIC COASTAL REGION OF BANGLADESH

Mehdi Azam, Tapan Sarker

STREAM RESERVATION ENCROACHMENT IN SRI LANKA: CAN IT BE SOLVED BY IMPROVING THE EXISTING COMMUNICATION CHANNELS?

S.S.K.Chandrasekara

WATER SCARCITY IN IRAN

Shahram Khorasanizadeh

INDIAN RAINFALL FORECASTING, VECTOR AUTO REGRESSION (VAR) & VARIANCE DECOMPOSITION (VDC) MODEL: A SPATIAL AND INTER-TEMPORAL ANALYSIS AND IMPLICATION FOR WATER MANAGEMENT IN THE CONTEXT OF CLIMATE CHANGE

Dr. Jyotish Prakash Basu

A RELIABLE FOOTING FOR SUSTAINABLE INTERNATIONAL COOPERATION ON CLIMATE CHANGE

Dillip Pattanaik

CLIMATE VARIABILITY, WATER RESOURCE SCARCITY AND POLICY SHIFT IN DRYLANDS OF RAJASTHAN, INDIA

Ajay Kumar, R.B. Singh

PREDICTION OF DROUGHT INDICES OVER INDIA USING MULTI-MODEL ENSEMBLE

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Abstract : The main focus of the present study is to develop a multi-model ensemble based system to predict drought through Standardized Precipitation Index (SPI) at meteorological subdivisions of India during summer monsoon (June-July-August-September). Two different multi-model ensemble (MME) schemes, viz., arithmetic mean of GCMs (EM) and weighted mean using singular value decomposition based multiple linear regressions (SVD-MLR) is implemented. It is found that among these MME techniques, SVD-MLR based MME has more skill as compared to simple MME as well as individual GCMs.

Keywords: *Indian Summer Monsoon Rainfall, Standardized Precipitation Index (SPI), General Circulation Model (GCM) and Multi-model ensemble (MME).*

1. INTRODUCTION

India is basically an agricultural country where the success or failure of the harvest and water scarcity in any year is always considered with the greatest concern. These problems are closely linked with the behavior of the summer monsoon (June to September abbreviated as JJAS) season, which is the main period of rainfall over India, delivers about 80 percent of the total annual rainfall. Indian economy being agro-economic the hydrological planning and disaster management of this country is centered at this season. Occurrence of drought adversely affects the economy of India to a large extent. Drought can be measured by using several drought indexes, which is typically a single value used for indicating the severity of a drought. These indexes are more useful than raw data in understanding the drought conditions over the country. Among several indices, Standardized Precipitation Index (SPI) has been widely used in recent years because of its computational simplicity and reliable interpretation. The studies made so far on the SPI have concentrated mainly upon the trend of SPI over India. However, the prediction of SPI has not gained much importance till date. It is well known that prediction of drought is always in high demand for agriculture, drinking water, transportation, health, power and the very livelihood of almost 1 billion people living in this country. Therefore in view of the importance of advance information regarding the severity of drought the main focus of present study is to develop a prediction system for drought through Standardized Precipitation Index (SPI). With the availability of climate predictions produced by several dynamical models, multi-model ensemble forecasting has drawn some attention recently for prediction of summer monsoon rainfall. Therefore, in the present study, a multi-model ensemble based prediction system is developed for predicting the SPI for monsoon rainfall (JJAS) over India. This prediction system is applied at meteorological subdivisions as well as country as a whole.

2. DATA AND METHODOLOGY

Hindcast runs (lead 1 for JJAS of 1982 to 2010) from nine global models (GCM or AOGCM) have been used in this study. These models include NCEP CFS system, USA, JAMSTEC, Japan model and other models run at IRI, USA. These data have been obtained from IRI as a part of special understanding between IIT Delhi and IRI, USA. These nine models are referred to as CFSv1, CFSv2, E4P5, GML, E4P5-CFS, JAM, MOM3-AC, MOM3-DC and CCM3v6 in our study. Some of these models are based on a 2-tier modeling system, in which predicted SSTs are prescribed and while some models are 1-tier systems, in which the SSTs evolve as a part of coupled ocean-atmosphere system. The models have varying number of ensemble members. However, for this study only the ensemble mean for each model has been used. These coarse resolution models are interpolated in observations grid ($1.0^{\circ} \times 1.0^{\circ}$) which have been provided by the India Meteorological Department (IMD). Detail description regarding model's atmospheric and oceanic components with the coupling is presented in the Acharya et al (2011) where the skill of all GCMs is discussed in the context of seasonal rainfall.

3. RESULT AND DISCUSSIONS

SPI for monsoon rainfall is calculated by accumulating the rainfall during JJAS. Therefore, for this study we calculate SPI4 considering 4-month (June to September) accumulated precipitation for observations and GCM's products. The mathematical foundation for SPI calculation is described by McKee *et al* (1993) in

details. Before constructing MMEs, a detailed diagnosis has been made for individual GCM's for the prediction of SPI. Among the nine GCMs, only three are found to have significant correlation (95% confident interval) at all India level. But this picture is slightly changed at meteorological subdivision (met-sub) level. The skill of GCMs at met-sub level is found varying. According to the classification of SPI value, the total time series is divided by three type of drought, viz extreme drought ($SPI < -2$), severe drought ($-2 < SPI < -1.5$) and moderate drought ($-1.5 < SPI < -1$). It is observed that some of the models are able to capture the spatial variability of those incidents and the rest could not capture them. Therefore, for disaster management or hydrological planning, it is difficult to take decision based on individual GCMs because of their lack of consistence. As a remedy, Multi-Model Ensemble (MME) based prediction can be applied in this situation by combining the outputs of all nine models. Two MME schemes are used for this study. The simplest one is arithmetic mean of GCMs (EM). Another one is multiple regression using singular value decomposition for estimation of weights of different GCMs (SVD-MLR). It is found that the skill of MME in terms of correlation is better than GCM. Especially, skill of SVD-MLR is much impressive than EM (Figure 1). It may be inferred that the poor performance of the individual GCMs is affecting the outcomes of the MME schemes. Therefore, we have screened some of models according to their skill for making EM and SVE-MLR. After rigorous analysis the skills of both the MME schemes are found to improve significantly after screening.

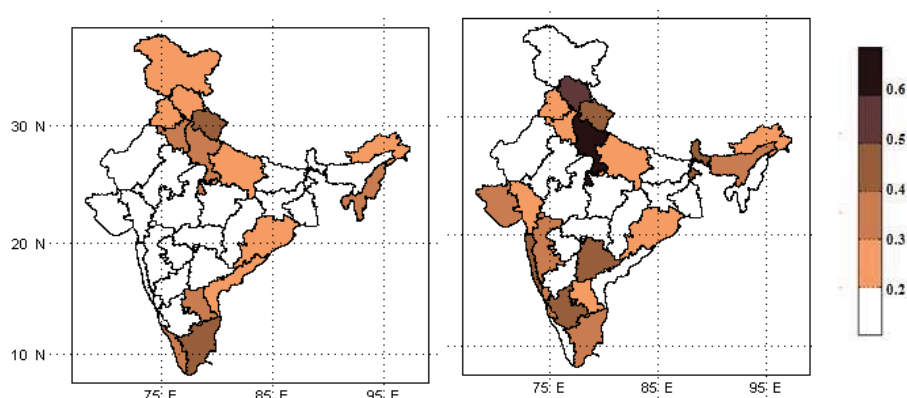


Figure 1. Temporal correlation coefficient for two multi-model ensemble (MME) schemes viz., EM and SVD-MLR with observation during JJAS for the period (1982-2010) over each 34 meteorological subdivisions.

4. CONCLUSIONS

Finally it can be concluded that the MME based specially SVD-MLR based MME prediction of drought indices (SPI) for summer monsoon time over India have significant skill. Therefore, such MME based drought prediction can be used for water management in real-time over India.

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CAN MODELS HELP TO FORECAST RAINWATER DYNAMICS FOR RAINFED ECOSYSTEM?

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Abstract: Simulation models are important tools to explore and illustrate dynamics of climatic variables in crop based ecosystem. In the rainfed ecosystem (RE), wheat production is impinged on certain climatic events *per se* high variability in rainfall, increased temperature, floods, drought, terminal heat stress and frost. These climatic events turn out due to climatic drivers like Sea Surface Temperatures (SSTs) and pressure like Indian Ocean dipole (IOD), El-Nino Southern Oscillation (ENSO) and Southern Oscillation Index (SOI). Current study was aimed to analyze long term rainfall data (1961-2011) of Pakistan's rainfed ecosystem by using Agricultural Production Systems Simulator (APSIM) and R model. The principal objective of this analysis was to study the link between SOI phases and SSTs; and thereby understanding the pattern of climate change due to these climatic drivers under rainfed conditions in Pakistan. The results revealed a positive link between SSTs and July SOI phases and the rainfall variability during October-November (the sowing time of wheat in Pakistan). The study justified the importance of models in the decision making processes and rainfall forecasting as a beneficial and necessary tool for rainfed ecosystem conservation.

Keywords: *Simulation models, rainfed ecosystem, Sea surface temperature, Indian Ocean dipole and R*

1. INTRODUCTION

Fluctuation in seasonal climatic conditions during crop growth period may cause reduction in yield and crop productivity. Several factors including SOI and SSTs like ENSO and IOD contributes to extreme climatic events. However, improved forecasting skills enabled producers to made good use of forecast for risk related decision makings (Motha, 2007). Similarly, forecasting may increase attentiveness and led to better socio-economic and environmental conclusions within an agricultural system (Meinke and Stone, 2005). Weather prediction is not a solution to all difficulties, but a risk management tools which show a crucial part in judgment making and strategic planning to progress agricultural productivity. However, Troccoli, (2010) concluded that seasonal climatic forecasting especially El Nino events predictions is playing most important role in decision making and strategic planning specially in dry regions. Consistent variability in the rainfall and increased temperature has been observed in rainfed areas in recent decade. Floods, drought, terminal heat stress and frost were the main climatic events of the decade affecting wheat production in the rainfed areas. These events were related to climatic drivers like sea surface temperatures (SSTs) and pressure like IOD (Indian Ocean dipole), ENSO (El-Nino Southern Oscillation) and Southern Oscillation Index (SOI). Seasonal weather depicted strong variations in wheat production which have teleconnections with SOI, ENSO and IOD. Therefore, the prime objective of this study was to study relationship between climatic drivers which further could be used for rainfall forecasting in dryland agriculture of Pakistan.

2. METHODOLOGY

The experimental site of rainfed ecosystem was Islamabad (33°40'N, 73°10'E, 508 m a.s.l.).The daily rainfall data were collected from the Meteorology Department of Pakistan (<http://www.pakmet.com.pk/>). Rainfall data (1961 - 2011) was analysed using the statistical software "R" to forecast rainfall of monsoon (JAS). The GAM (Generalized Additive Model) was used to link rainfall with SSTs. The accuracy of forecasting was then tested by forecasting skill scores like R², correlation, NSE (Normalized Standard Error), RMSE (Root Mean Square Error), BIAS, CSS (Skill Score S), BSS (Brier Skill Score) and ROC (Receiver Operating Characteristics) to determine the most parsimonious model.

3. RESULTS AND DISCUSSIONS

The results for Islamabad revealed that by using different lag period and SST rainfall for different period like monsoon (JAS), early wheat crop establishment (NDJ) and grain filling period (FMA) of wheat crop could be forecasted with good accuracy. However, significant strong signal was recorded for SST of May with lag period of July to forecast rainfall of monsoon season. Meanwhile for NDJ significant signals were recorded

for NINO1.2, NINO3 with R^2 of 59 (Table 1). Forecasting rainfall during early wheat growth (NDJ) period, individual month's SSTs of various months were deployed however, significant correlation was only observed with August and September's SSTs ($r^2=0.35$) at the high rainfall zone (Islamabad) while for the NINO1.2 covariates significantly ($p \leq 0.001$) with FMA rainfall at Islamabad with SST of August. The skill scores like NSE (Nash–Sutcliffe model efficiency coefficient), RMSE (Root Mean Square Error), S% (S Skill Score), BSS (Brier Skill Score), LEPS (Linear Error in Probability Space) and ROC (Receiver Operating Characteristics, p-value) for forecasting in season rainfall showed suitability of using SSTs in rainfall forecasting (Table 2). Forecast skills scores like NSE, RMSE, BIAS, CSS, BSS and ROC have depicted significant ability to forecast rainfall of JAS, NDJ, FMA and NDJFMA.

The life of dryland agriculture depends on the blue water (rainfall) management especially that is received during the monsoon period (JAS). Since models simulated rainfall during JAS period with accuracy therefore, it could be considered as an important risk management tool for rainfed agriculture. An additional amount of water will be required to produce the food to eradicate hunger in the developing countries like Pakistan which could only be achieved by crop per drop (Rockstrom *et al.*, 2007a and b). Wheat yield fluctuation under dryland agriculture due to different climatic drivers (SOI and SST) has a strong link with available soil water. The study demonstrated the use and scope of models for future risk management under rainfed agriculture by forecasting rainfall precisely. However, in the present study, soil moisture was not considered as a covariate in the model. Similarly, best lag period was used which could be changed by considering other climatic predictors. The methodology can also be used to identify teleconnections between SSTs and precipitation/drought of whole Pakistan (Van Ogtrop *et al.*, 2011).

4. TABLES

Table 1. p-value of GAM model with R^2 showing relationship with different months SSTs, lag and wheat seasonal rainfall prediction at Islamabad

SST	lag	Rainfall period	R^2	Intercept	Spear	p-value				
						s(NINO1.2)	s(NINO3)	s(NINO4)	s(NINO3.4)	s(OD)
March	AM	JAS	0.35	684	0.06	0.17	0.05	0.19	0.06	0.24
April	MI	JAS	0.33	656	0.25	0.07	0.78	0.77	0.88	0.11
May	J	JAS	0.4	464	0.02*	0.003**	0.003**	0.08	0.012*	0.44
J	ASO	NDJ	-0.012	90.7	0.72	0.24	0.41	0.68	0.43	0.09
J	ASONDJ	FMA	0.15	163	0.1	0.2	1	0.62	0.76	0.79
J	ASO	NDJFMA	0	238	0.08	0.9	0.7	0.7	0.5	0.8
A	SO	NDJ	0.07	101	0.84	0.04*	0.07	0.58	0.33	0.04*
A	SONDJ	FMA	0.3	213	0.84	0**	0.07	0.48	0.26	0.36
A	SO	NDJFMA	-0.008	347	0.38	0.54	0.36	0.34	0.09	0.66
S	O	NDJ	-0.01	89	0.62	0.22	0.43	0.76	0.66	0.047*
S	ONDJ	FMA	0.1	187	0.47	0.81	0.8	0.34	0.74	0.84
S	O	NDJFMA	0.13	271	0.34	0.04*	0.11	0.45	0.57	0.52
JA	SO	NDJ	0.01	89	0.75	0.08	0.14	0.88	0.23	0.04
JA	SONDJ	FMA	0.2	163	0.26	0.06	0.5	0.74	0.81	0.7
JA	SO	NDJFMA	0.02	237	0.23	0.5	0.5	0.5	0.9	0.9
AS	O	NDJ	59	88	0.7	0***	0.003**	0.01*	0.02*	0.001**
AS	ONDJ	FMA	0.2	149	0.22	0.1	0.42	0.38	0.58	0.41
AS	O	NDJFMA	0	279	0.69	0.47	0.68	0.13	0.61	0.87
JAS	O	NDJ	0.02	85	0.71	0.07	0.12	0.94	0.23	0.03*
JAS	ONDJ	FMA	0.2	90	0.02*	0.02*	0.6	0.45	0.14	0.87
JAS	O	NDJFMA	0	209	0.19	0.83	0.98	0.46	0.61	0.94

Table 2. Forecast skill for the GAM model at the Islamabad

SST	lag	Rainfall period	Correlation	NSE	RMSE	BIAS	CSS	BSS	ROC
March	AM	JAS	0.54	0.53	22	108.12	0.33	0.16	0
April	MI	JAS	0.54	0.53	22	28.22	0.33	0.02	0
May	J	JAS	0.55	0.54	23	-117.35	0.41	0.16	0
J	ASO	NDJ	0.12	0.12	8.67	67.6	0.25	-0.07	0.05
J	ASONDJ	FMA	0.25	0.25	14	-84	0.12	-0.17	0.04
J	ASO	NDJFMA	0.13	0.13	19	72	0	-0.08	0.04
A	SO	NDJ	0.33	0.33	8	124	0.41	0.14	0
A	SONDJ	FMA	0.56	0.55	11	-57	0.41	0.32	0
A	SO	NDJFMA	0.12	0.12	19	130	0.12	-0.19	0.02
S	O	NDJ	0.11	0.1	9	90	0.16	-0.13	0.02
S	ONDJ	FMA	0.22	0.21	14	-93	0.12	-0.3	0.15
S	O	NDJFMA	0.28	0.27	18	74	0.2	-0.08	0.012
JA	SO	NDJ	0.14	0.14	9	79	0.33	-0.04	0.02
JA	SONDJ	FMA	0.33	0.33	13	-64	0.16	-0.06	0.01
JA	SO	NDJFMA	0.22	0.21	18	135	0.21	-0.04	0
AS	O	NDJ	0.41	0.4	7	108	0.33	0.18	0
AS	ONDJ	FMA	0.38	0.38	13	-41	0.12	-0.02	0.008
AS	O	NDJFMA	0.14	0.14	19	97	0.16	-0.02	0.017
JAS	O	NDJ	0.15	0.15	8	78	0.33	-0.03	0.01
JAS	ONDJ	FMA	0.28	0.28	14	-97	0.08	-0.33	0.07
JAS	O	NDJFMA	0.21	0.2	18	129	0.33	0	0.01

5. CONCLUSIONS

The present study concluded that climatic variability under rainfed agriculture has significant relationship with SOI and SSTs, hence, proposed models as a risk management tools can be used in the agricultural system management to maintain yield sustainability.

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SEASONAL RAINFALL VARIABILITY AND ITS IMPACT ON VEGETATION DYNAMICS IN THE SOUTHWESTERN UNITED STATES: AN OUTLOOK ON FUTURE WATER BUDGET ISSUE

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Abstract: Under global warming, the more likely rainfall scenario expected should be characterized by a high variability. Considering the watershed as a functional unit with a range of biophysical components, the present study targeted the interactions between vegetation dynamics and rainfall variability. The study used historical rainfall data from 370 ground based stations for the last five decades as well as spatial and the last 22 years remote sensed data over regional watersheds in the southwestern United States. The region of study is a part of the North American Monsoon Region, and the seasonal period June-July-August JJA was considered in the study. From 1895 to 2011, the JJA precipitations counted in average for 22 to 43% of total annual precipitation depending of the region and that percentage gets higher in arid regions. Entropy theory which is a probabilistic approach has been used to address precipitation variability issue in time and space. However, the present document targets the results obtained with the Texas Gulf watershed. Different seasonal rainfall characteristics such as number of rainfall events, rainfall amount was involved in the analysis of the interaction between seasonal rainfall variability and vegetation dynamics. The amount of the seasonal rainfall variability induced by the watershed characteristics was investigated through different time series analysis. In final we found out that seasonal rainfall variability tends to be higher in arid regions. More the impact of seasonal precipitation variability on vegetation tends to be more pronounced in arid regions. The implication on water budget was analyzed and it came out potential changes in future terrestrial hydrological process particularly in arid regions.

Key words: Seasonal rainfall, variability, vegetation, water budget, climate change,

1. INTRODUCTION

In most regional watersheds, there is a notable trend that type and vegetation density are correlated with rainfall spatial distribution. It is common to find high density canopies in regions with high amounts of precipitation. These last decades, number of studies showed that the sustainability of natural balance of soil-water-atmosphere is threatened by the effect of global warming. However, there still remains a debate on whether the global warming effect will result in decreased or increased rainfall amounts (Easterling et al., 2000; Salve et al., 2011). Nevertheless, it has been shown widely that climate change will result in high frequency of extreme events such as floods, droughts, extreme temperatures, high rainfall variability and desertification (Groisman et al., 2004; Overpeck et al., 2011; Wehner et al., 2011). This study investigated how the actual trend between rainfall variability and vegetation dynamic can help to have an outlook on future water budget issue at large watersheds scale.

2. MATERIAL AND METHOD

The study area was extended to the whole southwestern United States which includes the Texas Gulf watershed. The study considered seasonal period June-July-August (JJA). Historical rainfall depth and number of rainy days data were collected for ground based stations spread in the spatial domain of study. Precipitation data were smoothed using a three year moving average. Inverse Distance Weighted method was used to fill precipitation gaps. To assess rainfall variability, Shannon entropy was used in the study. The theory of informative entropy is probabilistic and fits better random events. The smoothed historical rainfall data was set in categories in order to derive a probability distribution. The Shannon entropy was computed. Based on the Normalized Differential Vegetation Index NDVI data released by the United States Geological Survey, which combines Landsat 4 to 7 images and a Land Use Land Cover Interface, we were able to get the last 22 years NDVI values for different type of vegetation. These values were used for vegetation dynamics analysis. The implications for water budget were discussed.

3. RESULT AND DISCUSSION

The JJA seasonal rainfalls counted for an important part of the yearly precipitation in the southwest United States. Theoretically, the maximum possible value of informational entropy in the case of this study should be 2.08 bit and should correspond to a scenario of uniform probability distribution of seasonal precipitation records. This means high the variability is at a rain gage station less should be its entropy value. Targeting the Texas Gulf watershed, it came out that seasonal rainfall variability in term of number of rainfall events tends to be higher in the arid part of the watershed as shown by the figure 1. The NDVI time series

showed different trends according to the region. We noted that vegetation greenness has an important and increasing fluctuation in arid region of the watershed while in the humid region the fluctuation seems to be stable with an increasing trend (see figure 2). In regard of these results, it is clear that arid regions would be likely to be very sensitive to rainfall variability and the water budget may be significantly affected in the future if the actual trend remains continuous. The high fluctuation in vegetation canopies due to seasonal rainfall variability should lead to sparser vegetation. As result for the terrestrial hydrological process, we may assist to more runoff and less ground water recharge. That situation may contribute to increase pick flow in streams with high risks of flood in low plains. However, with the reduction of water infiltration, we may assist to higher frequencies of low flow in streams particularly those naturally fed by base flow. In regard of these results, we can understand how crucial it is for long-term water management to consider the change in hydrology and vegetation under global warming scheme.

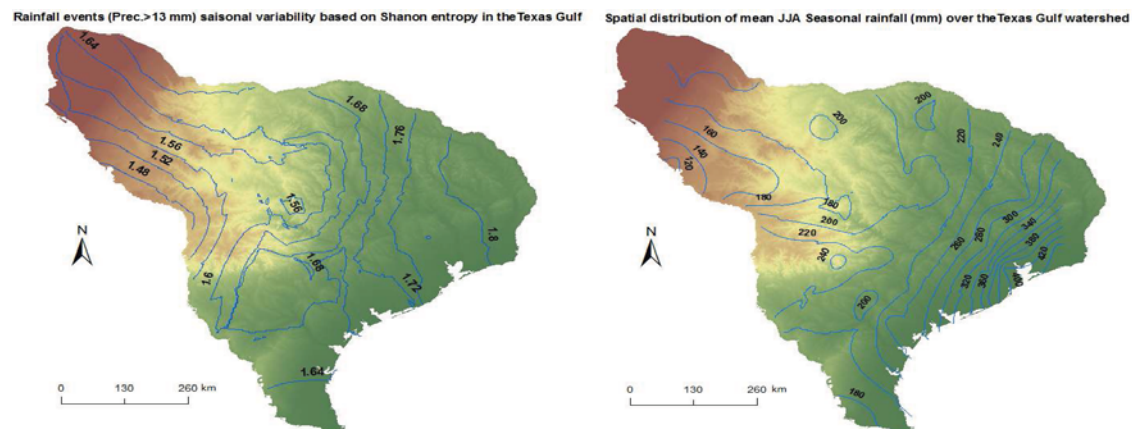


Figure 1: Relating spatial variability trend of seasonal number of rainfall events with humidity/aridity level in the Texas Gulf

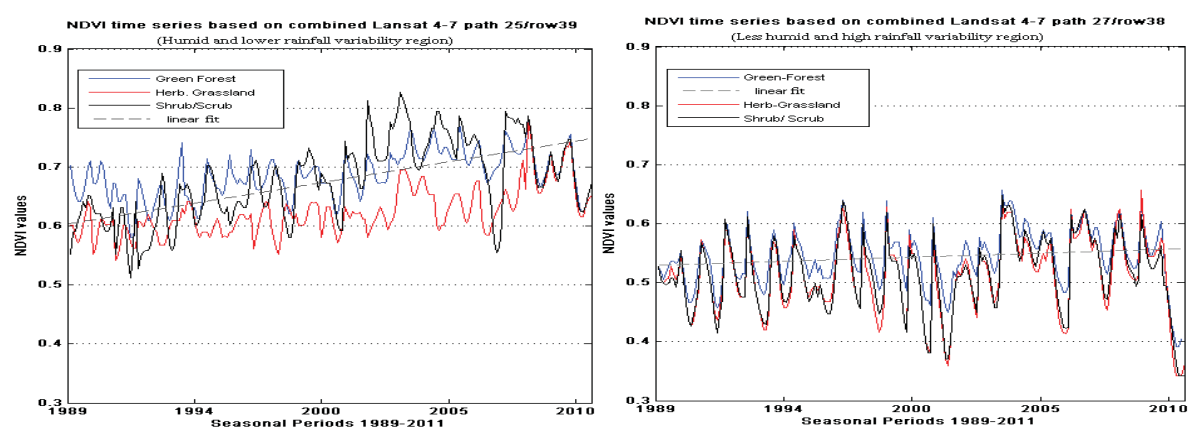


Figure 2: Comparing NDVI trends in two regions with different rainfall variability characteristics in the Texas Gulf watershed

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CLIMATE PREDICTIONS AND GRASS ROOT ADAPTATIONS: WILL THEY REMAIN PARALLEL OR CONVERGE: FIELD OBSERVATIONS FROM SOUTHERN INDIA

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Abstract: Indian Meteorological Department (IMD) through its Forecasts of Indian Summer Monsoon Rainfall (ISMR) in two stages advises about the monsoon variability. Primary stakeholder of these forecasts/ predictions is Indian agriculture. For, the summer monsoon in India accounts for almost all the annual rain in 75% of the geographical area and 78% of the gross cropped area in the country. On theoretical ground, these predictions are supposed to be basis for the decisions to be taken by the farming community, more so in rain fed agriculture regions of the country. However, interaction with farming community in three villages namely Ganikanahal (Irrigated) and Chaganur (Semi-irrigated) in Bellary District and Huilgol (Dry Region) in Gadag Districts of Karnataka in Tungabhadra River Basin of Southern India suggested the other way. For the command area farmers, the predictions are of limited use as they are ensured of water supply by the canal network, and farmers of dry land finding these predictions are useless as they are too generalized to be considered at micro level, say for instance, at farmer level or even at village level.

Keywords: *Climate forecasts, dry land farmers, crop yields*

1. INTRODUCTION

The summer monsoon in India accounts for almost all the annual rain in 75% of the geographical area and 78% of the gross cropped area in the country and its duration over various parts of India varies from about 2 months to 6 months. In spite of its regularity, monsoon exhibits large variability in space and time scales. The first operational Long Range Forecast of Indian summer monsoon rainfall for the region covering whole India and Burma was issued on June 4th, 1886 by Blandford who established Indian Meteorological Department (IMD) in 1875. Since then, IMD was issuing Long Range Forecasts (LRF) of Indian Summer Monsoon Rainfall (ISMR) by seasonal (four months of June to September) scale using two ever progressing approaches, viz., a) Empirical statistical method and b) Dynamical method. The former uses the historical relationship between the ISMR and predictors derived from global atmosphere-ocean parameters, while the later uses General Circulation Models (GCM) of the atmosphere and oceans to simulate the summer monsoon circulation and associated rainfall and at present, statistical models have proved to be better than the other. From 2003, IMD adopted a new strategy for issuing LRF and accordingly the LRF are issued in two stages. The first stage forecast issued in April consisting forecast for seasonal rainfall over the country as a whole and the second stage forecast issued by end of June consisting update for April forecast along with seasonal rainfall forecast for the geographical sub regions of the country and July rainfall forecast for the country as a whole. Primary end user of these predictions are agricultural sector in the country.

This study was undertaken to assess the extent of its use by end users – farming community. Three villages in the province of Karnataka were selected to undertake this study. The source of irrigation was primary factor for the selection of these villages. One Village represents totally irrigated by the ditributaries of River Tungabhadra and second village having one half irrigated by canal while the other half was rain fed while the third village does not have systematic irrigation sources and monsoon precipitation is only the source of agriculture. Primary crop in irrigated areas is paddy during Khariiff season and millets during the rabi period while in rain fed village, major food crops are Jowar, Wheat, Maize and Pulses while the important commercial crops are Groundnut, Chilies, Onion, and Cotton. Majority of farming community represents the land holding size of one hectare and few having couple of hactares and a few having more than 5 ha. Information was collected from the farming community through structured questionnaire, key Informant Discussions. Details of hundred farmers in each village (N = 300) were elicited to draw the following observations spread over three phases, viz. Sowing season, vegetative stage and harvest season..

Farming community is well versed with the details pertaining to the onset of monsoon and its varying behaviour. During sowing season, farmers under command area of irrigation scheme represent one set of end user, having lowest concern among all about behaviour of monsoon in initial stages as they are assured of water supply through canals. For them, the sowing season may be delayed in the event of poor monsoon. Farmers with partial irrigation facility are concerned about the progression of monsoon over the state as for them, main commercial crops are rain fed. However, it is the farmers from rain fed village showing utmost interest in the progression of monsoon. It was observed among this group that every bit of information from IMD was analysed by this group.

2. RESULTS AND DISCUSSIONS

During vegetative season, for paddy cultivators, monsoon predictions are of matter concern as timely precipitation would control the pest incidences, but for rainfed farmers, as it would impact the final yield, are more interested in weather bulletins. However, during the harvest period, entire community is worried as any untimely rain could snatch the year's labour from them but relevance of IMD inputs are minimal.

This study found that forecast by the IMD would best suit if a) they are more focussed on sub-regional level rather than regional level, and b) Line organizations programmes integrated with forecasts for suitable measures.

CLIMATE VARIABILITY AND ITS IMPACTS ON WATER RESOURCES IN OTI PLAIN

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Abstract: Understanding the spatial and temporal climate variability and its impacts on water resources at local scale is important for their sustainable protection and management. This study analysed the variability of rainfall and temperature in Oti's plain (north of Togo) over 51 years and the impacts on river discharge, depletion coefficients and groundwater. The results showed a decreasing trend in rainfall and an increase in temperature. Different change points have been detected in time series between 1970s and 1990s. The spatial analysis showed a lag of isohyets from North to South. However, there is a resumption of rainfall over the last decade. This climate variability has been correlated to Oti river discharge which decreased with a significant shift in 1969 while the depletion coefficients increased. This leads to the rapid draining of aquifers. Field investigations showed a drying up of rivers and wells and an accentuation of the difficulties in water supply for majority of local population who depend on these sources. The climate change is real at local scale and is having great impacts on water resources. This calls for urgent need to adopt measures in order to reduce the vulnerability of local people to climate change.

Keywords: *Climate, variability, discharge, depletion, groundwater*

1. INTRODUCTION

The importance of climate variability and the related impacts at local scales in vulnerable regions to climate change like West Africa is still an open issue.

Located in the north of Togo between 0°E and 1° 3'E Longitude and 9° 25'N and 11° N Latitude, Oti's plain, is a humid zone where the population is mainly rural and live on agriculture, livestock and fishing. During last decades, extreme events struck the region, resulting in floods and droughts. The characterization of climate variability and its impacts is necessary for the sustainable management of water resources of the plain.

In this study, the rainfall and temperature covering 51 years (1960-2010) were first analyzed. Then, the impacts on river discharge and groundwater were examined.

2. METHODOLOGY

The rainfall and temperature (1960-2010) and the river discharge (1957-1989) were collected from the national hydrometeorological services. After generating the missing data by linear interpolation, all the data were smoothed by the low pass filter of Hanning of first order. From Maillet formula, the depletion coefficients and groundwater volumes were estimated (Kanhin et al. 2009). The standard reduced indices were used to analyse the interannual variability. The statistical tests such as Kendall correlation rank, Hubert segmentation, Pettitt, Lee and Heghinian, and Buishand tests (Lubes-Niel et al. 1998) were implemented for trend and change points' detection by using Khronostat 1.01 - free software designed by the Research Institute for Development (IRD). The methods also included the spatial analysis by kriging, the linear regression and field investigation.

3. RESULTS AND DISCUSSION

The local climate is characterized by strong interannual fluctuations of rainfall, alternation of humid and dry periods and a general decreasing trend. There is a deficit over 1975-1996 and early 2000 but 2007-2010 is humid. The temperature has increased all over the area (Fig. 1). The spatial analysis of decadal rainfall showed a shift of isohyets from North to South. The increase in rainfall from 2007 may have contributed to the floods recorded in 2007, 2008 and 2009 in the plain. Break points have been detected in 1972, 1975, 1995, and 1996. These results are conform to previous studies which showed a deficit in rainfall all over West Africa since 1970s to 1980s, a decreasing trend and different break points between 1970s and 1980s (Conway et al. 2009, Paturel et al. 1998). Important droughts also occurred in 1976-1977 in Togo and in 1995-1996 in the investigated area.

Further analysis illustrated a decrease in river discharge and groundwater volumes and an increase in depletion coefficients (Fig. 2) with a break point in 1969 at a confidence level of 99%. After 1969, the average of river discharge decreased of 36.92%, 27.63% for groundwater volumes while the depletion coefficients have increased of 29.57%. This is due to the decrease in rainfall which is correlated to Oti river discharge with a coefficient of 0.717 and an increase in evapotranspiration through the increase in temperature. Mahe and Olivry (1995) proved a rapid emptying of aquifers in West Africa due to a persistent rainfall deficit since 1970 which has accelerated the depletion. Even if the rainfall is the first factor that determines the river flows and aquifers

recharge, the impacts of land use and land cover changes and other anthropogenic factors, not investigated here and difficult to separate from climate change (Conway et al. 2009), must not be neglected. Also, the method used for groundwater estimation is only for trend detection and does not give the absolute values.

Field investigations revealed that the rivers and wells are drying and because the majority of population fetch water from these sources, the difficulties of water supply especially during low flow periods increase.

4. CONCLUSION

Water resources in Oti's plain are affected by the high interannual climate variability and are likely to be strongly impacted by future climate change. Early adaptation measures are therefore necessary in order to protect the resources of the plain which are very important for local population but also for the country.

5. FIGURES

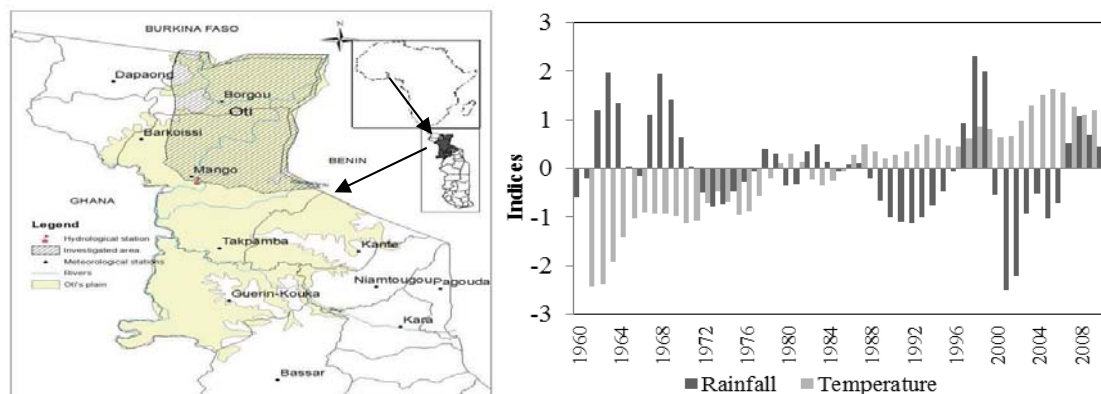


Figure 1. Research area and climate variability. Left: Oti's plain map; Right: Rainfall and temperature variability at Mango

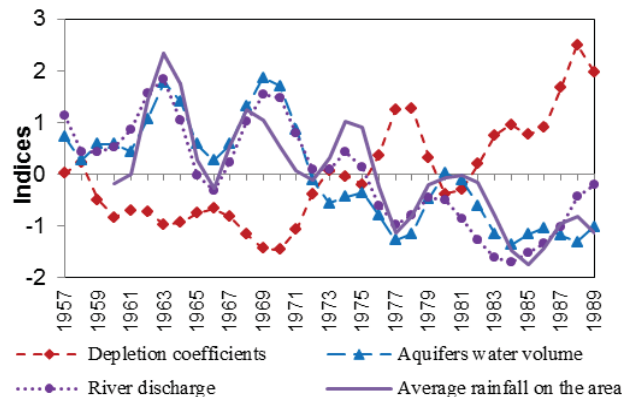


Figure 2. Left: Interannual variability of rainfall, river discharge, depletion coefficients and estimated groundwater

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VULNERABILITY OF COASTAL WETLAND TO CLIMATE CHANGE AND SEA LEVEL RISE OF BANGLADESH: ISSUES AND CHALLENGES

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Abstract : Coastal communities are used to face different types of natural disasters since primitive time in Bangladesh. Extensive area of coastal wetland, coastal wetland forest, drinking water facilities and fresh water availability are in critical condition which placed 40 million people (covering 147 coastal districts covering 47201 km) in danger. Besides some other natural and anthropogenic disasters, salinity intrusion due to sea level rise in the coastal wetland is the major unpleasant incident now days. The assessment of coastal wetland soil and water salinity is not conducted since 9 years in nation wide. Survey on coastal land and pore water salinity in 1973 and 2000 found that the saline effected land is increased from 0.83 million ha to 1.20 million ha within 27 years. Assuming that at present, the rate of salinity intrusion in the coastal wetland will be higher than those of 1973 and 2000. Soil pore water salinity was 18-20 ppt after *AILA* (a tropical storm) in the south-eastern coast of Bangladesh and increased further 2-4 ppt due to low precipitation which causes crop failure in the coastal area of Bangladesh.

Key words: Climate change, sea level rise, salinity intrusion, coastal wetland, Bangladesh

1. INTRODUCTION

Bangladesh is blessed with 710 km of coast line which has strong interactions with coastal wetland in the Southeastern and Southwestern sites. In total crop land (145, 9950.00 ha) almost $\pm 30\%$ of land could not contribute significantly on agricultural production and development (Ashraful, 2004). Besides drought, water logging and flood, salinity intrusion due to climate change and sea level rise in the coastal wetland is another new unpleasant incident now days (Abu Hena *et al.*, 2009). Coastal soil salinity has increased from 0.83 million ha to 1.20 million ha within 27 years (1973-2000) of time (SRDI, 2000, Prothom-Alo, 2009). Soil salinity was recorded 18-20 ppt after *AILA* in the Southeastern coast of Bangladesh and increased further 2-4 ppt due to low precipitation which causes crop failure (Prothom-Alo, 2010).

Water logging due to accretion of river 150,000.00 ha of land in Jessohor, Khulna and Shatkira were effected last year which resulted crop failure. It is assuming that million ha of crop land will be effected in future due to sea level rise, and 14,000.00 tons gain production failure in Eastern Bangladesh by 2030, and 252,000.00 tons by 2075. Prothom-Alo (2011) reported that 300 ha of Boro and Rabi crops are burned out of 4057 ha of targeted wetland in Teknaf, Cox's Bazar in 2010. Observation shows that the crop production will be reduced up to 30% in the South Asia including Bangladesh due to irregular rain pattern. Threatening the richest and most productive region of the country, climate change could have dramatic consequences for the Bangladeshi economy. However, a recent study estimates that the GDP will be decreased in the range of 28% to 57% due to 1 m of sea level rise.

2. IMPACTS AND ISSUES

The impact of climate change in the coastal environment of Bangladesh is apparent now. The Northern site of Bangladesh is Himalaya, where ice melt everyday, in the South, is the Bay of Bengal and adjacent coastal land effecting by sea level rise and cyclone, and at the middle, is flood prone area. Intrusion of salinity into the main land of Bangladesh (Table 1) due to sea level rise could interrupt the crop production while increasing in water level by flash flood may damage crop production and livelihoods of the people.

Table 1. Salinity affected coastal land in Barisal division, Bangladesh (2010)

Region	Total area (ha)
Pathuakhali	139350.00
Barguna	104230.00
Vola	93540.00
Pirojpur	27640.00
Barishal	11370.00
Gopalganj	10200.00
Jalakhati	3520.00
Madaripur	1190.00
Total	391040.00

Source: Prothom-Alo, 2010

3. CHALLENGES [FIGURE 1 (A-H)]

The challenges due to climate change and sea level rise is high in Bangladesh. Some challenges could be as follows:-

- a) Crops damages due to salinity intrusion and reduction of agriculture land;
- b) Decreases of fresh water availability and increases of water logged area;
- c) Scarcity of drinking water and depletion of ground water;
- d) Zone changes and decrease of soil fertility;
- e) Misery of coastal land due to tidal bore, flood, heavy rain and erosion;
- f) Increases of drought due to water shortage, and
- g) Loss of food security and increases the number of climate refugees.

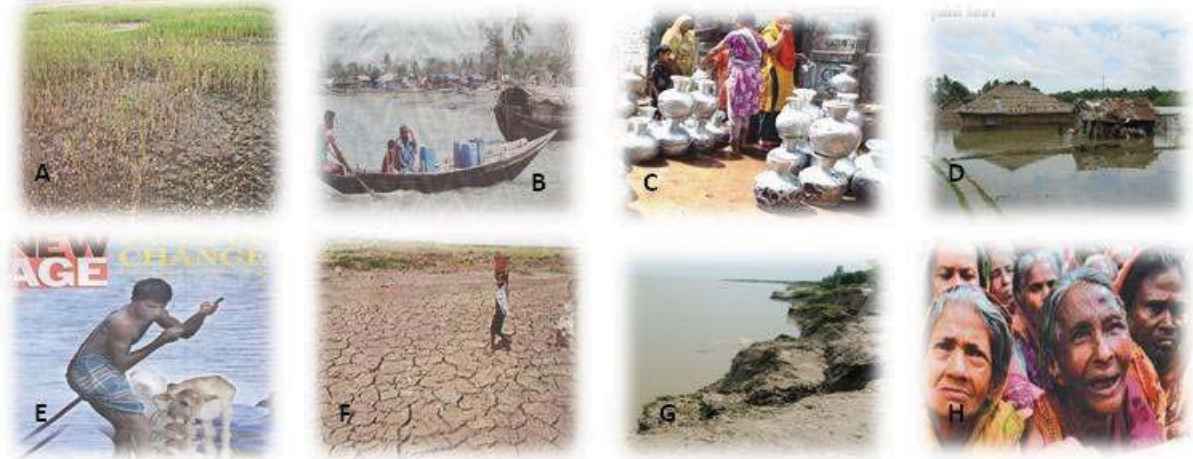


Figure 1.(A)Crop failure/burn, (B) Decreases of fresh water availability, (C) Scarcity of drinking water, (D) Tidal bore (E) flood, (F) Drought, (G) Erosion and zone changes, (H) Loss of food security and climate refugees.

4. CONCLUSION

The impacts due to climate change and sea level rise is soaring even though the emission of greenhouse gas by Bangladesh is low. Multidisciplinary planning and research works is needed to be incorporated into the management, adaptation and mitigation strategies in this country. Some could be as follows:

- a) Research on salinity level in soil and water in the coastal area of Bangladesh is needed urgently prior to ensure the sustainable planning for coastal wetland and agriculture land.
- b) Saline/drought tolerates rice could be introduced in the area effected by saline water/drought condition which had been cultivated 2 decades ago in the costal area of Bangladesh.
- c) Coastal land could be brought up or accreted using the flow of tidal water (Integrated Water Management, 2010) [For example, by using this process 31.32 km of land is being made higher in the Southwest coast (Bill Vienna and Bill Dakataia) of Bangladesh. This process of technique is called TRM (Tidal River Management). It is also assumed that using TRM, the management of siltation or settlement of total solid could enrich in the river area of Bangladesh which could eventually use as a counter acts against sea level rise.]
- d) Introducing new technologies for floating vegetable cultivation on the drift of water lily in the low lying area;
- e) Introducing mud crab and fish culture in the saline infected area which could help to income generate activities for the coastal communities.
- f) Coastal abandon land of shrimp pond could plan for green growth program through planting mangrove and salt marsh to combat the impacts of climate changes and sea level rise.

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RAINFALL VARIABILITY AND ITS IMPACT ON WATER RESOURCES IN HIMALAYAN HEADWATERS: NEED FOR LONG-TERM ADAPTIVE AND INTEGRATED WATER RESOURCE MANAGEMENT AND GOVERNANCE POLICY

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Abstract: Long-term changes in precipitation pattern are disrupting hydrological system of Himalayan headwaters through reduced groundwater recharge. Main objective of the study is to analyse rainfall variability in long-term perspective, and assess its impacts on headwater hydrological system with a case illustration of Kumaon Himalaya, India. Methodology included interpretation of long-term meteorological data, monitoring of water discharge in springs and streams, assessment of impacts of hydrological changes on water resources, and evolving policy planning framework for integrated water resource management. Results indicated that number of rainy days and amount of annual rainfall decreased, water discharge in streams and springs has diminished and natural springs and streams dried. Consequently, availability of water for drinking and irrigation declined, and food production decreased. An adaptive, integrated and community based water management policy planning framework has been evolved to enhance the efficiency and resilience of water sector to rainfall variability.

Keywords: *Water resources, Food deficit, Policy planning framework, Traditional water management system, Climate change adaptation strategy*

1. INTRODUCTION

Himalaya forms the tallest water tower of the world which constitutes the source of some of the major rivers of South Asia. Changing precipitation pattern has stressed the Himalayan rain-fed headwater ecosystem (ICIMOD 2007; IPCC 2007; Tiwari and Joshi 2012). These changes are disrupting hydrological regime of Himalayan watersheds through reduced groundwater recharge and drying of natural springs (Oki 2003). As a result, the regime of water resources is changing fast with respect to discharge, volumes and availability impairing basic ecosystem services, particularly drinking water and irrigation in both mountains and down-streams. This is increasing the vulnerability of large population dependent on subsistence agriculture to water, food and livelihood insecurity, in large part of south Asia which includes some of the poorest people of the world with access to less than 5% of planet's freshwater resources (Virioli and Weingartner 2003). It is therefore highly imperative to identify potential response strategies to respond these changes through evolving and implementing integrated water resource management and governance policies at local level.

2. OBJECTIVE

Main objective of the study is to analyse rainfall variability in long-term perspective, assess its impacts on headwater hydrological system and status of water resources, and evolve framework for guiding policy planning for integrated water resource management and governance at watershed level with a case illustration of Kumaon Himalaya, India.

3. METHODOLOGY

The study was carried out in the headwater of Kosi River – a rain-fed watershed – which encompasses a geographical area of 105 km² (3500 ha) between altitude ranging between 1425 – 2650 metre, in Kumaon Lesser Himalaya, India. The relevant data was generated through field based empirical observations, surveys and mapping; and monitoring: Long-term meteorological data was collected for the analysis of rainfall variability, and number of rainy days and amount of rainfall have been taken into account for the interpretation of changes in rainfall pattern. Information pertaining to the availability and status of water resources was collected through long-term hydrological monitoring of water discharge in springs and streams. The policy planning framework has been evolved in consultation with local communities, government agencies, civil society organizations and non-governmental organizations, and in light of the scientific findings of the research carried out in the region.

4. RESULTS AND DISCUSSION

The interpretation of hydro-meteorological data brought out the fact clearly that the number of annual rainy days have declined from an average of 60 days to nearly 50 days with a few exceptions. Consequently, the amount of annual rainfall had decreased from average 140 cm to approximately 115 cm and frequencies of dry

spells and flash floods increased respectively by 21% and 27% during the last 50 years. The water resources of the watershed are diminishing and depleting fast mainly due to reduced ground water recharge. These hydrological imbalances are clearly discernible in terms of: (i) long-term decreasing trend of stream discharge, (ii) drying of streams, and (iii) diminishing discharge and drying of springs. As a result, the water flow in streams and springs has diminished drastically which is clearly indicated by the observed trends of water discharge of the main river of the watershed – Kosi. The river showed a continuously declining water discharge between 2000 and 2011 except in the year 2007, and a stream-length of approximately 5736 m comprising mainly first order tributary streams of Kosi River have completely dried during the last 50 years. Further, it was investigated that nearly 34% and 11% natural springs have gone dry and become seasonal respectively primarily due to decreasing trend of rainfall and declining groundwater recharge. More than 61% villages have been facing great scarcity of water for all purposes in the region. Consequently, the availability of drinking water reduced (10%), and the irrigation potential has declined by 25% mainly owing to decreased ground water recharge and drying of springs and streams, and consequent decrease in the availability of water into the irrigation system during the last 50 years. These hydrological changes have unprecedented adverse impact on the agricultural productivity in the entire region. The productivity of agriculture has declined by nearly 25%, and per capita food productivity has shown a continuously decreasing trend during the last 50 years. As a result, the different settlements in the catchment are facing a food deficit of more than 55% (Tiwari and Joshi 2012).

In view of this, an adaptive, integrated and community based water management and governance framework has been evolved to guide long-term policy planning at watershed level (Tiwari and Joshi 2012). Attempts have been made to institutionalize water resources management through reviving and strengthening traditional water management system and existing participatory resource governance mechanisms and for building of grass roots institutions. Water Resource Management Committees (WRMCs) have been constituted in each of the 61 villages of the headwater. Provisions were made for the development of ‘Spring Sanctuaries’ around the springs and sources of streams by (i) planting water conserving trees, (ii) rainwater harvesting, (iii) conservation of water by constructing mud ponds, (iv) building of check dams on the streams for reducing run-off, (v) treatment of stream-catchments through afforestation, (vi) conservation of forests through reforestation, protection and regulated resource utilization, (vii) rehabilitation and development of waste and degraded lands through plantation of energy and fodder species, horticulture and cultivation of tea and medicinal plants, and (viii) improvement in traditional agricultural system through altering cropping pattern, adjusting crop rotation, cultivating abandoned land, relocating agriculture; and ensuring efficient utilization and equitable access to available water resources.

5. CONCLUSION

These observed changes in the precipitation pattern have increased the vulnerability of local communities to water and food security. The proposed water conservation framework is expected to regenerate and replenish depleting water resources through augmenting groundwater recharge, improving availability of water for drinking as well as for irrigation, and increase the productivity of food through strengthening traditional adaptation mechanisms. Hence, in order to reduce the vulnerability of marginalized mountain communities to climate change and resultant food and livelihood insecurity the proposed water management and governance framework should constitute one of the core components of climate change adaptation strategy in the region. The policy framework could be translated to other marginalized mountain ecosystems for enhancing the resilient and adaptive capacity of natural, social, economic and political systems to long term impacts of climate change.

6. ACKNOWLEDGEMENT

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IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES AND RICE PRODUCTIVITY IN DROUGHT PRONE AREA OF BANGLADESH

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Abstract: The management of water resources has become a critical need in Bangladesh because of growing demand for water and increasing conflict over its alternative uses. The aim of this study was to understand the impact of climate variability and change on irrigation water resources and rice productivity in drought prone area of Bangladesh. The main source of irrigation water during the last decade became groundwater. Nowadays, agricultural water management is under tremendous pressure due to climate change such as arsenic pollution and salinity in many locations, particularly in drought area. The long-term (1960-2009) CRU data of drought prone area in Bangladesh were used to analyze standardized precipitation index (SPI) and diurnal temperature range (DTR) for understanding drought condition over time. It was also observed that the seasonal distribution of rainfall in terms of SPI and variation of temperature in terms of DTR during *aman* rice season accounted for 41% yield variability. Therefore, to sustain rice production in drought prone area, it is urgently needed to manage irrigation water under changing climate.

Keywords: Water resources, Rice productivity, Drought, SPI, DTR

1. INTRODUCTION

Bangladesh is a low-lying riverine country located in southern Asia, covering a total area of 144000 km² having over 1000 person per km² (BBS 2010). As populations expand and make various uses of water, its growing scarcity becomes a serious issue in developing countries such as Bangladesh. The management of water resources has become a critical need in Bangladesh because of growing demand for water and increasing conflict over its alternative uses.

Irrigation is a prerequisite for agricultural cultivation during the dry season because during this season rainfall is considerably lower and without irrigation crops could not survive (Asiatic Society of Bangladesh 2006). *Boro* the dry season rice covers most of the rice production in Bangladesh. The development of irrigation infrastructure has contributed to the expansion of *boro* rice in both the traditional *aus* and the deepwater *aman* areas (Khan 2011). The Intergovernmental Panel on Climate Change (IPCC) estimates that by 2050, there will be changing rainfall patterns with increasing temperatures, flooding, droughts and salinity that would cause decline in rice production in Bangladesh by 8% and wheat by 32%, against 1990 as the base year (CCC 2009). The recent estimates using different models with changed assumptions predicts for 2050 reduction in production by 1.5-25.8% for *aus* rice, and 0.4-5.3% for *aman* due to effect of high temperature. The aim of this study was to understand the impact of climate variability and change on irrigation water resources and rice productivity in drought prone area of Bangladesh.

2. RESULTS AND DISCUSSION

Irrigation is considered being a necessary precondition to enhance agricultural production of Bangladesh (Fig. 1). Under a climate change situation with increased temperature, evapotranspiration will increase and the river system will suffer during dry months due to acute low-flow condition. Consequently, the dry season water demand for irrigated agriculture, salinity control, and stream flow maintenance will increase significantly leading to increased shortfall of water supplies. Groundwater became the major source of irrigation water during the last decade, which is being decreasing (0.1-05 m year⁻¹) in the study area. There is a question of risky overdependence of utilizing groundwater due to quality constraints and some emergent environmental consequences. Some challenging issues in relation to agricultural water management, like arsenic pollution, climate change, salinity, have been encountered nowadays in many locations, particularly in drought area. Arsenic contamination of groundwater within 59 out of 64 districts of the country has been reported. The arsenic concentration has been found maximum within the upper 50 m depth of aquifers in most regions (Fig. 2).

The long-term (1960-2009) CRU data of drought prone area in Bangladesh were used to analyze standardized precipitation index (SPI) and diurnal temperature range (DTR) for understanding drought condition over time. The data revealed that monsoon rainfall showed increasing trend, while rainfall has been decreasing during dry season indicating prolonged drought. Both maximum and minimum temperatures showed increasing trend. However, the increment rate was higher in case of minimum temperature than maximum (Table 1). The SPI indicated that frequent dry and wet conditions were prevailed in the study areas, while DTR showed decreasing trend. It was observed that rice productivity index and seasonal SPI have insignificant relationships. However, the relations are relatively strong during *aman* rice season (July to October). On the other hand, the relationship between *aman* rice productivity index and seasonal DTR was strong and significant ($P < 0.05$).

Generally DTR adversely influences the rice productivity by accelerating evapotranspiration and hampering physiological processes. It was also observed that *aman* rice productivity index and seasonal SPI and DTR have significant ($R^2 = 41$) multiple regression at 0.05 level of significance (Table 2). It indicated that the seasonal distribution of rainfall in terms of SPI and variation of temperature in terms of DTR during aman rice season accounted for 41% yield variability.

Table 1. Seasonal variation (SV) and decadal change (DC) of rainfall and temperatures over the period of 1960 to 2009

Parameter	Annual		March to June		July to October		November to February	
	SV	DC	SV	DC	SV	DC	SV	DC
Rainfall (mm)	1540.78	38.63	503.05	15.61	1008.16	21.49	29.56	0.15
MaxTemp (°C)	31.61	0.065	34.84	-0.014	32.31	0.097	27.67	0.099
MinTemp (°C)	20.73	0.209	22.88	0.198	25.06	0.104	20.73	0.312

Table 2. Rice, wheat and potato productivity index and seasonal SPI and DTR relationship regression equations and statistics (R^2 and SE) for different regions

Region	Regression equation	R^2	SE
Rice- <i>aus</i>	$RPI = 17.012 + SPI_i(0.8089) + DTR_i(-17.2472)$	0.14	5.521
Rice- <i>aman</i>	$RPI = 12.921 + SPI_i(-8.45) + DTR_i(-23.088)$	0.41*	3.760
Rice- <i>boro</i>	$RPI = 10.22 + SPI_i(-12.52) + DTR_i(-6.894)$	0.10	3.625

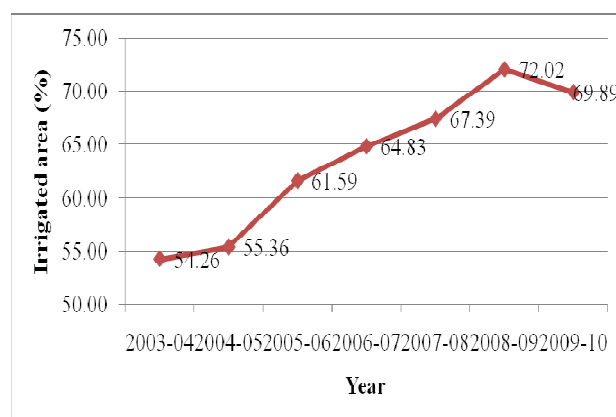


Fig. 1. Increasing demand of irrigation water mainly groundwater

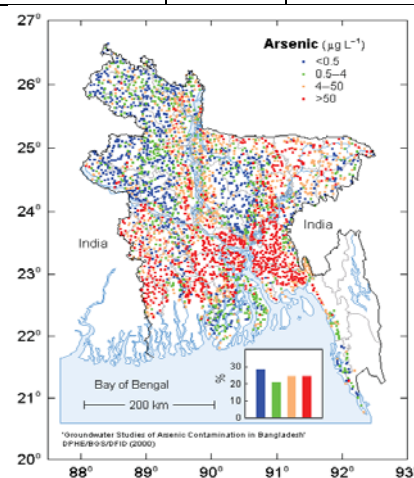


Fig.2. Arsenic contamination in Bangladesh

3. CONCLUSIONS

Careful consideration should be given to these environmental issues in order to harness the beneficial uses of irrigation water comprising both surface water and groundwater resources. It was observed that rice productivity was significantly affected by SPI and DTR during *aman* season and the yield variability was 41% in the recent years. These indicate that crop productivity would be hampered adversely in future if proper adaptation and mitigation options are not taken. Therefore, to sustain rice production in drought prone area, it is urgently need to develop new policy and drought tolerant varieties which would be helpful to manage irrigation water under changing climate. Policy maker, development worker, researchers, academicians and farmers should be engaged in water management activities.

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COMMUNITY FOREST OF NEPAL: HOW IT MAINTAINS ECOSYSTEM SERVICES AND COPES WITH GLOBAL WARMING?

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Abstract : *Community forestry of Nepal is providing different environmental services such as biodiversity conservation, water conservation and regulation, soil conservation, livelihood for poor people and carbon storage from the past 30 years. This poster tries to describe how the community forest is enhancing different environmental services and contributing to mitigate climate change and enhance green economy in local level.*

Keywords: *Community forest, Livelihood, Global warming, Climate change.*

1. INTRODUCTION

Nepal is a small country lies in Indian sub continent between China and India. The total area of the country is 14.7 million hectares and the total population of the county is 26 million (CBS 2005). Community forestry is a participatory forest management system in Nepal which is started from 1970s decade. Community forests are national forests handed over to the local user groups for protection, management and utilization according to the Forest Act, 1993 Till date 15,500 community forest is managing directly from the 1.5 million people which is about one third of households of Nepal are involved in managing the forests (DoF, 2011). Community Forest is considered quite a successful in terms of improving the condition of forests and people in Nepal. Community forestry aim primarily to fulfill the basic forestry product needs such as firewood, timber, fodder and leaf litter for compost-making (MPFS, 1989). Community forestry has been advocated by many practitioners as an important management model to achieve the twin objectives of forest conservation and livelihood security (Malla 2000, 2003, Gilmour et al. 2004). Perspective of payment for environmental services (PES) is a new thematic area of discussion in community-based forestry in Nepal. Forests can play an important role in regulating hydrological flows and reducing sedimentation. Forests are commonly associated with a range of environmental services delivered at watershed scale including regulation of water flow that is, maintenance of dry season flow and flooding control; maintenance of water quality, that is, minimization of sediment load, nutrient load, chemical load and salinity; control of soil erosion and sedimentation; reduction of land salinalization and/or regulation of ground water level (Bishop et. al., 2004). Nepal is vulnerable to several types natural disasters, including droughts, flood, landslides, windstorms, hailstorms, cold waves, disease epidemics, glacial lake outburst flood, fire and earthquakes, climate change, global warming.

2. DISCUSSION

Community forestry of Nepal are providing several environmental services provided such as provisioning services, regulatory services, cultural services, supporting services, biodiversity conservation, water purification and regulation, soil erosion protection, forest recreation and carbon storage are gaining some attention and need to protect the future of the forests linking commercial market and climate change adaptation and mitigation issues activity to conservation objectives from past 30 years.. In the case of Nepal, according to research more than 90 % people lives in village and around 31 % of current population lives below the poverty line and 72 % of these individual are forest dwellers, largely compromised of indigenous ethnic groups (Dhital et al 2009) and these people livelihood is heavily depend upon forest due to several reasons such as fuel wood, fodder, timber, non timber forest products. Government of Nepal is trying to enforce different climate change mitigation strategies such as Payment for Environmental services and Reducing Emissions from Deforestation and Degradation program. The forest certification is one of the tools for the forest management which is proving jobs in to the local people. Total 21 User Groups (CFUGs) with 14,086 hectors at Dolakha and Bajhang district received FSC forests management group certification covering 24 forest products where 4,695 household are getting directly getting benefit (Subedi 2005). On a global scale, land-use change and forestry mostly deforestation is estimated to account for 17.4 percent of anthropogenic GHG emissions; global transportation accounts for only 13.1 percent (IPCC 2007). Degradation of forests through logging, fire, disease and pathogens also contributes to CO₂ emissions. Nepal is one of the ten most vulnerable developing countries because of its geography, poor physical infrastructure and the low level of development of its social sectors (OECD, 2003). The temperature of the Nepal is increasing rapidly than other countries. Between 1977 and 1944, Nepal's average temperature rose at rate of 0.03-0.06 Celsius per annum, with a higher rate in the mountains than in lowlands (Shrestha et al. 1999). After hand over of forest to local community, the growing stock of forest has been improving increasingly. At time, the biodiversity of the resources has been increasing. There is also

increasing trends of the group fund. Rural poor are those who rely more heavily on natural resources to sustain their livelihood, the potential role of decentralization and community forest reforms can be remarkably effective to improve the livelihoods of the poor (Bene et al. 2009). The government of Nepal is developing different policy and management plan how can get more benefit from the community forest such as Payment for ecosystem services, Carbon market, Reducing Emissions from Deforestation and degradation plus, ecotourism, green jobs from the forest etc which can make direct benefit to the community people and helps to cope with climate change. Community forestry has been rewarded with US\$ 95,000 (approximately Rs 6.8 million) for reducing emissions in the atmosphere causing climate change through enhancement of carbon stocks and sustainable management of forests which was basically in the three watershed area and by comparing the carbon stock in 2009 and 2010 and these money are using for the different sources such as livelihood improvement, plantation etc (ICIMOD, 2011).

3. CONCLUSION

Community forestry program is very much suitable for the climate change mitigation and cope with the global warming. It has seen that community forestry is also providing different green jobs which can also lead to the sustainable development and green economy. The program such as REDD plus and PES mechanism is very much suitable for enhance more environmental services which is one of the best tools for climate change mitigation. The community forestry program is also contributing for the poverty reduction, it creates green jobs, provides sustainable rural development, ecotourism activities.

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APPLICATION OF CLIMATE INFORMATION ON IMPACT ASSESSMENT OF STREAM FLOW

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Abstract: The precipitation projections of 24 General Circulation models (GCM) from IPCC AR4 are used to investigate the impact of climate change on stream flows. The results show that higher level of stream flow in wet period and lower level of stream flow in dry period are discernible. The variability of projected rainfall is consistent with that of simulated stream flow. Similar strategies can be applied to the seasonal forecast datasets of GCMs to deal with the issue of seasonal forecast of water resources.

Keywords: Climate change, Stream flow, Statistical Downscaling

1. INTRODUCTION

The impact assessment of climate change on stream flow is a critical issue for hydrologists. Specifically, hydrologist always keen to know how the stream flow change in the future scenario and how to manage/ mitigate this impact are crucial for hydrologic designs, reservoir operations and disaster reductions.

In this study, the rainfall-runoff relationship is modelled by the Generalized Watershed Loading Functions (GWLF, Haith and Shoemaker, 1987) using historical data from gauges in the Danshei and Tsenwen catchments. With an A1B scenario, GCM models are statistical downscaled and provide the precipitation ratios and the differences in temperature in the future scenarios. Again, the downscaled data were applied to GWLF to simulate stream flow in the future scenario.

2. METHODS AND MATERIALS

The statistical downscaling data were provided by Aphrodite (Asian precipitation Highly Resolved Observational Data Integration Towards Evaluation) with a spatial resolution of 0.25°. This data set has been bias corrected. For more detail about Aphrodite, please find in <http://www.chikyu.ac.jp/precip/index.html>. In total, 24 GCM models provided by IPCC were collected in this study.

The precipitation / stream flow data collected from gauges with the length of data records more than 20 years. For comparison purpose, the Thiessen's polygon method was applied to produce areal-average rainfall upon which the comparison between single gauge rainfall and areal-average rainfall can be made.

GWLF is a water mass balance model, which can be applied to single catchment. The components in GWLF model are precipitation, surface runoff, infiltration, ground water, ... etc. For more technical detail of the GWLF model, please refer to Haith and Shoemaker (1987).

For model evaluation, we used four indices which are Nash-Sutcliffe efficiency coefficient (NE), Pearson moment correlation coefficient (R), mean error ratio (ME_{ratio}), and total percentage of volume change (Δ). Among these indices, the NE and R close to 1.0 reveal that the model performs better while the lower ME_{ratio} and Δ represent the lower unexplained error.

3. RESULTS

The rainfall-runoff relationships modelled from the gauge data using single gauge rainfall and areal-average rainfall revealed no obvious difference (Table. 1). This result implied that if there are no multiple gauges in a small catchment for areal-average rainfall, using single gauge rainfall to model stream flow is sufficient.

In the assessment of change rate in precipitation and stream flow, the ensemble results of the 24 GCMs revealed that the change in precipitation rate ranged from -3%~5% in dry period and 4%~5% in wet period (Fig. 1).

Table 1. Evaluation results for various catchments.

Catchments	Single gauge rainfall				Areal-average rainfall			
	NE	R	ME_{ratio}	Δ	NE	R	ME_{ratio}	Δ
Peishih Creek	0.83	0.97	0.88	11.86	0.85	0.97	0.90	10.33
Nanshih Creek	0.38	0.97	0.64	36.09	-	-	-	-
Sanhsia River	0.86	0.96	0.84	16.02	0.79	0.93	0.84	15.83
Tahan Creek	0.86	0.94	1.00	0.22	0.84	0.96	0.90	9.61
Keelung River	0.32	0.72	0.85	15.03	0.83	0.97	0.87	12.64
Tsenwen Creek	0.98	0.99	1.01	0.84	0.97	1.00	0.90	9.96

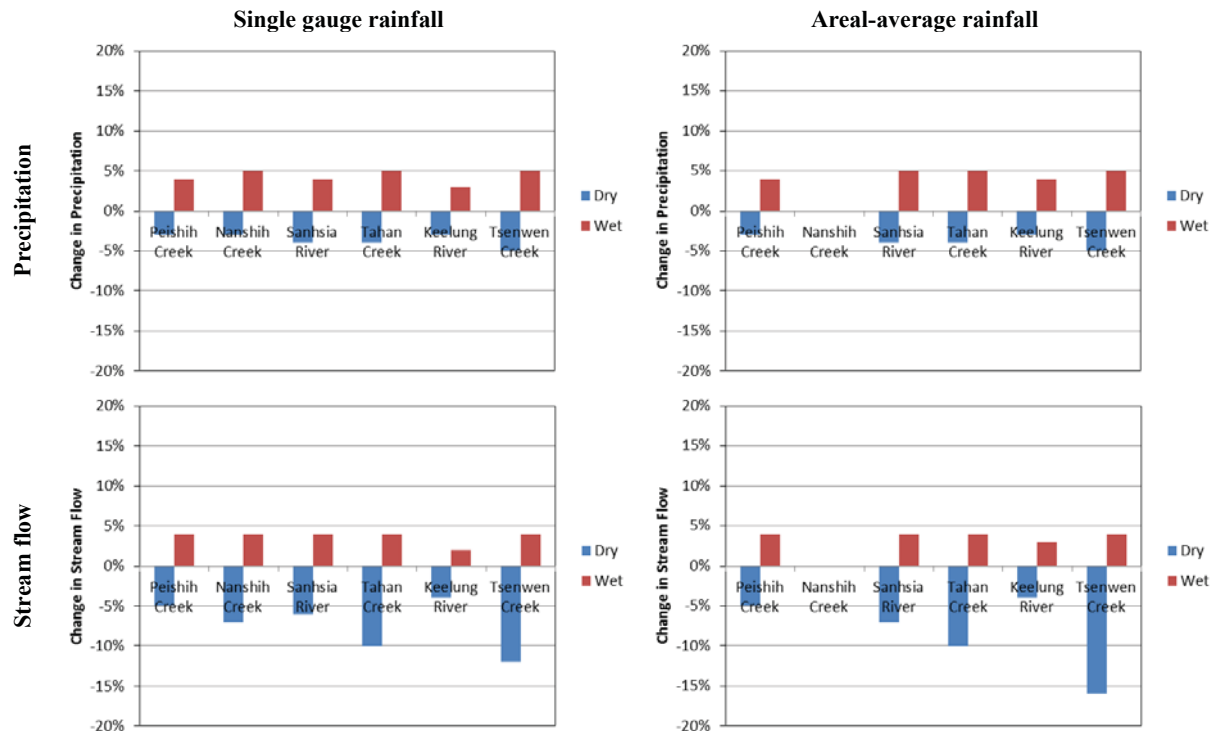


Figure 1. The change rates in precipitation and stream flow in the future.

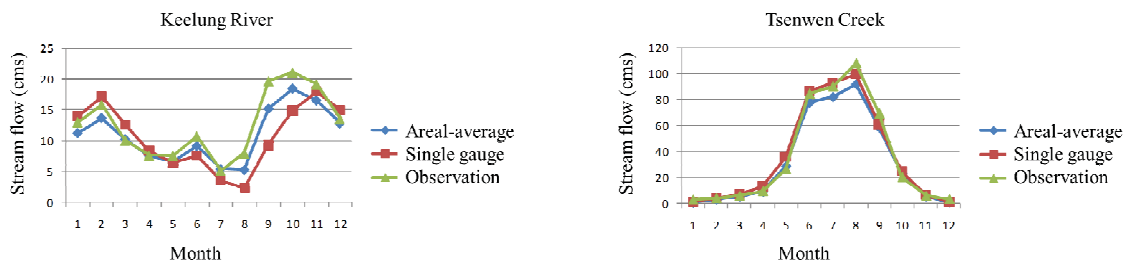


Figure 2. A comparison between simulated and observed stream flow. Left: Keelung River; Right: Tsenwen Creek.

With the precipitation information in the future, the GWLF was applied to simulate the stream flow in the future. Using two catchments as examples, the agreement of the simulated and observed stream flow were shown in Figure 2. In Fig. 2, it is clear that the GWLF simulated stream flow better with the areal-average rainfall in Keelung River catchment; while in Tsenwen Creek catchment the simulations of GWLF were closer to the observations with the single gauge rainfall (**Fig. 2**). With the simulated stream flow in the future, the change rates in stream flow were evaluated and it ranged from -4%~16% in dry period and 3%~4% in wet period (**Fig. 1**).

4. CONCLUSIONS

The stream flow simulated by GWLF modelled based on the precipitation information provided by the 24 GCMs were evaluated. This experiment was conducted in Danshei and Tsenwen catchments and the results shown that, in the future scenario (A1B), the stream flow decreased about 4%~16% in dry period while it increased about 3%~5% in wet period. This result suggested that hydrologist will encounter more severe challenges in water management and disaster reduction. Similar strategies can be applied to the seasonal forecast datasets of GCMs to deal with the issue of seasonal forecast of water resources.

Acknowledgement:

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CLIMATE VARIABILITY AND CHANGE IN BANGLADESH: A SPATIO-TEMPORAL ANALYSIS OF RAINFALL AND TEMPERATURE USING HISTORICAL DATA AND GIS

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Abstract: This study was an attempt to analyse the long term changes of temperature and rainfall over Bangladesh using the available historical data and geographical information system (GIS) over the time period of 1971-2010. The impact of climate variability and changes on agriculture and groundwater resources was also evaluated. The results show an increasing trend of mean, mean maximum and mean minimum temperatures and the temperature was increased predominantly over the last three decades than previous. Increasing rate of maximum and minimum temperature was higher in the central, southern and northern, north-western parts of the country, respectively. Though annual rainfall shows increasing trends, rainfall variability analysis shows that the rainfall is erratic during pre monsoon and very much erratic during post monsoon season. Due to climate change increase of winter temperature can reduce the environmental suitability for wheat, boro rice and other crops grown in rabi season and over abstraction of groundwater during dry season will create environmental problems.

Key Words: *Climate Variability and Change, Rainfall, Temperature, Climate Change Impact.*

1. INTRODUCTION

Due to the global environment change, the climate in Bangladesh is also changing and it is becoming more unpredictable recent years. Like many other countries, Bangladesh will face a tremendous challenge from the climate change. Among other sectors, its agriculture and water will face the deadliest experience from the impact of climate change such as floods, droughts, tornados, cyclones, tidal surges and soil salinities. Since Bangladesh is a primarily an agrarian and highly populated country, the development and planning works should be related to the climate change.

Intergovernmental Panel on Climate Change (IPCC) has reported in their fourth assessment report that global surface temperature increased 0.74 ± 0.18 °C during the 100 years ending in 2005 (IPCC 2007). It is also noted by the IPCC that the rise of mean annual temperature will be 3.3 °C per century (IPCC, 2007). Therefore, country level information about climate variability and change of Bangladesh is needed. In the past, a number of studies were carried out on trend of climate change over Bangladesh (Divya 1995, Mia 2003, Karmakar and Shrestha 2000, Rahman, 2012). It is essential to quantify the variation and changes of climatic parameters particularly the temperature and rainfall in recent years based on the historical data. Thus, this paper presented a study conducted on the long term changes of temperature and rainfall of Bangladesh.

2. DATA USED AND METHOD

Daily maximum and minimum temperature and rainfall data recorded at 35 meteorological stations of Bangladesh over the time period 1971-2010 were used. Trend analysis was conducted on annual average data for all the stations. Spatial distribution map was developed using inverse distance weighted interpolation technique and GIS. The coefficient of variation (CV) was used here to measure the rainfall variability. Trends, variability and spatio-temporal distribution pattern of the climatic parameters were compared with winter crops (wheat and boro rice), drought and ground water uses to assess the impact of climate change in the area.

3. RESULT AND DISCUSSION

The annual mean maximum, mean minimum and mean temperature of Bangladesh were 30.44, 21.21 and 25.83 °C, respectively during the period 1971-2010. The increasing trend of mean, mean maximum and mean minimum temperatures was 0.020, 0.022 and 0.018 °C per year, respectively for the last 40 years (1971-2010). The rate of change of temperature was more accelerated in the last 30 years (Table 1) and it is clearly found from Table 1 that maximum temperature was increased dramatically over the last 30 years period. Spatial pattern shows that increasing rate of mean maximum and mean minimum temperature was higher in the central, southern and northern, north-western parts of the country, respectively. It was also found that the mean temperature has increased more in the southern, south eastern and extreme north western parts of the county.

During the period 1971-2010, the average annual, pre-monsoon and post monsoon rainfall were 2387, 446 and 77 mm, respectively. In the trend analysis of rainfall data, increase in annual (7.13mm/year) and decreases in pre-monsoon (March-May, -0.75mm/year) and post monsoon (November-February, -0.55mm/year) rainfall were observed in the last 40 years (1971-2010). But the rate of change of rainfall was decelerated in the last 30 years (Table 1). Furthermore, variability analysis depicts that the rainfall was erratic during pre monsoon (CV=44.84%) and very much erratic during post monsoon season (CV=85.25%). The spatial pattern of annual

rainfall trends shows an increasing trend in the country except the western and central southern parts. Annual rainfall variability was higher in the north western, northern and eastern parts of the country (Figure 1b).

Temperature ($^{\circ}\text{C}/\text{yr}$)	1971-2010 (40 yr)	1981-2010(30 yr)	1991-2010 (20 yr)	2001-2010 (10 yr)
Mean	0.020	0.024	0.031	0.048
Mean Maximum	0.022	0.028	0.034	0.051
Mean Minimum	0.018	0.021	0.028	0.045
Rainfall (mm/yr)				
Annual Average	7.130	-5.616	0.005	-34.64
Pre-Monsoon	-0.750	-4.769	-2.567	-11.79
Post-Monsoon	-0.550	-1.296	-4.025	-1.283

Table 1. Trends of mean, mean maximum, mean minimum temperature and annual, pre and post monsoon rainfall

Predominantly Bangladesh is an agrarian country and produces several seasonal crops. In winter season (November-February), the main crops of Bangladesh are Boro (rice), wheat and potato. During the winter and pre-monsoon season (March-May) wheat and Boro mainly grow in the north, north western, central and eastern parts of the country (Figure 1c, 1d). Figure 1a shows that the trend of minimum temperature is higher in the north, north western and central parts of the country. Therefore, changes of climate (rising temperature) will severely decline the grown of various winter crops in these parts of the country. High rainfall variability is also an indicator of drought and therefore, these parts of the country (particularly the north western) are prone to drought hazard (Figure 1b). Consequently, the rate of use of groundwater for irrigation in this area is higher than that of the other parts of the country (Figure 1e). Climate change scenarios (rising temperature and high rainfall variability) will amplify to extract more groundwater during the dry season which may cause further declination of groundwater level in the area.

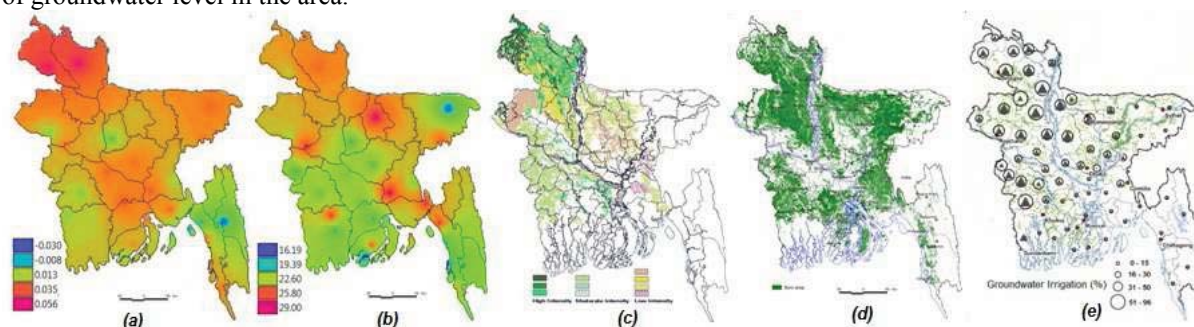


Figure 1. (a) Trends of mean minimum temperature ($^{\circ}\text{C}$); (b) rainfall variability (CV %); (c) wheat area distribution; (d) boro rice area distribution; and (e) groundwater-fed irrigation (as % of land)

4. CONCLUSION

In Bangladesh temperature is increasing and the rate of increasing is more during the last 30 years and central, southern, south eastern, northern and north western parts of the country are sensitive to climate change in respect to rising temperature. In contrast, though the annual rainfall shows an increasing trend during the period of last 40 years (1971-2010), the annual rainfall of the country is decreased over the last 30 years period. Pre and post monsoon rainfall also decreased in the country during the stipulated time period. Therefore, based on rainfall trends and variability the north western, northern and eastern parts of the country are very much susceptible to climate change impact. Therefore, agriculture can be affected more, drought situation will be prolonged and the use of groundwater for irrigation will be increased in these parts of the country by future climate change. Hence, agricultural practices, harvesting of surface water and optimum use of groundwater need to be incorporated into mitigation policies and programmes and, the government, the people of Bangladesh and international bodies will have to work together to face the future climate change impact.

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ASSESSMENT OF CHANGES OF ANOMALY TEMPERATURE AND EXTREME PRECIPITATION IN THE MIDLATITUDE ASIA-PACIFIC REGION

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Abstract: The dynamics of monthly and seasonal precipitation and air temperature of 25 meteorological stations located of Primorye and the Amur Region from 1966 to 2012 were investigated. Statistically significant changes of the extreme periods were analyzed. The possibility of use RegCM in determining the future of extreme periods were estimated. Change intensity (increases or decreases) in different part of regions were simulated. The spatial correlation coefficient between simulated and observed month and seasonal temperature and for month and seasonal precipitation were assessment. As a result the use of the results of RegCM simulation for future prediction of extreme periods of intensity precipitation and temperature is useful for choose adaptation strategies. Use a result of simulation future periods of precipitation can be relate to hydrological predictions, which can enable proactive planning and adaptive responses.

Keywords: *Climate, extreme events, temperature, precipitation, regional modeling*

1. INTRODUCTION

The development of the global numerical models considerably increased the accuracy of meteorological forecasts by the begin of the 21th century. The meteorological society achieved the most outstanding success in the short-range and medium-range weather forecasting methods are in progress for long terms (season and more) including those based on the use of ensembles of hydrodynamics models. However, the quality of such forecasts is not quite satisfactory so far due to the lack of understanding of physical formation mechanisms of various weather conditions and due to the unrepresentative global observational network. Moreover concerns regarding the changes in climate extremes are increasing. In last decade the frequency of periods with anomalous values of temperature and precipitation are increasing (Solomon et al, 2007). The study of the dynamics of regional rainfall and temperature is enable to better understand the statistical structure of these important meteorological indicators to identify trends change and develop solution to reduce the negative impact of abnormal periods on the functioning of natural and anthropogenic systems.

2. DATA AND ANALYSIS

The dynamics of monthly and seasonal precipitation and air temperature of 25 meteorological stations located of Primorye and the Amur Region from 1966 to 2012 were investigated. Anomaly temperature and precipitation are used in this study. Changes of anomalies temperature and precipitation were estimated linear trend. Statistically significant changes of the extreme periods were analyzed (Chernysheva, Platonova, 2010).

The trends of anomalies temperature with 95% of significance are significant for mostly weather stations especially for summer season. Only for 5 weather stations significant trends is less then 90 %. The number weather station with significant trends of extreme precipitation is much smaller than that for extreme temperature. The percentage of weather stations with significant trends is less than 15%.

The following regularities in the dynamics of the characteristics were estimated:

1. Cold half-year (November - April): on the Amur region no long-term trends. On the Primorye region from begin-1980's to the mid-1990's were more frequently observed extreme winters and a trend of intensity precipitation was decreasing. In recent decades, on the contrary, the frequency of extreme cold and snowy winters were increasing.
2. Warm half-year (May - October): from the mid-1990's to the present time in July, August and September periods of extreme low intensity precipitation and high temperatures were increasing. All trends of temperature are positive, the maximum increasing trends were found in August and September. All weather stations are currently located near or within such region as small towns and rural, so that the local urbanization is not contained in the quantified magnitude of trends, calculated in this study. Currently tendencies of global and local warming are similar. Positive trends of precipitation are observed at May and June.

3. SIMULATION OF THE CLIMATE WITH REGCM

The possibility of use the regional climatic model (RegCM) in determining the future of extreme periods was analyzed. The RegCM code base is actively developed by a community of developers internal and external to the International Center for Theoretical Physics (ICTP) (Gutowski et al, 2008; Krichak et al., 2011). Set of the simulations are realized with 25 km and 18 vertical levels space resolutions. The top of the model's

atmosphere is defined at 80 hPa. The model domain used covers parts of Asia-Pacific region (APR). The size and configuration of the model domain have been selected to allow a representation of main synoptic processes important for description of the APR climate.

In order to enhance capabilities for modeling future trends of extreme events, anomaly temperature and precipitation in observed database were compared with simulated data were investigated. The research base on the ERA-interim dataset comprise a large amount of reanalysis data, created by the European Centre for Medium-Range Weather Forecasts. (1.5°x1.5° resolution) and on the EH5OM dataset, for scenario IPCC A1B (1.875°x1.875° resolution, 17 pressure levels).

Of control run of the RegCM both simulations of temperature and precipitation in midlatitude eastern Asia was estimated. Change intensity (increases or decreases) in different parts of regions were simulated. The spatial correlation coefficient between simulated and observed month and seasonal temperature and for month and seasonal precipitation were assessment. Validation observed and modeling data of month and years with extreme temperature (minimum and maximum) from the «warm half-year period" 2000-2009 shown, that May, June and September modeling data less then observed data on the 2 – 4°C. July and August modeling data are more then observed data on the 2°C. Obtained result is very useful, in particular to improve understanding the future long-term scenario of trends extreme temperature. Unfortunately trends in precipitation extremes are more localized and that is a problem for good simulation of precipitations.

The changes of temperature and precipitation for June, July and August 2012 with using the RegCM were simulated. In Primorye the observed and model data for June and July 2012 were compared. As a result, in June and July of model data on air temperature were 2-4°C higher than the real ones. Precipitation was also higher to 20-30 mm.

4. CONCLUSIONS

Analyze future climate projection simulated by regional climate models may have potential to compare the observation data with modeled data and later use model outputs to fill the spatial gaps between observation sites. Furthermore, validation through the comparison allow us to project future directions of extreme climate events using climate model simulations from regional through global scales.

The above results improve understanding of the ongoing regional trends in extreme values. Regional climate model allows us to gain knowledge about the possible future directions of change. Modeling based on the IPCC A1B scenario show good results in predicting regional temperature trends. This will allow us to adapt the ongoing climatic changes have a major impact on various sectors of the economy including agriculture, forestry and fisheries, the coastal and marine environment, natural disasters, health and so on.

Use of regional climate model for simulation future periods of precipitation will be relate to hydrological predictions, which can enable proactive planning and adaptive responses, such as to seasonal water supply shortages. Future climate outlook are important to the urban and rural water industry, both for planning restrictions and for decisions on introducing new water sources. A particularly useful result of future research will be one that provides water utility companies with a way to predict where their storages will be at the end of the filling season. Extreme weather events can have a serious impact and advance warning will provide opportunities for improved allocation and use of water supplies.

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WATER RESOURCES MANAGEMENT IN INDIA UNDER A CHANGING CLIMATE

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Abstract: Changing climate has large impact on the water resources of India, threatening securities in water, food and energy and adversely affecting national economy. Water related health issues are worsening. Changing climate leads to social and economic issues related to water such as disputes over water allocation, migration to reliable river basins and urban centres, hiking cost of reliable water for domestic use and large investments required for adaptation and impact mitigation measures. In spite of this, India's preparedness for the effects of climate change is poor. Implementation of national policies related to climate and water is slow. Though several initiatives have been started in the water sector as part of adaptation, they often fail in fulfilling objectives because of issues like lack of coordination of departments, weak and corrupt administration, social issues and vested political interests.

Keywords: *Climate change, Water Resources, India, Adaptation, Policy*

1. INTRODUCTION

Managing water resources under a changing climate is a major challenge in India. With millions living in climate sensitive river basins and wetlands, India is one of the countries highly vulnerable to the impacts of climate change. Drylands of India are potentially threatened by desertification. Indian economy and life of the majority has been traditionally linked to agriculture, the largest consumer of water (91 %, followed by municipal use of 7% and industrial use of 2%, FAO (2010)). Abnormalities in rainfall seriously affect water availability and this is reflected in agricultural production and rural life. Extreme hydrological conditions affect hydropower generation and industrial development. States like Kerala that depends largely on hydro power are heading towards energy crisis (Mangalam, 2012).

2. CLIMATE CHANGE IMPACT ON WATER RESOURCES

Rainfall in certain parts of India is becoming more and more seasonal, creating seasonal floods and droughts. High seasonality also leads to wasteful runoff, reduced groundwater recharge and summer water shortage (Nair, 2002). Characteristics of the tropical storms in the Bay of Bengal and the Arabian Sea are changing (Niyas, et.al., 2009). Changes in their intensity, frequency and tracks results in coastal flooding, contaminating the coastal aquifers. Increased convective activity is observed in the Western Ghats Mountain region. Increasing seasonality and intensity of rainfall in this region results in erosion and sedimentation, reducing reservoir capacity and summer flow in rivers (Nair, 2011). Retreat of Himalayan glaciers is likely to have large impact on water resources in almost all parts of north India. The glaciers, which regulate the water supply to these rivers, are believed to be retreating at a rate of about 10-15m each year (WWF, 2005). All major rivers in North India originate in the Himalayan ranges. Many rivers of India have experienced dramatic changes in flow, reducing their natural ability to adjust to and absorb disturbances. Given expected changes in global climate and water needs, this may lead to loss of native biodiversity and risks to ecosystems and humans (Gosain et al, 2006).

Study using the water balance model of Thornthwaite & Mather (1955) modified by Nair (1987) reveals that the present per capita availability of the water surplus for the country as a whole is 2150m³, if fully utilized. In two decades from now, at the current rate of growth of population and with the predicted increase in global temperature, the availability will be drastically reduced to 972m³. Even today some states have no surplus water from precipitation after meeting the requirements for evapotranspiration and soil moisture recharge. In almost all parts of India, seasonal water deficiencies show an increasing trend and the seasonal water surpluses show a decreasing trend. Rainfall increase may be considerable in the north-west India, but, it may be very low in the south and north, where the increase in precipitation may not be able to compensate for the reduction in soil moisture due to rise in temperature (Bhalme, 1997). The north-eastern States and the Bay Islands have high values of per capita availability. But, the very high growth rate of population in these regions will reduce the availability up to one-fifth of the present level by 2030.

Water related health issues in India also worsen when climate changes. Vector-borne and water-borne diseases extend into new areas. Malaria is likely to spread into almost one-third of the country in two decades, if predicted change in climate really happens (Bhattacharya et al, 2006). Seasonal floods and water logging contaminate the water resources and result in the growth of vectors. Every year, during the monsoon season more than 50 % of the population in the state of Kerala is affected by diseases such as diarrhea, dengue fever, chikungunya and Japanese encephalitis (Joseph, 2012).

Changing climate leads to several social and economic issues related to water such as worsening of water disputes, migration, pricing of water that is unaffordable to millions and large investments for the adaptation and mitigation. Failure in rural agriculture due to hydrological extremes promotes migration to already overpopulated urban centres. Thousands of farmers have committed suicide in flood-hit and drought-hit states of India during the last few years (Nair, 2010). Present economic growth also is likely to be haltered.

3. WATER RELATED POLICIES

India's preparedness for the effects of climate change is poor and India was too late to develop a climate policy (Hindustan times, 2007). National policies including water policy and wetland policies lack strong guidelines for the effective implementation. The revised draft national water policy (Ministry of Water Resources, 2012) is silent on key issues (Seth, 2012). Several initiatives have been started in the water sector as part of adaptation. National Action Plan on Climate Change in the water sector includes initiatives such as action plan for major rivers, water-harvesting measures, rejuvenation and revival of traditional water storage systems, regulation on groundwater extraction, community involvement in water resources management, implementation of flood-proofing measures and Drought Prone Areas Development Programme to improve agricultural productivity. However, they often fail in fulfilling objectives because of issues like lack of coordination of departments, weak and corrupt administration, social issues and vested political interests. Vulnerable groups are often neglected in the typical political setup. Projects lack transparency and accountability (Nair, 2011).

India urgently needs appropriate policies and adaptation strategies and an efficient implantation mechanism to face the climate challenges. A mix of traditional environment-friendly methods and modern technologies in water conservation and quality improvement could perform better. Disaster preparedness should be made an important component of climate change action plans, and better management practices and policies should be identified to reduce vulnerability of ecosystems. Farmers should be made aware of the new agricultural practices, new drought resistant or pest-resistant seeds, crop diversification, etc. Indirect adaptation options - legislative, technical, educational and behavioural - are also necessary. Changes in climate may be wisely exploited. For example, floodwater may be stored or diverted to dry zones or may be purified to make potable. Based on the shift in regional climate, region of farming, time of farming and type of crop may be changed. Fast decreasing availability of reliable water invites critical attention to problems relating to water resources development and management.

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CLIMATE CHANGE IMPACTS ON GROUNDWATER-DEPENDENT IRRIGATION SYSTEM IN NORTHWEST BANGLADESH

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Abstract: A study has been carried out to estimate the change in irrigation water demand and its impacts on groundwater-based irrigation in Northwest Bangladesh in the context of climate change. FAO-56 model is used to estimate irrigation water demand from reference evapotranspiration, percolation and seepage losses, water required for land preparation and irrigation periods under changing climate scenarios. The study shows that though there will be no appreciable change in total irrigation water demand, the climate change will increase the daily use of water for irrigation by an amount of 0.8 mm/day in the end of this century. As groundwater is the main source of irrigation in Northwest Bangladesh, higher abstraction rate of groundwater will cause negative impacts on already stressed groundwater resources.

Keywords: *Groundwater-dependent Agriculture, Climate Change, Irrigation demand, Bangladesh*

1. INTRODUCTION

Groundwater is the lifeline of irrigated agriculture in Bangladesh. Groundwater use in irrigation has increased both in absolute terms and in percentage of total irrigation, and therefore, it has emerged as an important factor for food security and poverty alleviation in Bangladesh in the recent years (Shahid and Hazariak 2010). At the same time, stress on groundwater of Bangladesh is increasing to meet the demand of growing population for sufficient food and water as a basic requirement to improve livelihood. It has been anticipated that rising temperature and spatio-temporal variations in precipitation due to climate change (Shahid 2011) will put more stress on groundwater-based irrigation system in near future. A study has been carried out in this paper to estimate the change in irrigation water demand and its impacts on groundwater-based irrigation in Northwest Bangladesh in the context of climate change.

The study area comprises 82 sub-districts of Northwest Bangladesh (Fig. 1a). Annual average rainfall in the area varies between 1,400 and 1,900 mm (Shahid 2010a). However, only less than 6% rainfall occurs during the irrigation period of dry season Boro rice (January to April) which is the lifeline of local economy (Shahid 2010b). Recurrent drought is a common phenomena in the area (Shahid 2008). Ever increasing ground water extraction for irrigation has caused the groundwater level falls to the extent of not getting fully replenished in the recharge season causing overdraft (Shahid and Hazariak 2011). The problem is becoming progressively more acute with the growth of population, extension of irrigated agriculture, climate change and other anthropogenic activities.

2. METHOD

FAO-56 model is used for the estimation of irrigation water demand from crop evapotranspiration, water required for land preparation, percolation and seepage losses of water from paddy field and effective precipitation. Modified Penman method is used to calculate reference evapotranspiration from climate data. Soil information is used to estimate the spatial distribution of percolation and seepage losses from the paddy field. Thornthwaite soil water balance algorithm is used to model the soil moisture deficiency to compute the water required for land preparation. Climate change modelling software SCENGEN is used to project the future change in rainfall and temperature in the study area. A temperature based crop phenology method known as degree-day method is used to model the change in rice growth period under increased temperature.

Average Boro rice cultivated area during the period 1998–2002 in North-western Bangladesh is used in the present study for the calculation of irrigation water requirement. Monthly climate data at seven stations situated in and around the study area are used to calculate the climate baseline (1961–1990). The changes in temperature and rainfall predicted by climate models are added with the baseline temperature and rainfall to compute the future change in the climate of the area. Soil map is used for the computation of seepage and percolation losses from paddy field.

3. RESULTS AND DISCUSSION

Climate models predict an average increase of temperature by 1.4°C in 2050 and 2.4°C in 2100. In case of rainfall, most of the climate models predict increased rainfall during the summer monsoon and decreased rainfall in winter. The change in Boro rice phenology under projected temperature shows that the total growing period of Boro rice will shorten to 136 days in 2050. The soil moisture deficiency in the biggining of crop

cultivation season shows that the water required for land preparation will increase from 119.1 mm in the base year to 145.7 mm in 2050. Evapotranspiration from the rice field will increase from 397 mm to 422 mm and the effective precipitation will increase from 132 mm to 187 mm during the irrigation period. The modelled values of crop irrigation period, evapotranspiration, effective precipitation and soil moisture deficiency for different soil groups are used to compute the change in irrigation water demand. The sub-district level map of projected irrigation water demand in 2050 is shown in Fig. 1b. The average values of predicted irrigation water demand in the different years are shown by graph in Fig. 1c. The result shows no appreciable change in irrigation water demand in the study area. The average value of irrigation water will change from 1,057 mm to 1,036 mm in 2050 and 1044 in 2100. It means that though the soil moisture will decrease and daily evapotranspiration will increase, there will be no major change in total irrigation water requirement due to the shortening of crop growing length and increase of precipitation. However, the climate change will increase the irrigation rate or daily use of water for irrigation. The increase of irrigation rate in 21st century in the study area is shown by a graph in Fig. 1d. In base years, an average of 1,057 mm water is used for irrigation for the time period of 125 days. In 2050, an average of 1,036 mm water will be used for irrigation in 136 days. Consequently the irrigation rate will be increased from 8.5 mm/day in the base year to about 8.9 mm/day in 2050 and 9.3 mm/day in 2100.

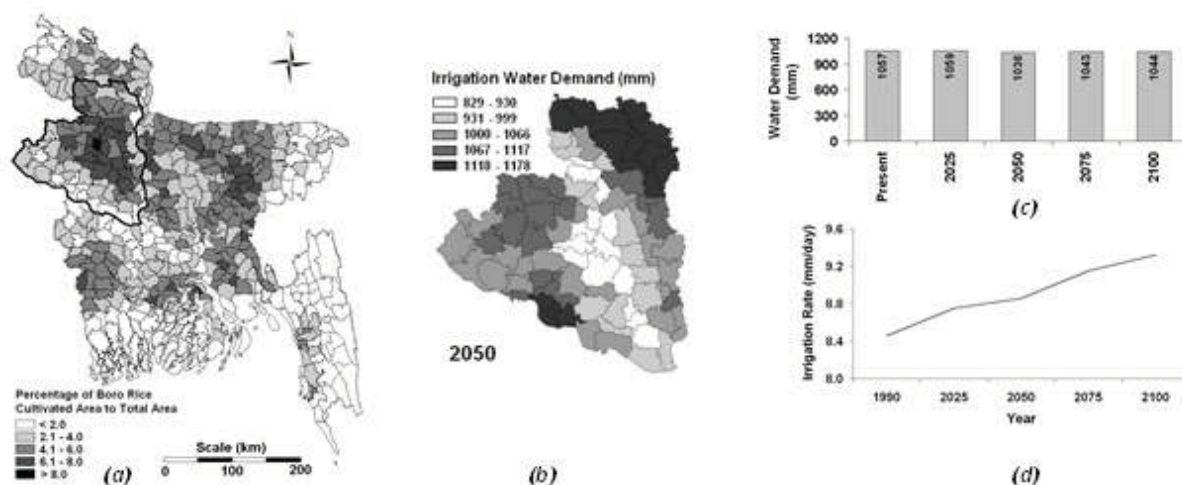


Figure 1. (a) Location of study area in Bangladesh; (b) spatial distribution of projected irrigation demand in 2050; (c) projected change in total irrigation water demand; (d) projected change in irrigation rate with time.

As there is a direct relation between groundwater level and pumping rate, higher per day abstraction to meet the irrigation requirements due to climate change during the peak dry season may cause further declination of groundwater level. Consequently, more energy will be required to sustain the yield of groundwater for sufficient irrigation. Therefore, higher rate of groundwater abstraction will certainly aggravate the situation of declining groundwater trend in the area. It may also cause an increase in production cost of rice and might hamper the government policy of poverty alleviation through irrigated agriculture.

4. CONCLUSION

Climate change will increase irrigation rate, hence abstraction rate of groundwater which in turn may cause negative impacts on groundwater resources in the region. The declining groundwater level will increase irrigation cost and economic losses of farmers. Development of surface water resources for irrigation is essential to reduce growing pressure on ground water. It is also essential to identify the best irrigation water management practices to increase the irrigation water use efficiency in the area.

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NATURAL FACTORS AND ANTHROPOGENIC IMPACT OF THE ESTUARIAL AREA OF THE AMUR RIVER RUNOFF FORMATION

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Abstract: Runoff is one of the main factors forming hydrological regime of the Amur River. Runoff changes analysis made possible to divide three periods: natural period with unchanged runoff (till 1974), period of intensive changes caused by construction of the Zeya Dam (1975-1982), period of damming controlled by Zeya Reservoir (1983-2002). These aforementioned changes of runoff for all observed periods reflect at large influence of the complex of economical and climate factors. In order to evaluate impact of the economic activity on the Amur river runoff the method of Shiklomanov was used. It is based on studying of annual fluctuations of hydrological characteristic in closing gate in aggregate with changes of runoff-forming factors and its indication on the background of an impact level of the all operating anthropogenic factors in water drainage basin area.

Key words: estuary; runoff; reservoir; climate factors.

1. INTRODUCTION

The Amur river estuary is situated near the confluence into the Amurskiy liman. The estuarial area has not overwater delta. In modern conditions the Amur is still forming delta (bayou and fairways of the Amurskiy liman), which is overflowed now [1]. The top of underwater delta is a section of the river near the city of Nikolayevsk-na-Amure which is located 48 kilometers far from the estuary zone. It is considered that the estuary section of the Amur River is a place of the river output into the Amurskiy liman – of the area between Tneyvakh and Nizh.Pronge capes.

Runoff is one of the main factors forming hydrological regime of the Amur River. Observations under the river runoff were started from 1933 in the top of the estuarial zone near Komsomolsk . Average annual runoff in the peak of the estuarial area is 343 cu. Km. per year (11000 m³/s), minimum annual water flow is 7140 m³/s, maximum peak is 15200 m³/s. The Amur river runoff differs by a rather big instability during all the year. The most part of runoff - about 90% of all amount - drops into the river channel in warm season (May-October). In winter the runoff is almost insignificant. In summer a period of minimum water flow is absent (Figure 1).

In a period till 1975 runoff of the Amur river has been seriously damaged by the constructions of the Zeya Hydroelectric Power station (Zeya Dam), and the Bureya hydroelectric power station (Bureya Dam) in further.

Runoff changes analysis [3] made possible to divide three periods (Table 1): natural period with unchanged runoff (till 1974); period of intensive changes caused by construction of the Zeya Dam (1975-1982); period of damming controlled by Zeya Reservoir (1983-2002).

Table 1. Changes of seasonal runoff parameters influenced by the natural factors and anthropogenic impact

Season	Periods of water runoff, m3/s			Water flow changes in periods, m3/s					
	Natural periods Q1 1934-1974	Period of intensive changes Q2 1975-1982	Damming period controlled by Zeya Reservoir Q3 since 1983	Period of intensive changes Qch=Q2-Q1			Damming period controlled by water-storage basins Qcon=Q3-Q1		
				m3/s	Anthropogenic impact, %	Complex influence of the natural and anthropogenic factors, %	m3/s	Anthropogenic impact, %	Complex influence of the natural and anthropogenic factors, %
Cold period (XI-IV)	3020	2340	3720	680	10,30	22,50	700	12,90	23,2
Warm period (V-X)	19300	15500	18200	3800	9,30	19,70	1100	3,60	5,7

As you can see on this table, during the intensive changes of the runoff, water discharge has declined by 19-22% towards to normal indexes of the same period. From 1983 the Amur river runoff characterized with

period of damming controlled by Zeya Reservoir: water discharge has declined by almost 23% towards to normal indexes in warm period. Significant runoff increase occurred in February and March when the lowest water flow has reduced almost twice in comparison with a natural period.

Since April 2003 filling of the Bureya reservoir started. Positive tendency of the damming is kept: winter runoff increased, summer – declined.

These aforementioned changes of runoff for all observed periods reflect at large influence of the complex of economical and climate factors.

In order to evaluate impact of the economic activity on the Amur river runoff the method of Shiklomanov[4] was used. It is based on studying of annual fluctuations of hydrological characteristic in closing gate in aggregate with changes of runoff-forming factors and its indication on the background of an impact level of the all operating anthropogenic factors in water drainage basin area.

Equations of regression are presented in the form:

$$Q_B = f(Q_1, Q_2, Q_3, Q_4, Q_5), \quad (1)$$

where

Q_B = water runoff in closing gate near Bogorodnoye village,

Q_1, Q_2, Q_3, Q_4, Q_5 = appropriate values of runoff in river basin for natural period (1934-1974).

The most reliable equations of regression are equations of this type:

$$Q_B = b_0 + b_3 Q_3 + b_4 Q_4 + b_5 Q_5, \quad (2)$$

where

Q_3, Q_4, Q_5 = water flow corresponding to estimate value in next hydrological sections: Selemdja river – Ust Ulma (Q_3), Bureya river – Kamenka (Q_4), river Tunguska – Arkhangelovka (Q_5);

b_0, b_3, b_4, b_5 = regression coefficients.

Due to this equations has been made an evaluation of the runoff changes which influenced by economic activity only (table 1).

Therefore runoff changes influenced by economic activity only contain about half of amount of changes that have been made under impact of the complex of natural and anthropogenic factors.

Amur waters undergo the pollution of industrial sewage and household runoff of factories that are situated mostly in the river downstream.

Estimation of the pollution level may be represented in the diagram form (figure 2), composed of annual observations data. The most typical pollutants in the Amur estuary – oil products and phenols, exceeded MPC (maximum permissible concentrations) in 60% of all observations. Pollution level of organic chemicals and SSAS (synthetic surfactants) is a few below than oil pollution but rather large. It exceeds MPC in 50% of all observations.

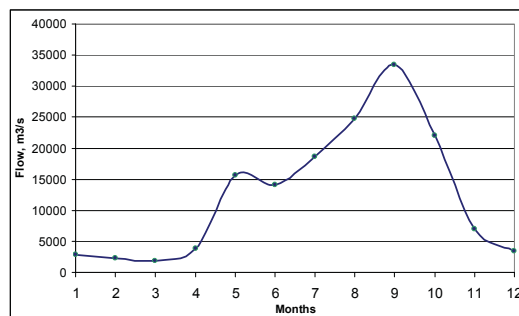


Figure 1. Annual distribution of the Amur River runoff.

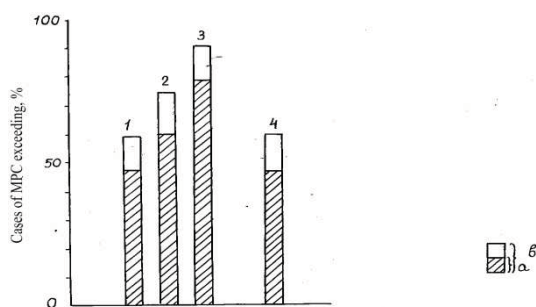


Figure 2. Characterization of the Amur river contamination by different pollutants near Nikolaevsk-na-Amure in the background section (a) and in the control section (b).

1 – BOD, 2 –phenols, 3 – oil products, 4 – SSAS (synthetic surfactants)

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THE APPLICATION OF CATASTROPHE THEORY TO THE POSSITIVE CLIMATIC TRENDS

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Abstract: The simple models of the catastrophe theory to apply to the world ocean are shown. Climatic control parameter is the spatial density gradient of the sea surfaces water. This is shown that a slow accumulation of control parameter may result to fast changing of the system structure. There are two examples of oceanic nonlinear dynamic systems - a jet current, a large-scale vortex. The control parameter for the jet current is the density gradient across the axis of the jet. The control parameter for the large-scale vortex is the spatial density gradient between the centre and at the periphery. The estimations of the critical value of the controlling parameters to lead the system collapse are demonstrated. The variational model interpretation of the steady condition as the minimum of entropy production is considered. The stationary steady condition of a system describes as the variational technique of the local potential

Keywords: *Climatic trend, entropy production, fold catastrophe*

1. INTRODUCTION

There are many of interconnected factors to influence the climate: variation of the planetary orbit, solar radiation, glaciers, atmospheric and oceanic impacts and man-made changes. This does not allow separating roles of every factor to the formation of the climatic trends. It is possible to describe a chosen physical process: climatic trend of the special gradient of the sea surface temperature - $grad(SST)$, entropy production in the World ocean, structural stability of the ocean currents.

The aim of the report is to show that the slow accumulation of thermodynamic parameters owing to climatic trends can cause a fast structural instability of ocean structures. The application of catastrophe theory to research the instability of the ocean jet currents is shown.

2. DATA AND THE CLIMATIC TRENDS

The SST is an inertial cumulative parameter for determining the climatic changes irrespective of some individual factors. There are the linear trends of the $grad(SST)$ for 1947 – 2010 years based on the Data Set of SST (Rayner, N.A., Brohan P.,...2006) to give the physical interpretation. For example (Kilmatov T., Trinko O., Dmitrieva E. 2012) the time climatic trend of a temperature gradient along the pole - equator direction (0^0 - 60^0) is presented in the Table 1.

Table 1. Trends of $grad(SST)$ in the North (NP) and the South (SP) Pacific

$\alpha = grad(SST) \text{ } ^0C/degree$	
February (NP)	$\alpha = 2 \cdot 10^{-5}t + 0.5347$
August (NP)	$\alpha = 4 \cdot 10^{-5}t + 0.3445$
February (SP)	$\alpha = 10 \cdot 10^{-5}t + 0.4081$
August (SP)	$\alpha = 7 \cdot 10^{-5}t + 0.4465$

The spatial gradient of temperature $\alpha(t) = grad(T)$ determines the intensity of climatic thermodynamic heat engine of the planet. In this case the parameter α is responsible for the available potential energy (APE) production. The APE and wind stress energy are sources of the kinetic energy (KE) in an ocean. We see that there is the climatic tendency of the gradient increase and an intensity of the KE production of the geostrophic currents (planetary scale) in the Pacific Ocean.

3. THE STRUCTURAL INSTABILITY OF JET CURRENTS

The small linear trends may create some illusion that the process of the climate change is the monotonic. The accumulation of properties can lead to structural instability and then to the fast change of the stationary climatic state. There is a simple modeling example based at the variation functional of the minimum entropy production (Glandsdorff P., Prigogine I.) and the catastrophe theory (Arnold V.I., Thompson J.M.T.). The modeling object is a steady climatic ocean jet to apply to the Kuroshio Extension. This area is the border between the subtropical and subarctic regions in the Northern Pacific. There are two climatic fronts – the density front of the Kuroshio Extension and the thermohaline Subarctic front. A variational stationary model is used

where a zonal channel on an f -plane with a fixed density difference on the southern and the northern borders is set. The geostrophic approach along the channel is carried out. The hydrostatics equation is applied to the vertical direction. The advection and turbulence forces across the channel are considered (Kilmatov T., 2008). The approximate analytical solutions are constructed by the direct variational method with the addition of the oceanographic information on physical fields. The convergence process across the channel is also set as a priori. The stationary solution shows that the width of the current is proportional to Rossby's scale. The model shows that the existence of the Kuroshio Extension may be limited by climatic factors. There is a critical parity between the north-south difference of water density, convergence, turbulence intensity, when the current is not a jet current anymore.

Some other way the same result follows from an integrated energy model using the catastrophe theory. There is a simple energy interpretation of a geostrophic current in reference to the Kuroshio. The stationary condition of the conservative system is defined by the minimum of the mechanical energy E : $E = APE + KE$, $E(L) = \min$. Here, L is the width of a geostrophic jet current. It is a single determining parameter. The stationary condition of the nonconservative system is defined as a minimum of the mechanical energy production. Finally, the model is reduced to the following cubic equation concerning unknown L ,

$$\left(\frac{L}{R}\right)^3 - \left(\frac{L}{R}\right) + g(\alpha) = 0. \text{ If } g_{crit}(\alpha) = \frac{2}{3\sqrt{3}}, \text{ then } L_{crit} = \frac{R}{\sqrt{3}}.$$

Here, R is scale of length Rossby, $g(\alpha)$ is any continuous function of the climatic parameters. If $g(\alpha) = 0$ then the current width is equal to scale Rossby, $L = R$. If there is a monotonous climatic increase of the function $g(\alpha)$ to the critical value, the width of current equals L_{crit} . When the parameter $g(\alpha)$ exceeds critical value, the cubic equation has no positive roots and it means that the jet current is destroyed. This is fold catastrophe in terms of bifurcation theory.

The full analogy to investigate the structured stability of the geostrophic vortex in the cylindrical coordinate system is shown.

4. CONCLUSIONS

Nonlinear theory shows that the gradual accumulation of some properties will lead the nonlinear systems to bifurcations and structural instability. This possibility has been shown when the physical ocean fields are smoothing. However marine data shows that the spatial SST gradient has the contrary tendency to increase.

Though these models do not forecast the future events but they have the heuristic value.

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EVALUATION OF WATER DEMAND-SUPPLY RELIABILITY BASED ON CLIMATE CHANGE SCENARIO IN HAN RIVER BASIN

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Abstract: The objective of this study is to evaluate the reliability of water demand-supply system based on climate change scenario. For this, Han River basin is selected as study area and RCP 8.5 scenario is used for considering climate change. SLURP model is used as rainfall-runoff model for calculating runoff in study area and water budget analysis is carried out during 2001~2099 using K-WEAP model. As a result, annual and monthly runoffs are steadily increased and the reliability of water demand-supply system is decreased by climate change impact in Han River basin. Especially, in 2090s (2081~2099), water deficit has increased by over 300% than now. From these results, water demand-supply management will become more difficult and the measures for improving water management efficiency will be very important for adaptation to climate change impact effectively.

Keywords: water demand-supply reliability, water deficit, RCP scenario, climate change, K-WEAP

1. INTRODUCTION

Because climate change is becoming a reality gradually, it is expected that the uncertainty of water resources management and the damage caused by flood or drought are increased (MLTM, 2010). Also, the hydro-meteorological characteristics, such as the biased seasonal precipitation and the spatial concentration of available water resources, are the reason that water resources management condition is very difficult in Korea. To overcome these problems, it is very important that the foundation of water resources management system is established to respond the expected situation by the understanding and analysis about hydrological cycle (Moon et al., 2011).

In this study, the evaluation of water demand-supply reliability considering climate change impact in Korea is carried out. For considering the change of hydrological characteristics in future, runoff simulation is done using climate change scenario (RCP 8.5). And then, the expected water shortage is analysed by water budget analysis using water demand-supply networks in Korea. For runoff simulation, SLURP (Semi-distributed Land Use – based Runoff Process) model, which is semi-distributed rainfall-runoff model, is used and K-WEAP (Korea Water Evaluation And Planning system) is used for the evaluation of water demand and supply. Annual and monthly mean runoff calculated from climate change scenario is compared with the status in present. Also, for the assessment of water deficit variation, water shortages expected in future are compared with the results of National Water Plan in Korea (MLTM, 2011).

2. STUDY AREA AND DATA

In this study, Han River basin is selected as the study area. This basin is the first major river basin in South Korea (Fig. 1). The basin area is 26,120 km², taking up 26.2% of the total area of South Korea. It is the river that flows from the east in mid-Korean peninsula to the west and into the sea. The Han River Regional District is composed of Han River's main stream basin and Imjin River basin. But this study will only deal with the Han River's main stream basin.

The Han River, which is one of the representative rivers of the South Korea, is mainly divided into the southern Han River and northern Han River that flows separately and then joins with the southern Han River, being the main stream. The Han River basin spreads across two metropolitan cities and four provinces. The Han River basin's shape is a combination of arborescent and fan shapes, and the topography is generally characterized of many ups and downs. The eastern part is high while the western part is low.

For this study, the meteorological data about



Figure 1. Map of the Han River Basin (MLTM, 2008)

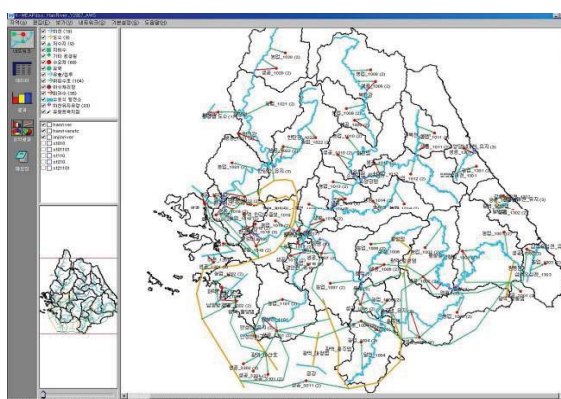


Figure 2. Water demand-supply network

climate change are collected from the CCIC (Climate Change Information Center) website (<http://www.climate.go.kr>) and the data from National Water Resources Plan in Korea (MLTM, 2011) are used for water budget analysis, such as water demand, dam operation rule, and so on. Fig. 2 shows the water demand-supply network in Han River basin constructed by K-WEAP.

3. APPLICATION AND RESULTS

Runoff is very important factor for water resources management because a respectable amount of water intake depends on the runoff in river. So, the uncertainty of runoff can have an important effect on water resources management plan in the future. Therefore, in this study, annual and monthly mean runoff from climate change scenario is compared with the status at present. Fig. 3 shows the comparison results of annual mean runoff. The simulated runoff in the future is increased more than at present and 2050s (2041~2060) is the biggest runoff. This pattern is confirmed in monthly mean runoff distribution (Fig. 4). In Fig. 4, mean runoff is increased most months in the future than at present. From these results, according to climate change scenario, the flood hazard can be increased in the future and the establishment of the valid measures is essential in Korea.

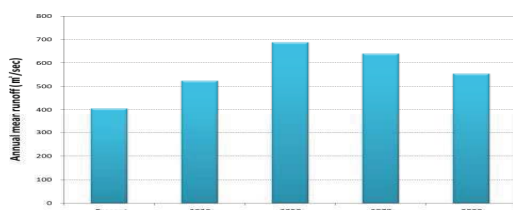


Figure 3. Annual mean runoff

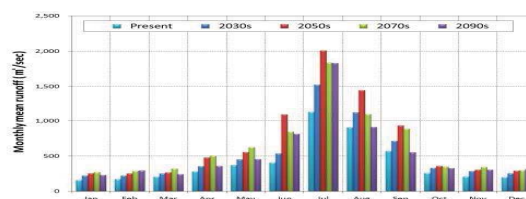


Figure 4. Monthly mean runoff

Secondly, the reliability of water demand-supply system in Korea is analysed by water budget analysis using K-WEAP model based on climate change scenario. Fig. 5 shows the water deficit by year in Han River basin. From this result, water shortage expects to be decreased between the mid-2030s and 2080, but since year 2082, water shortage is increased greatly. Fig. 6 shows the ratio of the future water deficit against the present and water shortage is increased by over 300% in 2090s (2081~2099).

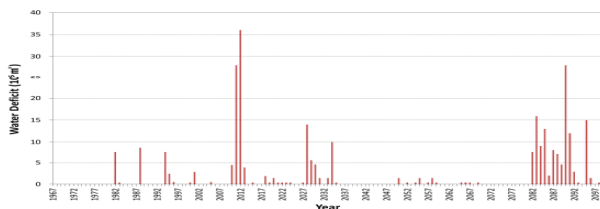


Figure 5. Water deficit by year in Han River basin

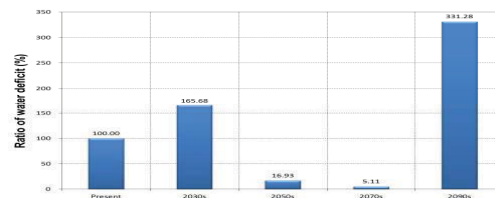


Figure 6. Ration of water deficit against the present

4. CONCLUSION

In this study, runoff in Han River basin is simulated by SLURP model using climate change scenario (RCP 8.5) and the reliability of water demand-supply is evaluated by K-WEAP model in the future. The results show that the runoff of Han River can be increased by climate change impact and the flood risk can be increased. Also, the water demand-supply reliability can be decreased by climate change impact. From these results, in the future, extremely wet or dry period can be repeated and water demand-supply management and flood management will become more difficult. Therefore, the measures for improving flood and drought management efficiency will be very important for adaptation to climate change impact effectively in Korea.

Acknowledgement:

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ASSESSMENT OF HISTORICAL RIVER FLOWS AND CLIMATOLOGY OF UPPER INDUS BASIN (UIB) AND TO DEVELOP RELATIONSHIPS BETWEEN RIVER FLOWS AND CLIMATIC VARIABLES IN UIB

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Abstract: Different hydrological regimes must be taken into consideration in planning, design, management and operation of water resources of River Indus as it is the life line of Pakistan. Upper Indus Basin (UIB) receives considerable amount of snowfall during winter season. Stream flow here is mainly due to melting of this snow. Glacier melt is also one of the major contributors in it. The snow and glacier melt stream flow is especially valuable because it occurs in the period of April, May and June before the monsoon rains. This early stream flow runoff is therefore available for irrigation, power generation and water supply at the time when there would otherwise be extreme drought. Proper and timely estimates of river flows and their relationship with climatic variables are essential to gauge the occurrence and intensity of floods which cause serious damages to crops, human beings and other infrastructures. For this, historical river flows and their relationship with climatic variables and snow and glacier melt is essential. In this study, different hydrological regimes of River Swat (an important sub-tributary of River Indus) are investigated by using different approaches i.e. Graphical approach, Regression analysis, Annual and Seasonal Correlations, Monthly Correlations of Runoff with rainfall and temperature and Serial Correlation Analysis. The Collective Month-wise Technique (a Regression Analysis technique) has been found a useful tool for River Swat Basin at Kalam for predicting flows in River Swat. This technique will also be validated and replicated on the other basins of UIB.

Keywords: *Climatology, river flows, Upper Indus Basin, linkages/ relationships, correlations.*

1. INTRODUCTION

As much of the flow abstracted from the River Indus for irrigation originates in the Himalaya, Karakoram and Hindukush mountains, an understanding of hydrological regimes of mountain rivers is essential for water resources management in Pakistan. The construction of large dams over Indus, Jhelum and Kabul rivers was aimed to provide storage to assure irrigation and power supplies at all times of the year. The water of these reservoirs comes from two sources: the melting of snow and ice and monsoon rainfall. Melted water supplies are most important in the first half of each year and rainfall assumes most important from the beginning of July. Therefore, the irrigation water supply necessary for maturing the Rabi crop and for planting the Kharif crop is derived from melted water. It is important to determine the comparative magnitude of this melted runoff.

According to David Archer 2002, past studies concentrated primarily on the role of seasonal snow accumulation based on surface measurements (De Scally, 1994) or on remotely sensed assessments of snow covered area (Rango et al, 1977; Dey et al; 1989). De Scally (1994) studied the Jhelum Basin and obtained high correlation coefficients between annual maximum snow peak water storage or total winter precipitation and annual runoff, whilst summer precipitation was of little use in estimating annual flow. Kolb (1994) showed, with reference to five gauged catchments the runoff generating mechanism and characteristics difference between catchments, which are predominantly, fed by glacial melt and those where runoff depends mainly on the melt of seasonal snow peak.

Many of river catchments lie in the most northern part of Pakistan. The climate here is arid and semiarid. Having high altitudes, these catchments receive a considerable amount of snowfall during winter season. Stream flow here is mainly due to melting of this snow. The snowmelt stream flow is especially valuable because it occurs in the period of April, May and June before the monsoon rains. This early stream flow runoff is therefore available for irrigation, power generation and water supply at the time when there would otherwise be extreme drought. It should be noted that snow-melt and glacier-melt continues in July and August, but usually by this time of the year there is an abundance of water from the monsoon, often so much water that there can be damaging floods.

By not having proper estimates and relationships of river flow and climatic variables and especially snow-melt stream flow relationships there is always a chance of floods which causes serious damage to crops, human beings and other infrastructures. A proper study therefore is required to understand and analyze the runoff regimes and its relation to the climatic variables to forecast the river flow at the proposed site. So here in this study, we chose River Swat initially for this purpose as it is an important sub-tributary of River Indus). It is fed by a combination of melt water from seasonal and permanent snow fields and glaciers and direct runoff from rainfall both during winter and monsoon season from July to September.



Upper Indus Basin of Pakistan

Source: APN report, 2005

2. METHODOLOGY

Data Acquisition

Hydro-meteorological data (Maximum and Minimum Temperature, precipitation and relative humidity data for the period from 1971 to 2000 have been hired from WAPDA Pakistan.

Data Analysis

Following approaches have been used for the data analysis.

- 1) Graphical Approach
- 2) Regression Analysis
- 3) Annual and Seasonal Correlation
- 4) Monthly Correlations of Runoff with rainfall and temperature and
- 5) Serial Correlation

3. RESULTS AND DISCUSSIONS

Graphical Analysis: The following major graphs have been developed over the data from 1971- 2000 by this approach:

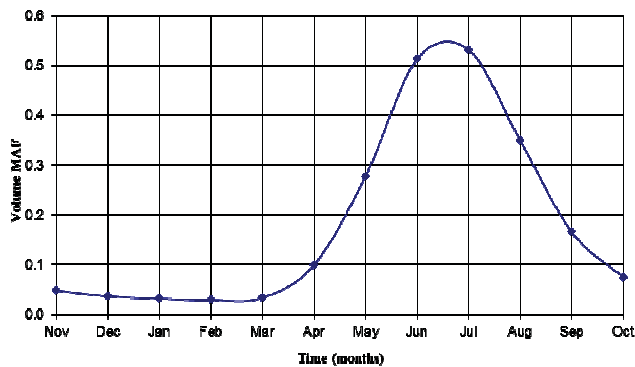


Figure-1: Normal Monthly Average Hydrograph for Swat River Basin

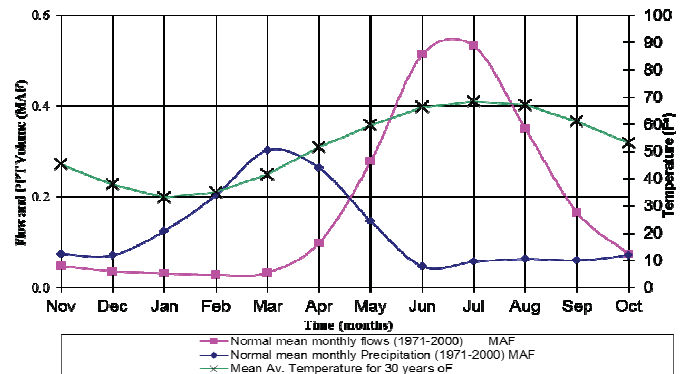


Figure-2: Linkage of variation of flow, temperature, and precipitation (1971-2000)

Regression Analysis: Two approaches of regression analysis (both for simple and multiple) have been used in this study. i.e. 1) Individual month-wise approach 2) Collective month-wise approach

Collective Month-wise Approach (Multiple Regression)

In this approach Multiple Regression Analysis has been performed for the whole normal year (30 years average) between river flow and climatic variables (temperature, precipitation and relative humidity) to estimate the flows and the following regression equations were developed:

$$Q = -0.697 - 5.9 P + 0.0132 T_{\text{avg}} + 0.00355 R.H.$$
$$R^2 = 77.7\% \quad (\text{Nov-Oct})$$

$$Q = -1.35 + 23.8 P + 0.0357 T_{\text{avg}} - 0.0105 R.H.$$
$$R^2 = 95.1\% \quad (\text{Apr-Oct})$$

$$Q = -1.17 - 10.3 P + 0.0159 T_{\text{avg}} + 0.00972 R.H.$$
$$R^2 = 93.9\% \quad (\text{Nov-May})$$

Thus these obtained equations can be used for prediction of flow if the future climatic data is known.

4. CONCLUSIONS

River flows in Swat River catchment are maximum in the months of June and July due to monsoon rainfall and snowmelt and are minimum in the months from November to March. There is a time lag of three months between precipitation peak and flow peak. A direct relationship between river flow and temperature and for river flow and relative humidity mostly inverse relationship has been observed. Collective monthwise data analysis technique for predicting flow in river is a useful technique for Swat River Basin at Kalam. In serial correlations better results were obtained but there were sharp discontinuities in correlation in the changeover months from accumulation to ablation and from ablation to accumulation.

This work will be validated and replicated for the other basins of UIB.

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ADAPTATION STRATEGIES FOR SAFE WATER SUPPLY IN THE DELTAIC COASTAL REGION OF BANGLADESH

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Abstract: This study examines why the salinity affected coastal regions of Bangladesh (destination path of the Ganges, the Brahmaputra and the Meghna Basin), particularly the Khulna and Bagerhat districts, have a scarcity of safe drinking water. Local people's perceptions are examined through community consultations, and baseline surveys are carried out. This paper determines that the most important factors are: salinity intrusion (from both human and natural causes), the local hydro geological condition, poor implementation of water supply management and surface water management in the polders, a reduction of upstream flow of water, and lack of strong policy and research initiatives for technological innovation. Accordingly, 3 model strategies for developing a more sustainable water supply are suggested: community based management, community water enterprise, and household demand based management. It is concluded that the solution is to update present policy initiatives (focusing on climate change adaptation), improve institutional capacity building, and consider climate change as a management challenge to be negotiated.

Keywords: Bangladesh, Climate change adaptation, Coastal area, Water supply, Water scarcity

1. INTRODUCTION

Water management in Bangladesh is a critical issue owing to growing demand for the resource and poor infrastructure, particularly in the country's low lying climate vulnerable coastal regions that border the Bay of Bengal (Chowdhury, 2010). The existing methods of water supply in Bangladesh remain very traditional. For instance, about 97% of the people in Bangladesh uses aquifers and hand pumped shallow tube wells as the main sources of drinking water. However, the coastal region of Bangladesh that comprises over 32% of the country's land mass but is inhabited by more than one fourth (28%) of the total population has limited fresh-water availability due to increased levels of salinity (BBS 2001).

This study aims to identify the factors that influence the shortage of water supply in the low lying coastal region in Bangladesh. The study also highlights possible solutions and adaptation strategies for low cost water supplies within the vulnerable coastal areas of Bangladesh, in the face of climate change. This study suggests three strategies that may assist in the implementation of technologies which could help to provide a more sustainable set of water supply systems in the coastal region of Bangladesh. These strategies include: the implementation of community based water management systems, formation of community water enterprises, and household water demand management systems. These strategies would need to be implemented by improving existing policy initiatives with a particular focus on community based climate change adaptation, institutional capacity building, and strengthening the initiatives of NGOs and local government institutions. The context for this discussion was based on extensive community consultations and baseline surveys in the affected coastal regions of Bangladesh.

2. DISCUSSION AND CONCLUSION

From experiences in many developing countries, even technologically very good water agencies cannot successfully operate and maintain a network of widely dispersed water systems without the full involvement and commitment of the users (Lammerink, 1998). To achieve this, the study suggests three model management approaches that could be used to minimize the water stressed condition to some extent at community level.

Community based management strategy

This approach can be described as a 'bottom-up' approach, in which the need for a management strategy is expressed and devised by the community. Once the specifications for the management system have been identified, the community may seek to gain financial assistance or advice from the government, NGOs or other funding institutions. For this strategy to be effective it is important to foster a sense of community ownership, this can be achieved by part-sharing the cost of technology and infrastructure (10-20%). An organized Village Committee should be made responsible for managing the facilities, recovery of the costs, operation and maintenance of the equipment (Figure. 1).

Community water enterprise

Under this model, a selected group of people within a poor community would have full ownership of the system. They would be responsible for the installation, operation, maintenance and management of the system. This community based water market would be a self-sustainable approach, as the cost of water would be within the purchasing power of consumers, and the loan taken to pay for this capital intensive technology would be recovered from selling water to the people. Once the payback period is over, the poor people involved in the business would own the technology involved (Biswas and Merson, 2005).

Household demand based strategy

In this approach or model, both household filter and rainwater harvesting tanks (RWHT) can be implemented to form a combined water supply strategy at the individual/household level. Under this model, GOs or NGOs can make necessary arrangements to provide the technology to interested people, who repay the loan as easy installation to micro-credit organizations (Figure. 2).

Based on the above findings, this study suggests and develops three strategies help to resolve these problems and to reduce communities' vulnerability to water scarcity and can create strong communities and user involvement by giving either a sense of ownership or operational responsibility of the water supply facilities to the community. Mainstreaming the ideas suggested in this paper through pilot programmes, practical demonstrations and information delivery to policy makers and water experts should also be an important consideration in order to update existing systems to support climate change adaptation in the grassroots level.

3. TABLE AND FIGURE

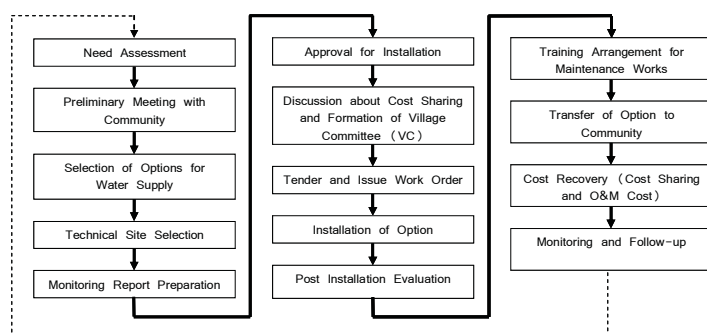


Figure 1. Implementation process of community based water supply system

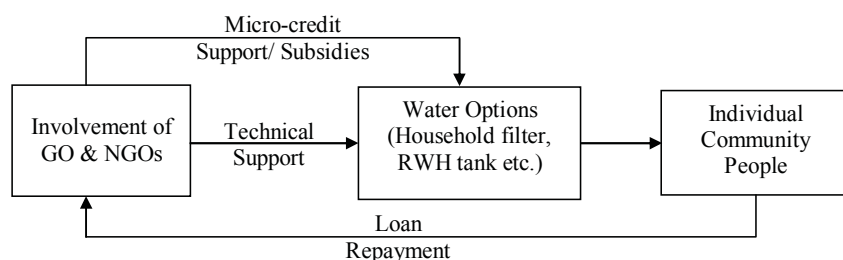


Figure 2. Implementation process of household demand based strategy

Acknowledgements: The authors acknowledge the support of the German Ministry for the Environment, UNEP, and UNESCO for providing the fellowship and support to carry out the research project. Special thanks to Prodiapn (NGO), Bangladesh Meteorological Department and Department of Public Health and Engineering for providing access to relevant data and information required for the study.

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STREAM RESERVATION ENCROACHMENT IN SRI LANKA: CAN IT BE SOLVED BY IMPROVING THE EXISTING COMMUNICATION CHANNELS?

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Abstract: Sri Lanka is endowed with 103 rivers which have total length of 4560 km. With the time, stream reservation areas of most of these rivers are encroached by the civilian for living and commercial activities. The stream encroachment damages the conditions of the stream environment as well as the livings nearby. Though there are legislations, encroachments of river reservations continue unabated. The field study was carried in the two villages which are heavily stream encroached, prone to frequent flooding and landslides. Focus group discussion was carried out with 40 officers from 8 major government institutions to find reasons for the failure of protection of stream reservation in Sri Lanka and to suggest mechanisms to overcome the problem. Study revealed that lack of coordination among institutions is the main hindrance to implement legislations related the stream encroachment. Author suggests that improving the existing communication channels among public, institutions, climate and natural scientists and, policy makers will facilitate protection of stream reservations in Sri Lanka.

Keywords: *Stream Reservations, Encroachment, Legislations*

1. INTRODUCTION

Sri Lanka consists with 103 rivers which flow in a radial pattern as a shape of a cart wheel and reach the sea at their specific destinations. In the ancient era, civilians lived close to streams to satisfy domestic, livestock and agriculture water requirements, but there was no necessity to declare stream reservation, because civilians didn't mischief stream environment. However with the time stream reservation encroachment increased due to increased population, urbanization, industrialization, landlessness to living and esthetic attractiveness of the streams. Nowadays encroachment of stream reservation is considered as one of the major problems contributing to the water resources degradation in Sri Lanka, as it leads to water pollution due to increased soil erosion, stream bank erosion, sewerage and solid waste disposal. Health issues (i.e. mosquito breeding, phlegm) due to improper disposal of waste, flooding situations in the rainy seasons and low accessibility to the stream water in the drought seasons are some of the problems face by the encroachers.

However preliminary studies showed that there were adequate legal mechanisms and institutions to prevent stream reservation encroachment in Sri Lanka (Chandrasekara, 2011). Though there are legislations, encroachments of river reservations continue unabated. Field survey was carried in the study using two severely stream encroached villages {i.e. *Egoda Kalugamuwa*; in *Kalugamuwa* Grama Niladari (Village Leader) administrative division (GN division) and *Elpitiya* in *Udowita* GN division in *Geli Oya* region} (Fig. 1). The study revealed that encroachers tend to occupy the reservations due to landlessness, poverty, and the social cohesion among their own communities (Chandrasekara and Gunawardena, 2010). These villages are near by the Mahaweli river; the longest and largest river in Sri Lanka and villagers frequently face to flooding and landslides with increasing water levels in the river (Chinci, 2011). Past evidences show that these two villages were under the flood on 1947, before the construction of Kotmale reservoir and nowadays villages are identified as areas likely to experience landslides (Kalubowila, 2006).

The studies related to climate change in Sri Lanka emphasize that the amount of annual rainfall is not varying significantly, but there can be higher frequencies of rainfall conditions (i.e. drought or flood) compared to that of such occurrences in the past. Therefore, it is logical to expect higher rainfall intensities under the scenario with "higher frequencies of extreme rainfall events, but with unchanged annual totals". Higher rainfall intensities generate higher surface runoff. The final result is enhanced soil erosion, deposition/siltation and flash flooding. Moreover, extreme rainfall events can trigger landslides although those are also related to the spread of human settlements into unsuitable areas which are prone to landslides (Wickramasinghe and Munasinghe, 2009).

In this study a focus group discussion was carried out with 40 officers from 8 major government institutions in the Central Province of Sri Lanka, within which two villages are located. These officers represented the authorities which deal on the stream reservation declaration and protection. They were requested to provide information as to why people encroach river reservations and to make suggestions to minimize the problem.

2. DISCUSSION AND CONCLUSION

Lack of coordination among institutions is the main hindrance to implement legislations related the stream encroachment. The relevant institutions work in isolation and do not work together to address the

common issue. Lack of institutional capacity to perform stream reservation protection, willingness of the officials to perform their mandated responsibilities and political interventions are other constraints in protection of stream reservations in Sri Lanka.

Creation of a new common institution to manage stream reservation does not guarantee its success unless there is an acceptance from the authorities and public at large. Therefore strengthening the existing district and divisional institutional arrangements will be advantageous to manage stream reservation among district and divisional levels in Sri Lanka.

Improving the existing communication channels among public, institutions, climate and natural scientist and, policy makers will facilitate protection of stream reservations in Sri Lanka. Interdisciplinary and participatory communication channels are mandatory for decision making in the declaration and prevention of the stream reservation. Most importantly frequent disseminating of the scientific knowledge and findings among the public is advantageous to early warning of disasters in these vulnerable areas and to prepare for the disaster situations.

However these developed interdisciplinary and participatory communication channels should guarantee the livings of public, but should not encourage the further stream reservation encroachment in Sri Lanka.

3. TABLE AND FIGURE

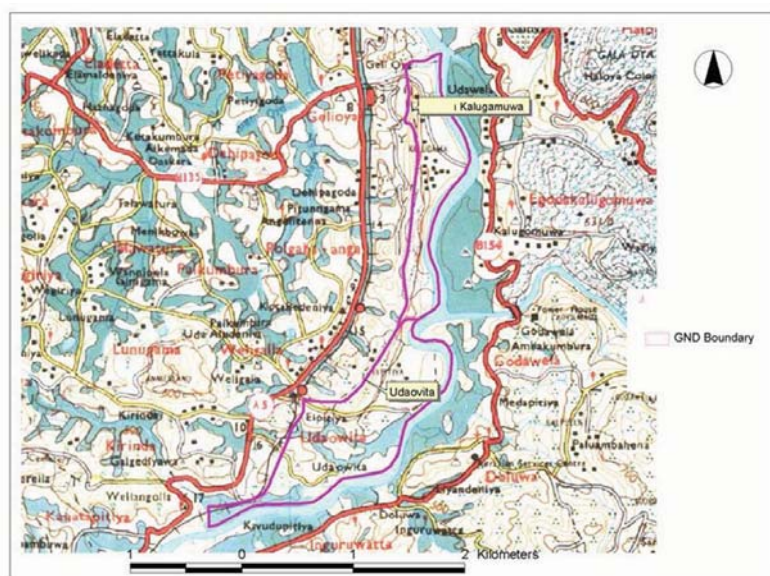


Figure 1. Selected Grama Niladari (Village Leader) administration divisions for the study

Acknowledgement:

Author would like to thank villagers in Kalugamuwa and Elpitiya for providing support to conduct the survey. Special thanks go to GNs of relevant villages, Divisional Secretaries and officer of Mahaweli Authority of Sri Lanka for giving their valuable time and information.

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WATER SCARCITY IN IRAN

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Abstract: Water scarcity has several economical, social and environmental impacts, depending on its intensity and duration. Unlike floods that have limited coverage areas, water scarcity usually affect vast regions, and this causes a more widespread and extensive range of impacts which last for a long time.

Iran is located in an arid and semi-arid region. Having an average annual precipitation of 250 mm, Iran receives less than one third of global average precipitation (750 mm). In addition, the rainfall distribution pattern over the country is not the same everywhere. Bearing in mind such a climatic condition, many severe or mild droughts are inevitable to come up. Any drought can inflict a severe damage on the agricultural, domestic and industrial sectors of the country. This paper presents some facts on precipitation and climate variation as well as drought conditions in Iran with some suggestions for mitigating the impacts of the drought by presenting relevant statistics to drought damages.

Keywords: *Water Scarcity, Drought, Natural Disaster, Climate, Water*

1. INTRODUCTION

Iran is located in an arid and semi-arid region. Due to the unfavourable distribution of surface water, to fulfil water demands and fluctuation of yearly seasonal streams, Iranian people have tried to provide a better condition for utilization of water. The country covers an area of about 1.648 million km.

Iran is bordered on the north by Armenia, Azerbaijan, Caspian Sea and Turkmenistan; on the east by Afghanistan and Pakistan; on the south by Oman Sea, Strait of Hormuz and Persian Gulf; and on the west by Iraq and Turkey. Climatologically, of the total area, 13% has a cold and mountainous weather, 14% has a moderate climate and the remaining 73% is covered by dry weather. Water balance of the country according to 30 years of data shows that the average annual precipitation is 250 mm. 30% of the precipitation occurs in the form of snow and the rest in the form of rain.

Principal uses are categorized in different sectors in the country. Although uses in the agricultural sector is much more dominant in comparison with the other (i.e. Industrial and urban and rural), it has had much less growth. From the point of view of the number of dams under construction in the country, Iran is among the first countries in the world. A great deal of emphasises has been placed on the surface runoff control and optimized utilisation of these resources and their high potential.

At present the Ministry of Energy, I.R. Iran, realizes the importance of control and optimum utilization of water. The specifications of the water supply services are: more than 130 reservoir dams with regulating capacity of 34 billion cubic meters, major irrigation and drainage networks in 1.5 million hectares, minor irrigation and drainage networks in 0.7 million hectares, hydropower plants with a capacity of 11000 megawatts and finally 110,000 deep wells and 300,000 semi-deep wells with total capacity of 44 billion cubic meters. Dam construction in Iran dates back to the ancient times. Iranians are credited for invention subterranean canals (Qanats) which is well-known in the world.

2. DROUGHT IMPACTS IN IRAN

The effects of drought produce complex impacts that span many sectors. In Iran, the three-year (from 1999 to 2001) drought has severely affected 10 of the country's 28 provinces, leaving an estimated 37 million (over half the country's population) vulnerable to food and water insecurity. Twenty provinces have experienced precipitation shortfalls during winter and spring 2001. According to the statistics of Ministry of the Interior, water reserves in the country were down by 45% in July 2001. 800 qanats (25 percent of 3170 qanats in Yazd) dried up. The extreme drought conditions have led to widespread migration, particularly from villages to the cities. Iran must also contend with the swelling number of refugees who are seeking to escape drought and political instability.

In the agricultural sector, Iranian farmers have sold roughly 80% of their livestock, and an estimated 800,000 livestock were lost in 2000 as a result of the drought. An estimated 2.6 million hectares of irrigated lands and 4 million hectares of rain-fed agriculture have experienced the drought's impact in 2001. The United Nations estimates the damages to agriculture and livestock at \$2.5 billion in 2001, up from \$1.7 billion in 2000.

According to the FAO report entitled “Millions of people seriously affected by drought in Near East and South Asia”, in Iran, severe drought in 1999 cut wheat production by more than 3 million tonnes, or about 25 percent compared to the previous year. Official reports indicate that this year's drought may be more severe than last year's and its impact "is likely to be exacerbated by already low reserves in dams and reservoirs," the alert says. The outlook is also unfavourable for barley, which is very important for livestock production on which a large groups of the population depend.

In 1999/2000, Iran imported nearly 7 million tonnes of wheat, making it one of the largest wheat importers in the world. This year's imports threaten to be even larger. The Government recently approved an emergency aid package for US\$183 million to assist drought-affected farmers.

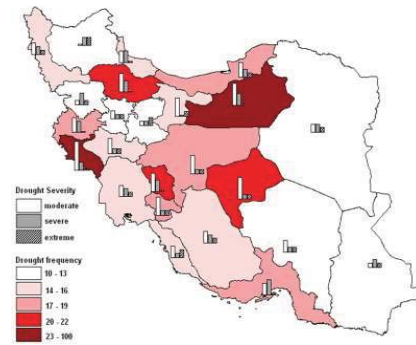


Figure 1. Drought Frequency Map (based on initial rainfall data); 1960 to 1998 (39 Years)

3. WATER SCARCITY MITIGATION STRATEGIES

Some water scarcity mitigation strategies are as follows:

- ◆ Risk management instead of crises management
- ◆ Preparing the national drought atlas as well as national drought mitigation plan
- ◆ Drought statistics and information recording
- ◆ Convincing the farmers to make use of the treated domestic wastewater in irrigation
- ◆ Coming up with a special fund to support the farmers who are willing to enhance their irrigational method
- ◆ Investing on constructing water reservoirs as well as modern irrigation networks
- ◆ Training and education of the users and consumers of water on the efficient ways of utilizing this resource. General training on this subject is to be a constant part of the public educational programs.
- ◆ Provision of adequate storage facilities for better water quality, particularly in the remote residential districts, with the priority given to the most drought susceptible locations
- ◆ Formation of a National Drought Committee, with members from all the ministries and organizations directly concerned with water-related issues is necessary.
- ◆ Providing drought forecasts, monitoring and early warning systems for all stakeholders, particularly farmers in the most susceptible areas.
- ◆ Introducing the right cropping pattern to the region
- ◆ Capacity development for farm management strategies to improve crop water productivity through improved agronomic practices, use of genetically improved seeds and using software and models such as AquaCrop
- ◆ Improving the irrigation methods
- ◆ Extensive crop insurance programs to cover all the major crops in any region, particularly where the farmers are poor and where the local economy is dominated by agriculture
- ◆ Provision of water supply for the wild life to discourage their migration due to drought

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INDIAN RAINFALL FORECASTING, VECTOR AUTO REGRESSION (VAR) & VARIANCE DECOMPOSITION (VDC) MODEL: A SPATIAL AND INTER-TEMPORAL ANALYSIS AND IMPLICATION FOR WATER MANAGEMENT IN THE CONTEXT OF CLIMATE CHANGE

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Abstract: The objectives of the paper are three fold. First, is to forecast south west monsoon across six different regions of India namely Core India, North West India, North East India, Central North East India, West central India and Peninsular by using Variance Decomposition model under VAR set up. Second, the paper tries to measure the variability of rainfall over 138 years (from 1871-2008) across the above regions of India. Third, the paper also attempts to measure inter-regions correlation matrix of south west rainfall. The analysis has been done using by Vector auto regression model as the south west monsoon data have followed stationarity by ADF test statistic. The rainfall variability across different regions of India is judged by standard deviation and the result shows that there is wide variability across the regions. The correlation matrix of rainfall for all regions shows that there is a strong relation of relationship of rainfall across the regions. The paper has important policy implication for management of water resources applications as well as the effective utilization of water resources. This prediction model takes care for the prevention of floods and droughts.

Keywords: forecasting, vector auto- regression, rainfall variability, correlation matrix, variance decomposition model

1. INTRODUCTION

In an agricultural country like India, the success or failure of the crops and water scarcity in any year is always viewed with the greatest concern. A major portion of annual rainfall (about 80%) over India is received during the southwest monsoon season (June-September). Water resources are directly dependent on the abundance of rainfall and snow. Rainfall, temperature, runoff, groundwater and stream-flow are key variables controlling water availability. With an increasing population, a changing climate, and the expansion of human activity, water management has unique and evolving challenges. The study is significant for changes in rainfall due to climate change influence the hydrological cycle and the pattern of stream-flows and demands (particularly agricultural), requiring a review of hydrologic design and management practices. Changes in run-off and its distribution depend on likely future climate scenarios. Intergovernmental Panel on Climate Change (IPCC, 2007) concluded with high confidence (90 % probability) that the extent of drought-affected areas will likely to increase.

The objectives of the paper are three fold. First, is to forecast south west monsoon across six different regions of India by using Variance Decomposition model under VAR set up. Second, the paper tries to measure the variability of rainfall over 138 years across different regions of India. Third, the paper also attempts to measure inter-regions correlation matrix of rainfall.

2. DISCUSSION

This is an empirical paper based on data collected from secondary sources. The paper utilizes rainfall data from India's meteorological department. Data ranges from 1871 to 2008 and monthly in nature. Rainfall data are taken on six different regions of India namely Core India, North West India, North East India, Central North East India, West central India and Peninsular India from 1871 to 2008. Stationary test by Augmented Dickey Fuller test or ADF test statistic on the south west monsoon data across different regions of India has been calculated. The result of stationarity test by ADF shows that the rainfall data on Core India, North West India, North East India, Central North East India, West central India and Peninsular are stationary at level.

After conforming stationary test, Vector Auto regression model (VAR) is used to estimate the parameters. We have six vector auto-regression equations with 14 parameters to be estimated using Vector Auto regression model. The result showed that the previous year rainfall of Core India has positive and significant impact on the rainfall of Core India at the current period. Similarly, previous year rainfall of North West India has negative and significant impact on the rainfall of core India at the current period. It is also observed that the last two previous year's rainfall of North West India has positive and significant impact on the rainfall of North West India at the current period. It is also noted that previous year's rainfall of Central North East India rainfall has negative and significant impact on the rainfall of North West India at the current period. Previous year rainfall of Core India has positive and significant impact on the rainfall of Central North East India while the

previous year rainfall of North West India has negative and significant impact on the rainfall of Central North East India.

Variance Decomposition method is used for prediction of rainfall. The prediction result shows that the rainfall for West Central India, Peninsular India, North east India and Core India will be decreasing while rain fall prediction for Central North East India and North West India will be on the rise. The result of the variability (by the measure of standard deviation) of South West rainfall across different regions of India show that the variability lies between 248.76 and 391.36. The lowest variability of rainfall is observed in Peninsular India while the highest variability is perceived in North East India.

The positive value of correlation coefficient is found to be highest (0.86) between Core India rainfall and West central India rainfall while the lowest value of the correlation coefficient (0.04) is between Central North East India and North East India. The negative correlation coefficient is observed between North East India and Core India, between North East India North West India, between North East India and West Central India, between North East India and Peninsular India.

3. CONCLUSION

In conclusion, the prediction result shows that the rainfall for West Central India, Peninsular India, North east India and Core India will be decreasing while rain fall prediction for Central North East India and North West India will be on the rise. The rainfall variability shows that there is a wide variability across the regions of India. The correlation matrix of rainfall for all regions shows that there is a strong relationship of rainfall across the regions.

The paper has important policy implication for management of water resources applications as well as the effective utilization of water resources. This prediction model takes care for the prevention of floods and droughts. Our study shows that the mean rainfall in North East India is about 3494 mm which is above the all India average rainfall (2145 mm). The flood due the excess rainfall in this region is occurring every year. If prediction is made appropriately, the government may be able to take preventive measures for flood control in well advance.

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A RELIABLE FOOTING FOR SUSTAINABLE INTERNATIONAL COOPERATION ON CLIMATE CHANGE

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South Asian Youth Climate Coalition, India

Abstract: To succeed in reducing carbon dioxide emissions, a sustainable effective climate policy must establish reliable long-term incentives for investments in physical capital and research and development. We argue that credibility implies that international agreements should focus on enhancing coordination and collaboration between countries, rather than on coercion. At the national level, credibility requires political and economic incentives that can be provided by long-term tradable emissions permits, but it needs more flexibility than can be provided by a conventional permit system. We argue that the best mechanism for providing credible long-term incentives is a hybrid system of long and short term emissions permits. Key aspects of the system would be coordinated across countries but the permits would be issued and traded solely within national borders.

Keywords: *Climate, Research, international, Cooperation*

1. INTRODUCTION

Increasing competition over natural resources because of population and economic growth, climate change and other drivers is magnifying the challenges of natural resource management. As outcomes for food, water ecosystems, land degradation, and desertification increasingly transcend national boundaries there is greater need for international cooperation on land and water. Climate change, air and water pollution, globalization, increasing competition over natural resources resulting from population and economic growth and other global changes have also driven cooperation in natural resource management.

2. CHALLENGES

The challenges are very many. They are compliance with conventions and international laws, limited funding support for regional and international initiatives. There are signs of increased non-cooperation and mistrust at the regional and international levels, which is a result of national unilateral actions in response to the food price crisis, the ongoing stalemate of the World Trade Organization (WTO) Doha Round, and unilateral bio-fuel policies and international land leases and purchases by several countries. In the face of these challenges, the natures of emerging issues and international resolve for cooperation have created an environment for enhanced future cooperation.

3. SUSTAINABLE INTERNATIONAL COOPERATION ON LAND AND WATER

Cooperation on land and water resources is motivated by scarcity and degradation and economics. There is a need to increase access and productivity, and ensure land and water remains a conduit for agricultural and economic growth and for the general advancement of human well-being. The United Nations system plays an important and unique role in international cooperation in regard to the management of land and water resources. It has facilitated a series of key meetings on the topic and helped establish a range of international organizations and programmes focussing on enhanced management and improved support to land and water. International cooperation on agricultural research has been one of the shining examples of successful cooperation and has achieved significant impacts on the livelihoods of the global community. International cooperation concerning land and water resources was first linked to food security and rural development. The green revolution, a global overhaul of the agriculture production system that originated in the mid 1940s, and between 1970 and 1990 more than doubled cereal production in Asia (Hazell, 2002), was technology centered.

4. AUTHOR'S PERCEPTION

To succeed in reducing carbon dioxide emissions, a sustainable effective climate policy must establish reliable long-term incentives for investments in physical capital and research and development. We argue that credibility implies that international agreements should focus on enhancing coordination and collaboration between countries, rather than on coercion. At the national level, credibility requires political and economic incentives that can be provided by long-term tradable emissions permits, but it needs more flexibility than can be provided by a conventional permit system. We argue that the best mechanism for providing credible long-term

incentives is a hybrid system of long and short term emissions permits. Key aspects of the system would be coordinated across countries but the permits would be issued and traded solely within national borders.

5. CONCLUSIONS

International cooperation in exchanging ideas and technical knowhow on climate change and environmental issues is likely to increase drastically during the next decade, in response to the multiple challenges and opportunities linked to the management of natural resources, as described above. New global L&W governance is emerging, and will need to specify clearly the roles and the responsibilities of international and regional organizations, national institutions, the private sector and the communities using the land. Such new governance will rely on the strong political commitment of governments and development agencies. It is expected that this report will provide useful guidance to all partners concerned. Reduction in CO₂ emissions globally is an international concern. Every state asks others to reduce the CO₂ emission without doing its own bit under the pretext of being a developing nation. That will require a sustainable emission plan in which nations globally agree. The agreements must be based on the principles of natural justice because poor nations require to have industries, development programs and they need to be compensated by new technologies that can help in reducing carbon emissions

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CLIMATE VARIABILITY, WATER RESOURCE SCARCITY AND POLICY SHIFT IN DRYLANDS OF RAJASTHAN, INDIA

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Abstract: The climatic variability has its impact on all ecosystems, regions and sectors. The regions which are scarce on resources are very vulnerable to climate change like the drylands of Rajasthan. With an overall rise in temperature over the drylands of Rajasthan and changing precipitation trends the humidity provinces as defined by Thornthwaite have shifted eastward. Rajasthan has acute surface water scarcity along with over-exploitation of groundwater resources. One reason for this phenomenon is the absence of sufficient number of surface irrigation facilities. The water scarcity and the high per capita arable land increases the demand for irrigation water which is being met through mining of groundwater resources. The government has initiated watershed development projects and has constructed many water harvesting structures in various parts of the region but due to paucity of rainfall the projects have not attained expected success. Water security in the region can be attained through expansion of canal network and Integrated Water Resource Management.

Keywords: *Climate variability, Water scarcity, Irrigation, Dryland agriculture, Water conservation*

1. INTRODUCTION

The world is experiencing a high variability in climatic parameters. The variability is both spatial and temporal in nature. The nature and extent of vulnerability to climate change differs with adaptive capacity of individual, society and region. The availability of resources is a decisive factor in determining vulnerability. The status of resources is very much dependent on the population and climatic parameters of the region. In an area dominated by arid and semi-arid lands, water is a very limited and has high percentage of degraded land due to Aeolian processes. The vulnerability of arid regions is further accentuated by low levels of socio-economic development, and this is the case with arid regions of India (Singh and Gurjar 2011). The high population density of Indian desert is intensifying the pressure on the water resources, which leads to fast depletion of water resources. Whatever might be the nature of climate change that bound to occur in a region, the outcome would be large scale displacement of normal human activity (IPCC 2001). According to Sen Roy and Singh (2002) changing climate elements and their extremes will significantly alter productivity in agriculture and forest ecosystem, which in turn will affect the socio-economic conditions of many societies. Therefore, only climate change mitigation steps are not enough; there is an immediate need to strengthen the adaptive capacity of people and regions. In India, the hot Arid-zone occupies 9.8 per cent i.e. 0.32 million sq km of the total land area of 3.29 million sq km. The western arid region includes 12 districts and the Indian Thar Desert is most populous desert in the world, with density of around 84 persons per sq km.

2. RESULTS AND DISCUSSION

Climate Variability

In the Western Rajasthan during last 30 years the temperature has shown a great variability with an average rise of about 0.5 °C for the month of June. The maximum rise is visible during 1995-2000. Whereas for the month of January the average rise in temperature is about 1°C during last 30 years. The temperature rise for January is more consistent and the fluctuations are not so abrupt as compared to June. This rise in temperature is mainly attributed to global rise in GHG concentration but along with that the local factor influencing the temperature rise is increased cloud cover during winter months. The Western Rajasthan suffers from scarcity of rainfall. The average annual rainfall in the region is measured to be 350 mm per year and above that the rainfall pattern in the region shows large variability and has never been consistent. The scarcity accompanied by variability creates water stress conditions in the region and is responsible for droughts. During last 30 years the average annual rainfall has shown a decrease of 50 mm. With an overall rise in temperature over the region and changing precipitation trends the humidity provinces as defined by Thornthwaite have shifted eastward. In 1973 the arid region consisted of Barmer, Bikaner, Ganganagar along with western parts of Churu, Hanumangarh, Jalore and Jodhpur, But according to 2008 meteorological datasets eastern parts of Churu, Hanumangarh and Jodhpur, and western parts of Jhunjhunu, Nagaur, Pali and Sikar have been added to arid type of humidity province. Increase in aridity i.e. fall in index values have been noticed over major part of the region. Whereas a small part including of western Bikaner, northern Jaisalmer, central Barmer and western Jalore have experienced decrease in arid conditions.

Water Resource Scarcity

The region is characterized by heterogeneity in groundwater conditions. The region has all formations, viz., unconsolidated, semi consolidated and fully consolidated, with varying groundwater potential (Ozha and Sharma 2011). Rajasthan stands first in terms of degree and extent of over-exploitation of groundwater resources in the country. The low to medium rainfall in most parts, high evapo-transpiration demands for water, high frequency of occurrence of droughts resulting from the departure of rainfall from mean values, and the high per capita arable land increases the demand for irrigation water. This is being met through mining of groundwater resources.

The subsidized power supply in agriculture has continued for many years, and the existing pump horse power based pricing of electricity encourage over-pumping and inefficient and often wasteful use of groundwater. The data reveals that depletion in ground water level is very significant in the region. Out of total 12 districts, 10 districts in the region shows depleting trend of ground water level. On the basis of average depletion these districts have been further classified as most critical (> 10 m), critical (average depletion is between 5 to 10m) and moderate (average depletion is between 0 to 5 m). Overall, the estimated groundwater resources in Western Rajasthan are limited due to deep aquifers and low recharge. Based on the ratio of annual pumping to annual recharge, the stages of groundwater development have been categorized as safe (<70 per cent), semi-critical (70-90 per cent), critical (90-100 per cent) or overexploited (per cent 100 %) (Rathore 2005; Narain et al. 2005). The groundwater is overexploited in Barmer, Jalore, Jhunjhunu, Jodhpur, Nagaur, and Sikar districts.

The irrigated area by all sources was only 9.3 per cent in 1951 which has increased by about 43 per cent in 2000-01 out of the total potentiality (53 per cent) of irrigation in the western Rajasthan. This expansion of irrigation has resulted inclusion of new lands, which were earlier under fallow lands, pastures and grazing and land not available for cultivation and further it caused shrinkage of pastures and grazing lands. The advent of Indira Gandhi Canal in the northern parts of arid region of Rajasthan has led to immense change in the land use pattern of the region. The once barren land has been now converted into highly productive green belt. Such initiatives in the fragile desert ecosystems help the region to cope with high variability in rainfall. The rainfed areas and region dependent on groundwater sources suffer more during frequent drought periods occurring in the region.

3. CONCLUSION

The climate over Western Rajasthan is showing definite signs of change. The water resources are scarce, adding to vulnerability of region towards climate change. The present policy of government relying on watershed based developmental planning, where rainwater harvesting structures are been constructed and less emphasis is been given on extending the canal network. Therefore in context of changing climate with decreasing rainfall such structures may become defunct therefore the government policy should focus on Integrated Water Resource Development where groundwater should be preserved for drinking and network of canal should be used for irrigation purposes along with diversification of the source of livelihood. Rajasthan has a total of 21713 MCM surface water available in about 14 small river basins, the state government should learn lesson from South Korea's River Restoration Project, as out of five objectives three objectives viz. securing abundant water resources to combat water scarcity; improving water quality and restoring river ecosystems; and regional development centred on the rivers could also be implemented in Rajasthan.

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Index of Posters

The official poster session will be held on Wednesday 12 September at 14:40-16:00.
The Posters will be available in front of the conference venue during the session.

Prediction of drought indices over India using Multi-Model Ensemble- Nachiketa Acharya and U.C. Mohanty

Can models help to forecast rainwater dynamics for rainfed ecosystem?-M. Ahmed and F.F. van Ogtrop²

Seasonal rainfall variability and its impact on vegetation dynamics in the southwestern United States: an outlook on future water budget issue- Clement Sohoulade, Vijay Singh

Climate predictions and grass root adaptations: will they remain parallel or converge: field observations from southern India -K. Lenin Babu

Climate variability and its impacts on water resources in Oti plain - Badjana Heou Maleki,

Hounkpe Koffi, Abalo-Sama Abide, Wala Kperkouma, Edjame S. Kodjovi

Vulnerability of Coastal Wetland to Climate Change and Sea Level Rise of Bangladesh:

Issues and Challenges- Abu Hena M K

Rainfall variability and its impact on water resources in Himalayan headwaters: need for

long-term adaptive and integrated water resource management and governance policy- Prakash C Tiwari, Bhagwati Joshi

Impacts of climate change on water resources and rice productivity in drought prone area of Bangladesh-

Community Forest of Nepal: How it maintains ecosystem services and copes with global warming?-Bidur Khadka

Assessment of changes of anomaly temperature and extreme precipitation in the midlatitude Asia-Pacific region Viktoria Platonova

Climate variability and change in Bangladesh: a spatio-temporal analysis of rainfall and temperature using historical data and GIS -Md. Rejaur Rahman

Assessment of historical river flows and climatology of Upper Indus Basin (UIB) and to develop relationships between river flows and climatic variables in UIB -Engr. Amjad Masood, Qurat Ul Ain Ahmad

Water resources management in India under a changing climate-Shadan Nair

Climate change impacts on groundwater-dependent irrigations system in northwest Bangladesh- Shamsuddin Shahid

Natural factors and anthropogenic impact of the estuarial area of the Amur River runoff formation-Polina A. Sokolova, Tamara G. Ponomareva

The application of catastrophe theory to the positive climatic trends- Talgat R. Kilmatov, Olga I. Trinko

Evaluation of water demand-supply reliability based on climate change scenario in Han River Basin Jang-Won Moon, Dong-Ryul Lee, Si-Jung Choi

Assessment of historical river flows and climatology of Upper Indus Basin (UIB) and to develop relationships between river flows and climatic variables in UIB -Engr. Amjad Masood, Qurat Ul Ain Ahmad

Adaptation strategies for safe water supply in the deltaic coastal region of Bangladesh -Mehdi Azam, Tapan Sarker

Stream reservation encroachment in Sri Lanka: can it be solved by improving the existing communication channels?-S.S.K.Chandrasekara

Water scarcity in Iran-Shahram Khorasanizadeh

Indian rainfall forecasting, vector auto regression (var) & variance decomposition (vdc) model: a spatial and inter-temporal analysis and implication for water management in the context of climate change -Dr. Jyotish Prakash Basu

A reliable footing for sustainable international cooperation on climate change-Dillip Pattanaik

Climate variability, water resource scarcity and policy shift in drylands of Rajasthan, India - Ajay Kumar, R.B. Singh





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