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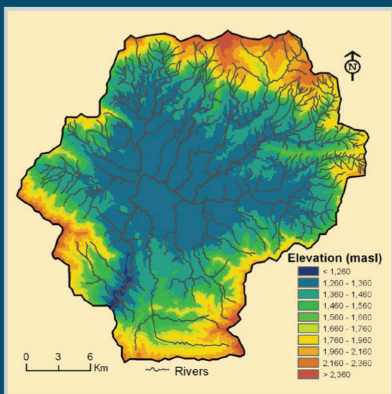
KATHMANDU VALLEY GROUNDWATER OUTLOOK



Editors
Sangam Shrestha
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ABOUT PUBLISHING ORGANIZATIONS

Asian Institute of Technology (AIT)

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AIT is an International Intergovernmental Organization and the leading multicultural regional hub of educational and research in Asia. Since its establishment in 1959, AIT has expanded network of partnerships with industry and educational institutions and promoted development, transfer and adaptation of educational and research inputs from global sources to the region and spread local knowledge to the rest of the world. AIT is academically structured into three schools namely, School of Engineering and Technology (SET), School of Environment, Resources and Development (SERD), and School of Management (SOM). Environment and sustainable development has featured high in AIT education and research activities and two of its prominent schools (SET and SERD) have been involved in a significant number of environment and natural resource related activities and research projects, providing education to its students and expertise to other organizations. AIT has educated more than 17,000 students and 26,000 short-term trainees from more than 75 nations. Excellence in Learning, Research, Quality Assurance, Transparency of Administration and Good Governance, Unity in Diversity, Culture of Collaboration and Partnership have all formed the core values for the development of AIT.

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SEN is a non-governmental organization (NGO) established in March 2001. SEN was founded to develop and enhance students-teachers-scientists (STS) networks to promote sustainable lifestyles through educational outreach and knowledge sharing. Research, awareness, advocacy and capacity development are the approaches of working. It supports activities that reduce the impacts of human activities on local, regional and global environments. SEN has a broad spectrum of working arena in the field of environment, however, it focuses specially on water, weather and climate information, climate change. It has also spread its wings on waste management and promotion of renewable energy technology.

Center of Research for Environment Energy and Water (CREEW)

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CREEW was founded in 2008 as a non-profit making and non-government research based organization. It strives to contribute for resolving problems and issues relating to water, environment and energy in Nepal by conducting scientific study and research. In addition, CREEW works for the development, management and promotion of water, environment and energy activities. Government organizations, universities and research institutes are the major working partners of CREEW.

International Research Center for River Basin Environment-University of Yamanashi (ICRE-UY)

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ICRE-UY was established in 2007 to contribute as a prominent international research and education stronghold in line with the activity plan of the 21st century Center of Excellence (COE) program of University of Yamanashi (UY) launched in 2003. With active participation of nearly 50 highly motivated staffs (faculties, researchers, technical assistants and administrative staffs), from both home and abroad, ICRE-UY has consolidated its expertise on five thematic areas; namely, river basin hydrology, environmental dynamics, environmental management, regional planning, and health risk. ICRE-UY has also a strong international network especially in Asia Monsoon Region. It has promoted collaboration between medicine and engineering to ensure application of science for the safety of the people and local communities. Application of advanced techniques (e.g., isotope, Doppler radar, DNA analysis) to carryout research is one of the unique characteristics of ICRE-UY.

Kathmandu Valley
Groundwater Outlook

Editors
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PREFACE

This book is the product of a year-long collaboration among Asian Institute of Technology (AIT), The Small Earth Nepal (SEN), Center of Research for Environment Energy Water (CREEW) and International Research Center for River Basin Environment-University of Yamanashi (ICRE-UY), which began with organizing two consecutive national symposiums 'Groundwater in the Kathmandu Valley: Challenges and Opportunities' in December, 2009 and March, 2011 in Nepal.

This book consists of findings of scientific research, experiences and opinions of concerned authorities and experts on groundwater of the Kathmandu Valley. The aim of this book is to document and disseminate the knowledge about the groundwater among policy makers, academicians, researchers, practitioners, and professionals from diverse domains of quantity, quality and management aspects of groundwater of the Kathmandu Valley. The book is targeted to a wide range of audience from high level policy-makers in governments, affiliates of INGOs, NGOs and civil societies, researchers to graduate students from universities and academic institutions, and other concerned stakeholders.

We believe that the data, information and findings from various research and reviews in this book would be very useful to policy-, and decision-makers to formulate new policies or to amend the existing policies, which guide the sustainable development and management of groundwater resources of the Kathmandu Valley. Furthermore, the current research findings and recommendations in this publication has opened new avenue to conduct research that address the current management challenges due to demographic and socio-economic changes and challenges that may arise due to the impacts of climate change.

The editors would like to thank the authors for their outstanding contributions and patience throughout the writing and editing process. We would also like to thank all of the reviewers for their valuable feedbacks. We would like to acknowledge the continuous support and guidance of the advisory editors Prof. Gordon Young (International Association of Hydrological Sciences), Prof. Futaba Kazama (International Research Center for River Basin Environment-University of Yamanashi), and Dr. Madan Lall Shrestha (Nepal Academy of Science and Technology) and Ms. Yatsuka Kataoka (Institute for Global Environmental Strategies). We are also grateful to Dr. Kei Nishida from University of Yamanashi for his enormous support to make this publication possible. Sincere appreciations are also extended to Global COE Program of University of Yamanashi in Japan, CREEW in Nepal and AIT in Thailand for the financial support. Importantly, it would be injustice if we fail to thank Ms. Suchita Shrestha for her help in communicating with authors and reviewers throughout the publication process.

Sangam Shrestha, Asian Institute of Technology
Dhiraj Pradhananga, The Small Earth Nepal; Centre for Hydrology at the University of Saskatchewan
Vishnu P. Pandey, International Research Center for River Basin Environment-University of Yamanashi

FOREWORD

Groundwater has played an important role in the sustainable development of many parts of the world by providing water for domestic, industrial and agricultural uses. However, the indiscriminate and excessive use of groundwater is posing serious threats to its sustainability. Much emphasis has been given to groundwater resources development without giving careful attention to its management despite its strategic role in sustainable development. This is mainly due to lack of comprehensive understanding of groundwater systems. Need for visualization of a bigger picture incorporating the different aspects of this resource has been strongly felt. Therefore, it is imperative to increase the scientific understanding of occurrence and behavior of groundwater systems and its associated demand, use, governance and institutional mechanisms for the sustainable groundwater management.

The *Kathmandu Valley Groundwater Outlook* is the outcome of an excellent joint effort of different institutions, all conducting scientific research aimed at sustainable development and management of groundwater. The Asian Institute of Technology (AIT) is honored to work together with the Center of Research for Environment Energy and Water (CREEW), The Small Earth Nepal (SEN) and International Research Center for River Basin Environment-University of Yamanashi (ICRE-UY) to make this publication possible. AIT is committed to contribute significantly in the areas of water resources management and the AIT Research Strategy (2012-2016) features water resources management prominently in conjunction with sustainable land management. The critical relation between water resources and land management was evidenced through the Great Thailand Flood of 2011 which signified effective water resources management can only be possible through integrated land and water resources management.

This book provides an in-depth and up-to-date information on the status of the groundwater resources in the Kathmandu Valley by compiling the findings of research in groundwater aquifers and their hydrogeological characteristics, groundwater storage potential, recharge dynamics, groundwater quality, suitable treatment technology, characteristics of water use and contribution of groundwater, groundwater-based water markets and institutional and legal setups. Adequate scientific basis and background is provided for the issues dealt in all chapters. The book has been authored by and subsequently undergone a process of extensive review by experts in the respective fields.

I am confident that the book will benefit a wide range of readers from policy-makers in governments, affiliates of INGOs, NGOs and civil societies, researchers to graduate students from universities and academic institutions in the area. Though the book features specific case-studies at the local level, I strongly believe that the issues dealt, approaches followed, and conclusions drawn will be interesting and beneficial to the readers globally. I sincerely hope that this book will provide a sound basis for the respective decision making bodies of the Government of Nepal in addressing the valley's groundwater issues at the policy level giving due consideration to its sustainable development and management.

Prof. Said Irandoust
President
Asian Institute of Technology

9 February 2012

FOREWORD

Management and protection of the groundwater resource in the Kathmandu Valley has long been an issue of wide public concern. In 2006, the Kathmandu Valley Water Supply Management Board (KVWSMB) was established by the government through the Water Supply Management Board Act, to look after groundwater regulation, licensing, management and protection. KVWSMB has taken some initiatives in line with the provisions of the Act and has now realized that there is a lack of scientific knowledge, information and data on groundwater aquifers and resources. This has created obstacle to come up with workable groundwater development, management and protection plans. To understand the current state of knowledge and research need, KVWSMB organized a groundwater expert meeting on 5-6 July, 2010 and came up with a list of research to be carried out. Since then we have started many work including preparation of the Groundwater Regulation and Management Policy, but, there is much more to be done.

I am happy to see that this publication, the *Kathmandu Valley Groundwater Outlook*, has addressed many of the research issues identified in the groundwater expert meeting. The book has nicely synthesized different aspects of the groundwater issues in the Kathmandu Valley; including quantity, quality, use and institutions. Additionally, excellent review of previous research (focusing on issues covered, methods used and finding) and nicely prepared list of available publications would be excellent knowledge base and resource for all those interested in the groundwater of the Kathmandu Valley. I have no doubt that the information in the book shall help a lot to implement the Strategic Action Plan (2008-2025) and Groundwater Regulation and Management Policy 2011 prepared by the KVWSMB.

Moreover, as the head of KVWSMB responsible for groundwater management and protection in the Kathmandu Valley, I am pleased to see several reputed institutions, both national and international, joining hands to generate and disseminate scientific knowledge of the groundwater system in the Valley. I hope that the collaboration would continue and would contribute further in the management and protection of the groundwater resources in the Kathmandu Valley.

Thank you!

Hari Prasad Dhakal
Executive Director
Kathmandu Valley Water Supply Management Board
Kathmandu, Nepal

12 February 2012

FOREWORD

It is my great honor to write few words on this volume, *Kathmandu Valley Groundwater Outlook*, and about the colleagues who have engaged in this publication. I have been working as technician, researcher, activist and practitioner in water and sanitation for about twenty-five years. Water management in the Kathmandu Valley has always been my area of interest and I have spent most of my time working on it.

I met Prof. Futaba Kazama and Dr. Sangam Shrestha in early 2005 when they were exploring possibilities for carrying out research on the water sector in Nepal. At that time, I was associated with the Environment and Public Health Organisation (ENPHO) and was engaging in various research related to water and sanitation. I shared ENPHO's research and development programme and experience. Today, I am happy to see that many of our discussions from early 2005 have become reality. The International Research Center for River Basin Environment-University of Yamanashi (ICRE-UY) in partnership with the Asian Institute of Technology (AIT) has been deeply engaged in research and development of the water sector in Nepal for the past several years. As a joint effort, it has been possible to establish research institutes like the Center of Research for Environment Energy and Water (CREEW) and to strengthen partnerships with concerned government departments, UN agencies and existing research agencies like ENPHO and The Small Earth Nepal (SEN). I believe that this publication is one of the milestones of these collaborations.

This publication is unique as most of the papers have been prepared by young researchers on the basis of their own research findings. I am personally aware of the dedication of all the authors, of their hard work and of how they have maintained a high quality of research, particularly analytically. Therefore, we can consider the overall research findings to be of the highest class due to the high accuracy of the primary data.

This book serves as a wake-up call for all concerned stakeholders, including individuals living in the valley, for the need to understand the groundwater source situation and to devise plans to preserve groundwater for future generations. The best part of this publication is that it has not only indicated problems but also highlighted several possible solutions to help overcome current issues of water scarcity and to protect groundwater resources in the valley from further degradation. For example, one of the studies in this publication indicated that the shallow groundwater storage capacity in the valley is 1.5 billion cubic metres, indicating that it can act as a huge water storage reservoir for the entire valley. By harvesting rainwater at local levels, such underground areas could be recharged, thereby alleviating the problem of water scarcity.

As a practitioner, I have demonstrated and advocated for this concept by introducing rainwater harvesting and groundwater recharge through dug-wells at my own house since 2002. Since that time, I have lived off the city water supply grid. This publication helps strengthen my voice of advocacy by providing sufficient scientific evidences to demonstrate that such practices can be scaled up. In addition, studies in this volume also confirm that shallow groundwater in the valley can be recharged from different altitudes on the valley floor without reliance on the surrounding hills in the valley.

In short, I would like to conclude that this is one of the best publications that I have read and now I understand even more about the preservation and management of water resources in the Kathmandu Valley. This publication should certainly reach to a wider audience of policymakers, donors, academics and practitioners. I am extremely grateful to all three editors—Dr. Sangam Shrestha, Dhiraj Pradhananga and Dr. Vishnu Prasad Pandey—for their hard work in collecting and editing all of the relevant papers for this publication.

I congratulate all associated colleagues for this success!

Roshan Raj Shrestha, PhD
Patron and Founder Member of ENPHO
Currently engaged with UN-HABITAT/UDNP as International Settlement Improvement Advisor for Urban Partnership for Poverty Reduction Programme, Dhaka, Bangladesh

10 February 2012

FOREWORD

Effective groundwater management is one of the great water challenges of the 21st century. Groundwater has proven to be a highly valuable resource for cities, farmers, and households for several reasons. Groundwater is generally available all year, as compared to river flows which fluctuate greatly throughout the year. People can tap into groundwater when they want it, and households do not have to rely on city water supplies or an irrigation system to deliver water. In fact, groundwater is very often the supply of choice, and farmers are willing to pay significantly for ground water in terms of the equipment they buy and the energy required to operate pumps. Groundwater has allowed irrigated agriculture to flourish across the globe.

Groundwater aquifers in many areas of the world are under threat from overpumping and pollution. There is heavy demand for the resource, and pumping goes unregulated, leading to unsustainable groundwater drawdown. Surface water sources recharging groundwater can add heavy loads of pollution. Groundwater governance has been a challenge in developed and developing economies alike. Pumpers often tap into groundwater without heed to how much water is available or the impact on other groundwater users.

Groundwater use in the Kathmandu Valley exhibits many of the features common through the world. However, the valley's geography, culture, and governance system – in particular its situation in the mountain system of the Himalayas – are unique factors shaping the challenges and opportunities for groundwater management and use in the area.

The *Kathmandu Valley Groundwater Outlook* is the first publication of its kind for Kathmandu Valley and Nepal, and as such is a milestone for understanding the role of this important resource. The book is an important contribution to sustainable development, management, and governance of the groundwater resource in the valley. It details several aspects of groundwater management in the valley, from hydrology and geology to the use and governance of the resource. The book is an important resource for mountainous areas facing issues similar to those of Kathmandu.

The book is the result of a collaborative effort among several organisations that bring a wealth of local and international experience. This effort represents an important step from which further research and development actions can be defined. It is clear that there is a need for close collaboration in this area to meet the groundwater challenge of the future. ICIMOD hopes to continue the partnership with the initiators of this book to meet the challenge.

Dr. David James Molden
Director General
International Centre for Integrated Mountain Development

14 February 2012

ACRONYMS AND ABBREVIATIONS

AAS-HG	Absorption Spectrophotometry with Hydride Generation
ADB	Asian Development Bank
AGSO	Australian Geological Survey Organization
AIT	Asian Institute of Technology
Ave.	Average
BCM	Billion Cubic Metres
BDS	Bulk Distribution System
BGR	Federal Institute of Geosciences and Natural Resources of Germany
B.S.	*Bikram Sambat*
C.V.	Coefficient of Variation
CBS	Central Bureau of Statistics
CDES	Central Department of Environmental Science
CES	Consulting Engineers Salzgitter
cfu	Colony Forming Units
CGD	Central Groundwater District
CO_2	Carbon Dioxide
COE	Center of Excellence
CREEW	Center of Research for Environment Energy and Water
CWSS	Community Water Supply and Sanitation
DA	Deep Aquifer
DEM	Digital Elevation Model
DFTQC	Department of Food Technology and Quality Control
DHM	Department of Hydrology and Meteorology
DIC	Dissolved Inorganic Cabon
DMG	Department of Mines and Geology of Nepal
DNA	Deoxyribonucleic acid
DNI	Distribution Network Improvement
DOC	Dissolved Organic Carbon
DOI	Department of Irrigation
DOM	Department of Meteorology
DWSS	Department of Water Supply and Sewerage
E. coli	*Escherichia coli*
EC	Electrical Conductivit
e.g.	Example
ENPHO	Environment and Public Health Organization
etc.	et cetera
FMIST	Farmers Managed Irrigation System Promotion Trust
GCOE	Global Center of Excellence

GIS	Geographic Information System
GISP	Greenland Ice Sheet Project
GoN	Government of Nepal
GrWr	Groundwater Contribution in Total Supply
GSI	Geological Survey of India
GW	Groundwater
GWRDB	Groundwater Resources Development Board
H_2	Hydrogen
H.P.	Horese Power
hr/day	Hours Per Day
IAHS	International Association of Hydrological Sciences
IC	Inorganic Carbon
ICIMOD	International Centre for Integrated Mountain Development
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometer
ICRE-UY	International Research Center for River Basin Environment-University of Yamanashi
IDC	Inter Disciplinary Consultants
IGES	Institute for Global Environmental Strategies
INGO	International Non-Governmental Organization
IOE	Institute of Engineering
IRP	Iron Removal Plant
ISET-Nepal	Institute for Social and Environmental Transition-Nepal
JICA	Japan International Cooperation Agency
JVS	Jalsrot Vikas Sanstha
KUKL	Kathmandu Upatyaka Khanepani Limited
KVWSMB	Kathmandu Valley Water Supply Management Board
KVWSWSI	Kathmandu Valley Water Supply and Wastewater System Improvements
kW	kilo Watt
l/day	Litres Per Day
lpcd	Litres Per Capita Per Day
m^2	Square Metre
m^3	Cubic Metre
mbgl	Metres Below Ground Level
MCM	Million Cubic Metres
M.E.	Master of Engineering
meq/l	Milli-equivalent Per Litre
mg/L	Milligram Per Litre
MIS	Management Information System
ml	Millilitre
MLD	Million Litres a Day
mm	Millimetre
MoE	Ministry of Environment

MoEn	Ministry of Energy
MoI	Ministry of Industry
MoIr	Ministry of Irrigation
MoPE	Ministry of Population and Environment
MoPPW	Ministry of Physical Planning and Works
MoST	Ministry of Science and Technology
MoU	Memorandum of Understanding
MWSP	Melamchi Water Supply Project
N.A.	Not Available
NAST	Nepal Academy of Science and Technology
nec-CPS	Nepal Engineering College- Centre for Post-graduate Studies
NEWAH	Nepal Water for Health
NGD	Northern Groundwater District
NGO	Non-Governmental Organization
NGOFUWS	NGO Forum for Urban Water and Sanitation
NH_4-N	Ammonium-Nitrogen
NLSS	National Living Standard Survey
NO_2-N	Nitrite-Nitrogen
NO_3-N	Nitrate-Nitrogen
PhD	Doctor of Philosophy
NPC	National Planning Commission
NTU	Nephelometric Turbidity Units
NWP	Nepal Water Partnership
NWSC	Nepal Water Supply Corporation
ORP	Oxidation Reduction Potential
PO_4-P	Phosphorus
S	Storage Coefficient
S.D.	Standard Deviation
SA	Shallow Aquifer
SAPI	Special Assistance for Project Implementation
SC	Specific Capacity
SEN	The Small Earth Nepal
SERD	School of Environment, Resources and Development
SET	School of Engineering and Technology
SGD	Southern Groundwater District
SLAP	Standard Light Antarctic Precipitation
SOM	School of Management
SRWSP	Self Reliant Drinking Water Support Programme
STS	Students-Teachers-Scientists
Sup	Supply
Sy	Specific Yield
TU	Tribhuvan University

UEMS	Urban Environment Management Society
UfW	Unaccounted for Water
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UN-HABITAT	United Nations Human Settlements Program
UNICEF	United Nations Children's Fund
UofS	University of Saskatchewan
USAID	United States Agency for International Development
UY	University of Yamanashi
VDCs	Village Development Committees
VDWEA	Valley Drinking Water Tanker Entrepreneurs' Association
V-SMOW	Vienna Standard Mean Ocean Water
WDR	Western Development Region
WECS	Water and Energy Commission Secretariat
WES	Water Equilibration System
WHO	World Health Organization
WRMC	Water Resource Management Committee
WRMSCs	Water Resource Management Sub-committees
WSTFC	Water Supply Tariff Fixation Commission
WT	Water Temperature
WTP	Water Treatment Plant
WUA	Water User Association
‰	per mil
^{18}O	Oxygen isotope (8 protons, 10 neutrons; moles)
^{2}H (D)	Hydrogen isotope (1 proton, 1 neutron; moles)
$\delta^{18}O$	$((^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{V\text{-}SMOW})/(^{18}O/^{16}O)_{V\text{-}SMOW}$ x1000 (‰)
δD	$((^{2}H/^{1}H)_{sample} - (^{2}H/^{1}H)_{V\text{-}SMOW}) / (^{2}H/^{1}H)_{V\text{-}SMOW}$ x 1000 (‰)
µg/L	Micrograms Per Litre
µm	Micrometres
µS/cm	Micro Siemens Per Centimetre

CONTENTS

1. INTRODUCTION

1.1 BACKGROUND

Groundwater has been an important source of water supply in the Kathmandu Valley since time immemorial. The means of accessing groundwater, however, has been advancing towards mechanized extractions from traditional ones (e.g., stone spouts, springs, dugwells and infiltration galleries) used during ancient times. To cater the escalating water demands in the valley, mainly after the early 1970s, as the valley started to develop rapidly as an urban center, it was necessary to extract water from the deeper part of the aquifer; and the mechanized extraction made it possible. Driven by increasing population, urbanization, and industrialization (including tourism), extraction of groundwater took a sharp rise in the mid-1980s. The extraction is steadily increasing even today. Data from secondary sources indicate that the extraction has increased from 2.3 Million-Litres-a-Day (MLD) in 1979 (Binnie and Partners, 1988) to 80 MLD in 2011 (personal communication with Mr. Hari P. Dhakal, Executive Director, Kathmandu Valley Water Supply Management Board). Nearly half of the total water supply from the government's authentic operator, *Kathmandu Upatyaka Khanepani Limited* (KUKL), during wet season and 60-70% during dry season is derived from groundwater sources (ICIMOD, 2007). The extensive use of the groundwater (beyond the rate of recharge) coupled with inadequate management of solid waste and wastewater from urban centers has increased the vulnerability of the groundwater system to (groundwater) resource depletion, quality degradation and land subsidence (Pandey et al., 2010). On the other hand, injustice seems to be appearing in the valley from a high disparity in the use of groundwater. There is a vast difference in between 'haves' and 'have-nots', a rich person who can afford can use the groundwater as much as s/he needs and due to these activities, a poor is deprived of using the groundwater even for subsistence use. In this context, management of the valley's groundwater system including its source, quantity and quality is essential to ensure sustainable and equitable use of the precious resource.

Since the early 1960s, numerous studies have shed light on groundwater aquifers of the Kathmandu Valley. The studies focus on geological formations, groundwater environment, recharge and hydrogeology. Their scopes range from groundwater investigation(s) for the purpose of groundwater development to academic research for a better understanding the natural environment and the factors that have control on it. Major groundwater investigations made so far in the valley's aquifers are summarized in Table 1.1 along with groundwater-related focus of the studies. Several other studies carried out by scholars at universities, research institutes and non-governmental and/or governmental organizations are published (enlisted in Appendix-A1) in the form of reports, theses, conference proceedings and peer-reviewed papers.

Table 1.1 Notable groundwater investigation and research programs in the Kathmandu Valley

Name of the study/project	Organization(s) involved	Duration	Focus (groundwater-related)
Groundwater resources of the Kathmandu Valley	*Geological Survey of India (GSI)*	*1961-1966*	*Groundwater hydrology and geology*
Groundwater investigations in the Kathmandu Valley to prepare master plan for the water supply and sewerage for Greater Kathmandu and Bhaktapur	*World Health Organization (WHO), United Nations Development Programme (UNDP), Binnie and Partners*	*1971-1973*	*Assess groundwater recharge, potential for multi-purpose use; groundwater quality (physical, chemical and bacteriological); collect and evaluate available hydrogeologic data; construction of exploratory and observation wells*

Water supply for Kathmandu-Lalitpur from outside the valley (Groundwater resources within the valley)	*Binnie and Partners in association with MULTI Disciplinary Consultants and Coopers and Lybrand Associates*	*1987-1988*	*Updated assessment of groundwater resources within the Kathmandu Valley by observing water levels, testing recently constructed wells, estimate recharge, behavior of aquifers*
Groundwater management project in the Kathmandu Valley	*Japan International Cooperation Agency (JICA)*	*1989-1990*	*Hydrology, hydrogeology, recharge, groundwater simulation, groundwater management plans*
The assessment of groundwater pollution in the Kathmandu Valley	*Australian Geological Survey Organization and Department of Irrigation (AGSO/DOI)*	*1994-1997*	*Characterize groundwater quality and its spatial distribution*
Engineering and environmental geological map of the Kathmandu Valley	*Department of Mines and Geology of Nepal (DMG)/BGR*	*1994-1998*	*GIS-based mapping of all basic geological and environmental data, that help identify areas for preferable extraction of construction materials, groundwater protection zones, etc.*
Urban water supply and sanitation rehabilitation project for the Kathmandu Valley towns	*Consulting Engineers Salzgitter (CES) in association with GOPA Consultants, SILT Consultant and MULTI Disciplinary Consultants*	*1996-1999*	*Rehabilitation of 16 existing groundwater wells, construction of 11 new wells to cope with serious water supply shortage in certain areas of the Kathmandu Valley*
Urban water supply reforms in the Kathmandu Valley	*Metcalf and Eddy in association with CEMAT Consulting Company*	*1998-2001*	*Establishment of groundwater monitoring networks, preparation of inventory of groundwater wells, hydrogeologic properties of aquifer, and groundwater levels*
Optimizing water use in the Kathmandu Valley	*Acres International in association with Arcadis Euroconsult Land and Water Product Management Group, East Consult and Water Asia*	*2001-2004*	*Groundwater simulation, database of groundwater level, use and hydrogeology; short term action plan, management strategies*
Development of groundwater knowledgebase of the Kathmandu Valley using state-of-the-art technologies	*University of Yamanashi-Japan after signing MoU with local partners like ENPHO, TU and CREEW*	*2006-ongoing*	*Groundwater hydrology, quality, microbiology, treatment technology and public health*

BGR: Federal Institute of Geosciences and Natural Resources of Germany; ENPHO: Environment and Public Health Organization; TU: Tribhuvan University; CREEW: Center of Research for Environment Energy and Water; MoU: Memorandum of Understanding

1.2 NEED OF THE BOOK

Exemplary studies on groundwater system of the Kathmandu Valley have been conducted in the past by academicians, researchers, working professionals and the government. However, a major drawback reflected in the studies is the repetition of the key issues which have already been dealt with previously. Lack of proper documentation and the trend of keeping the data and information to oneself, which is very common in Nepal, has led to such duplication of work. A very slow pace of revising and updating the existing studies is also seen as a pronounced shortcoming. The concerned authorities not willing to be responsible to take the stake in carrying out comprehensive studies in an organized manner has further exacerbated the problem. Lack of resources and the decade-long turbulent political situation of the country has intensified the condition. These activities are mere losses to the society. This book advocates for and attends to the need of a coordinated approach to studies related to groundwater in the valley.

Compiling and disseminating latest results and findings about groundwater system through a single window helps for coherent visualization of various aspects of groundwater issues and potential ways to deal with them. It would provide a scientific basis to advocate for appropriate policies and need of subsequent institutional and legal arrangements for groundwater management in an area. This book is the first attempt to document and disseminate the latest understanding of groundwater system in the Kathmandu Valley among the policy makers, academicians, researchers, practitioners, and professionals from diverse domains. To ensure scientific reliability, the results and findings included in this book have undergone a peer-review process. Each chapter was reviewed by at least two experts in the relevant field and was then revised in accordance with the critical evaluation from the reviewers.

1.3 OUTLINE OF THE SECTIONS

The book is divided into five sections, twelve chapters, and three Appendices. The five sections focus on introduction, quantity, quality, use and institutions and policies, respectively. The 'Introduction' section consists of two chapters (Chapter 1 and 2) and introduces the book itself as well as current status of groundwater research in the Kathmandu Valley with respect to quantity, quality and management. The 'Groundwater Quantity' section has three chapters (Chapter 3, 4 and 5) which deal with geology and hydrogeology of aquifer systems, their groundwater storage potentials, and groundwater recharge altitudes within the valley. The third section is about 'Groundwater Quality', which accommodates three chapters (Chapter 6, 7 and 8) and provides an overview of chemical quality of groundwater, microbial contamination and technology to treat the contaminated water. The fifth section on 'Groundwater Use' consists of three chapters (Chapter 9, 10 and 11) and features an analysis of domestic water use, groundwater use under current and future contexts and due to evolution and spread of groundwater-based water markets in the Kathmandu Valley. Finally, the last section, 'Institutions and Policies', has only one chapter that provides an overview of the institutions and policies related to groundwater development and management in Nepal.

There are three Appendices in the book. 'Appendix –A1' enlists available publications related to groundwater in the Kathmandu Valley along with the type of publication (journal, report, conference proceeding and thesis) and potential location from where they could be accessed. 'Appendix-A2' provides an inventory of selected stone spouts in the valley. They were selected considering spatial coverage (distribution within five municipalities) and their present conditions (classification of present conditions were made in accordance to IOCN-UNESCO-RCUWM (2008)). The last Appendix (Appendix-A3) contains a brief biography of all the authors, advisors, editors, associate editors, research associates and reviewers who contributed their valuable time and expertise to this book.

1.4 TARGET AUDIENCE

The book is expected to be useful to a wide range of readers from high level policy-makers in governments, affiliates of INGOs, NGOs and civil societies, researchers to graduate students from universities and academic institutions, and other concerned stakeholders. The data, information and findings documented in this book would help strengthen the scientific knowledgebase about groundwater system in the Kathmandu Valley and be useful to formulate new policies or to amend the existing policies, which guide the sustainable development and management of groundwater resources in the valley.

1.5 REFERENCES

- Binnie and Partners (1988). *Water supply for Kathmandu-Lalitpur from outside the valley*. Final Report on Feasibility Study, Appendix-L (Groundwater resources within the valley).
- ICIMOD (2007). *Kathmandu Valley Environmental Outlook*. International Center for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal. ISBN 978 92 9115 019 9.
- IOCN-UNESCO-RCUWM (2008). *Situation of traditional water spouts in Kathmandu Valley*.
- Pandey V.P., Chapagain S.K., Kazama F. (2010). Evaluation of groundwater environment of Kathmandu Valley. *Environmental Earth Sciences* 60(6), 1329-1342.

2. COMPREHENSIVE REVIEW OF GROUNDWATER RESEARCH IN THE KATHMANDU VALLEY, NEPAL

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ABSTRACT

Drinking water quality and quantity has been one of the major concerns in water sector in the Kathmandu Valley, the biggest urban center in Nepal. Aquifer characteristics and groundwater flow properties are complex. They vary laterally, vertically and temporally creating dynamic, interdependent systems that can be affected in unpredictable and irreversible ways as a result of rapid development and mismanagement. Over-extraction of groundwater in the valley has resulted in groundwater depletion. The problems related to groundwater quality range from contamination from sewage line, septic failures, and open pit toilets, leaching from landfill sites, and direct disposal of domestic and industrial wastes to the surface water. Studies have shown that both the quantity and quality of groundwater in the valley are in immense threat that needs immediate attention. The research, development and management of groundwater resources are still emerging. Priorities need to be set up for effective mapping and monitoring of this resource by developing research, management plans and policies geared towards effective management of this valuable resource. This paper summarizes current status of groundwater research and suggests further research needs in the area based on available literature.

Keywords: *aquifer development, extraction, mapping, water quality*

2.1 INTRODUCTION

Groundwater resources play a major role in ensuring livelihood security across the world and can provide a uniquely reliable source of high-quality water for human uses (UNESCO, 2009). Not all groundwater is accessible. In many cases it is too deep or too salty to be used. In other case the ground water is soils with little permeability. In cases that groundwater is available; it is perceived by many, as inexhaustible resource. Therefore, in many places in the semi arid and arid areas of the world, groundwater tables are dropping with rates of 1 m/year or more (Clark and King, 2004). Base flows in streams, wetlands and surface vegetation are in many cases dependent on groundwater levels and discharges. Change in those levels or changes in groundwater quality induce cascading effects through terrestrial and aquatic ecosystems. In China, for example that once had many beautiful rivers, groundwater withdrawal caused these rivers to disappear or in some cases are filled with the wastewater from the cities. The same is true for Kansas, USA where rivers are becoming endangered (Palmer, 2003). The ability to access groundwater plays a major role in increasing incomes and reducing risks in agricultural economy (Moench et al., 2003). The depletion of groundwater is taken as the first indicator of water scarcity (Shah and Indu, 2004). The depletion also indicates unsustainable extraction and lack of proper management.

Drinking water quality and quantity has been one of the biggest concerns in water sector in the Kathmandu Valley, the biggest urban center in Nepal (Cresswell et al., 2001; Pathak et al., 2009). The problems related to groundwater range from contamination from sewage line, septic failures, open pit latrines (Jha et al., 1997), leaching from landfill sites, and direct disposal of domestic and industrial wastes to the surface water (Khadka, 1992; Karn and Harada, 2001). Surface water in the Kathmandu Valley is highly polluted due to unregulated disposal of domestic and industrial wastes. Such haphazard waste disposal systems cause contamination of shallow aquifers (SIWI, 2010). About 50% of the water supply in the valley is from groundwater systems that consist of both shallow and deep aquifers (Jha et al., 1997; Khatiwada et al., 2002). Varieties of systems such as tubewells, dugwells, and stone spouts constitute major mechanisms of groundwater use, due to insufficient supply of surface

3. GEOLOGY AND HYDROGEOLOGY OF GROUNDWATER AQUIFERS IN THE KATHMANDU VALLEY

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ABSTRACT

This chapter discusses geological formations in the Kathmandu Valley, their lithological descriptions, groundwater aquifer system and hydrogeologic characteristics. The description and discussion are based basically on secondary data and available study reports. Rocks in aquifer bed and in the hills surrounding the valley are subdivided into seven geological formations while the Fluvio-Lacustrine deposits that form the valley's aquifers are subdivided into eleven geological formations. Groundwater aquifer system in the valley is classified into seven types. From the perspective of hydrogeological characteristics, the aquifer system is also divided into three groundwater districts, namely, Northern, Central and Southern. Northern Groundwater District has high groundwater production potential compared to the Central and Southern Groundwater Districts due to predominance of coarse grained aquifer material like sand and gravel. In the central and southern groundwater districts, about 200 m thick lacustrine clay bed (kalimati) overlies the gravel aquifer. Hydrogeological parameters like Transmissivity (3.3-1963 m^2/day), Hydraulic Conductivity (10^{-2} to 10^{-4} cm/sec) and Specify Capacity (0.09-5.57 lps/m) are also higher in the north. Besides the soft sediments, hard rock aquifer mainly the carbonate rocks in the southern parts of the valley could prove to be a major source of water supply as evident from the fact that spring source contributed about 14 Million-litres-a-day (MLD) in 1999.

Keywords: *fossil water, groundwater districts, hard rock aquifer, hydrogeology, Kathmandu Valley*

3.1 INTRODUCTION

Groundwater has been widely used in the Kathmandu Valley since ages and for all purpose including drinking. In the past, groundwater from shallow aquifer were used extensively and taken for granted as it was available in plenty. In recent times, groundwater from deep aquifers has become a major contributor in the city water supply. About 49 municipal deep and shallow wells contribute 23.5 Million-Litres-a-day (MLD) (GWRDB, 2009) of groundwater to the municipal water supply. Most of the residents totally depend on shallow groundwater sources for their daily water needs which they receive through unspecified number of dugwells, hand pumps, borings and *dhunge dharas* (stone spouts).

In recent years, however, there has been large depletion of groundwater in both shallow and deep aquifers due to higher extraction than the natural recharge. However, due to fining southward sequence of sedimentary deposits in the valley, groundwater yield is lower in the southern part of the valley. Similarly, the impact of large scale abstraction is also not uniform throughout the valley. Hence the current study highlights the variation in local geology, the hydrogeological parameters associated with the variation and their impact on groundwater availability.

3.2 GEOLOGICAL SETTING

The valley consists of basement rocks on the bottom and the surrounding hills. The basin fill sediments overlie the basement rocks. The basement rock constitutes intensely folded, faulted and fractured, igneous and metasedimentary rocks which are more than 400 milion years old (Devonian to Precambrian age). The sediments on the valley floor consists of unconsolidated to partly consolidated sediments of 5 million years or younger (Pliocene and younger) (Stocklin and Bhattarai, 1977).

The rock types range from granite, gneiss, schist to migmatites in the north to northeastern parts which are highly weathered and thus gives rise to large amount of alluvial and colluvial deposits in the form of cone and fan (Figure 3.1). In the east and west, the rock type is mainly composed of phyllite, sandstone and limestone and to the south are slate, metasandstone, quartzite, siltstone,

4. GROUNDWATER STORAGE POTENTIAL IN THE KATHMANDU VALLEY'S SHALLOW AND DEEP AQUIFERS

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ABSTRACT

This study delineates spatial distribution of thickness and estimates groundwater storage potential of shallow and deep aquifers in the Kathmandu Valley. The 'groundwater storage potential' refers to the volume of groundwater that can theoretically be extracted if the aquifer were completely drained. The potential is calculated by multiplying aquifer volume with storage coefficient. GIS is used for calculating spatial variation of the storage potential. The study results show that total storage potential of the shallow aquifer is high (1.5 Billion-Cubic-Metres, BCM) compared to the deep (0.6 BCM). Spatial variation of the potential in the shallow aquifer is in a range of less than 100 to 6,800 m^3/400 m^2, which is higher than that of the deep aquifer; in which, the potential is less than 1,000 m^3/400 m^2 in most parts of the aquifer. If the groundwater reserve is used at the same rate as in 2001 (i.e., 21.56 Million m^3/year), the reserve would be emptied in less than 100 years. Furthermore, empty space above groundwater level in shallow aquifer can store 226.5 Million m^3/year (at maximum) of groundwater. If the space could be filled by artificial and/or managed aquifer recharge for future use, it could play a significant role in augmenting water supply in the valley.

Keywords: *GIS, groundwater, Kathmandu Valley, storage potential, water resources*

4.1 INTRODUCTION

Groundwater aquifers in the Kathmandu Valley are already under stress. Total extraction is exceeding recharge. Negative consequences of excessive groundwater development have been visualized in forms of drying of stone spouts, decline in design yield of wells and depletion in groundwater levels. Unfortunately, management interventions are yet to come into effect. An understanding of groundwater storage potential and its spatial distribution would help reduce pressure on groundwater resources through informed decision making. The estimated storage potentials - if analyzed together with other hydrogeologic characteristics - may help delineate 'potential areas for groundwater development', which has direct implications to groundwater management. Additionally, such estimates could be useful for conjunctive use planning and exploring the prospects of artificially recharging the aquifers and using the stored water during acute deficit in future. Therefore, considering future growth in water demand and sustainable use of groundwater resources it has become imperative to estimate and map groundwater storage potentials in the valley's aquifers.

Several earlier studies have shed lights on the geological formations (e.g. Yoshida and Igarashi, 1984; Dongol, 1985; Shrestha et al., 1998; Sakai, 2001) and hydrogeology of the valley's aquifers (e.g. Binnie and Partners, 1973; JICA, 1990; Metcalf and Eddy, 2000; KC, 2003). They revealed that the Kathmandu Valley is composed of two series of geological successions. Precambrian to Devonian rock forms the basement and hills surrounding the valley which are overlain by Quaternary sediments and recent alluvium (Kharel et al., 1998). The stratigraphy of the sediment deposit consists (in an ascending order) of: Tarebhir, Lukundol, and Itaiti Formations in the southern part; Bagmati, Kalimati, and Patan Formations in the central part; and Thimi and Gokarna Formations in the northern part of the groundwater basin (Sakai, 2001). From the perspective of hydrogeology, the sediment stratigraphy can be classified in three general hydrogeologic layers in a descending order as shallow aquifer, aquitard and deep aquifer (Figure 4.1). The shallow aquifer corresponds to Thimi, Patan and Gokarna Formation; aquitard corresponds to Kalimati Formation; and deep aquifer corresponds to Lukundol, Bagmati and Tarebhir Formations (Pandey and Kazama, 2011). The aquitard layer acts as a barrier for direct recharge of deep aquifer layer

5. SHALLOW GROUNDWATER RECHARGE ALTITUDES IN THE KATHMANDU VALLEY

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ABSTRACT

Isotope tracer methods were used to estimate shallow groundwater recharge altitudes in the Kathmandu Valley. Nine spring water samples in the Mt. Jamachowk area and 35 shallow groundwater samples in the valley floor were collected. Stable isotope values in spring water show a significant gradient with elevation; -0.15 permil/100 m for δD and -0.22 permil/100 m for $\delta^{18}O$. The recharge altitude range for shallow groundwater was calculated using relationship between δD and altitude and δD values of groundwater samples. The range is very wide (600~1,700 m). A higher (>1,500 m) recharge altitude was found in groundwater samples from northern and southern part of the sampling area whereas lower (<1,500 m) recharge altitudes for the central area. These results based on isotope data and surface geological conditions indicate that shallow groundwater in the Kathmandu Valley is recharged from different altitudes in the valley floor itself rather than mountains surrounding the valley.

Keywords: *altitude effect, groundwater recharge, Kathmandu Valley, oxygen and hydrogen stable isotope of water, shallow groundwater*

5.1 INTRODUCTION

The Kathmandu Valley receives a good amount of precipitation; about 1,755 mm in a year (Acres International, 2004). About four-fifth of that falls during July to September. A majority of that precipitation is drained out of the valley by Bagmati River. On the other hand, continuous withdrawal of groundwater resources from shallow and deep aquifers in the valley to fulfill a large proportion of total water demand has resulted in depletion of groundwater reserve. In this context, strategies and action plans to retain large amount of the monsoon rainfall in the valley's aquifers are to be developed without further delay. Identifying potential areas for groundwater recharge is the very first step in developing the strategies and action plans which help protect the areas to enhance natural and/or artificial groundwater recharge in the valley.

Isotope hydrology techniques are widely used to determine source and potential areas of groundwater recharge. Characteristic variation in ^{2}H (D) and ^{18}O content of precipitation which occurs due to differences in temperature, elevation and distance from the coast provides clue to infer recharge areas for groundwater, to indicate mixing, or to delineate different groundwater systems (e.g., Scholl et al., 1996; Fontes, 1980).

It is well known that D and ^{18}O values of precipitation and surface waters are depleted with increasing altitude. This altitude effect (Dansgaard, 1964; Siegenthaler and Oeschger, 1980) has been recognized in almost all the major mountain belts of the world. This effect results principally from Rayleigh distillation and the depletion of D and ^{18}O in precipitation and vapor as an air mass rises orographically and drains out moisture, though there are numerous other factors that can modify an air mass's isotopic scintillation profile. As a result, in regions of a single dominant moisture source, precipitation and surface waters at high elevations or on the leeward side of mountain ranges are often strongly depleted in D and ^{18}O as compared to waters on the windward side. The altitude effect is most often expressed as an isotopic lapse rate and given as a permil change in δD or $\delta^{18}O$ of precipitation per 100 m of elevation change. Such lapse rate varies depending on location on the earth. An equation that expresses altitude as a function

6. OVERVIEW OF CHEMICAL QUALITY OF GROUNDWATER IN THE KATHMANDU VALLEY

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ABSTRACT

This study was carried out to assess the overall quality of groundwater in the Kathmandu Valley, Nepal. Samples from deep and shallow groundwater were collected and analyzed for the major physicochemical parameters. The water quality variables such as; NH_4^+-N, Fe, Pb, Cd in most of the groundwater samples exceeded the WHO guideline levels for drinking water. Arsenic concentration was <10 μg/L (i.e. WHO standard) in shallow groundwater; whereas, in deep groundwater, 52% (n=42) exceeded the WHO standard. Arsenic varies spatially with higher concentration towards the central part of the valley. Water quality of deep groundwater is influenced by natural hydrogeochemical environment. Unlike deep groundwater, the shallow groundwater is influenced by local contamination from anthropogenic sources such as domestic wastewater.

Keywords: *arsenic, groundwater, Kathmandu Valley, water quality*

6.1 INTRODUCTION

Groundwater is an important natural resource, and it is being exploited for human use since the earliest civilizations. Groundwater and surface water are the major sources of drinking water in the Kathmandu Valley, Nepal (Metcalf and Eddy, 2000; ICIMOD, 2007). With increasing population and industrial activities, water demand is abruptly raised in the valley. On the other hand, surface water quality is increasingly being deteriorated. Unplanned disposal of municipal wastes, a common phenomenon in the area, has resulted in excessive accumulation of pollutants into the rivers and land surface. Subsequent leaching of the pollutants has evidently caused deterioration of water quality of surface water and shallow groundwater. This has further increased the use of deep groundwater resource as an alternative, safe and reliable water source. However, quality of deep groundwater is generally not satisfactory. Earlier studies have reported high levels of ammonia, iron and arsenic in the deep groundwater and *E. coli* and nitrate mainly in shallow groundwater in the valley (JICA, 1990; Khatiwada et al., 2002; JICA/ENPHO, 2005).

Groundwater quality is likely to be affected with the increase in groundwater extraction, changes in land use patterns and socioeconomic conditions. It is influenced by natural (underlying sediment, sediment-water interactions) as well as human activities; therefore, its quality may get changed over time (Hoencamp, 1997; Kouras et al., 2007). In the absence of long-term groundwater monitoring program, status of groundwater quality in recent years under the changing land use pattern of the valley is poorly known. This study assesses current status of groundwater quality in the valley and evaluates its suitability for drinking with respect to WHO guideline (WHO, 2004). Relatively more emphasis is given to describe occurrence of arsenic.

6.2 MATERIAL AND METHODS

6.2.1 Sampling

A total of 55 water samples, consisting of 42 deep and 13 shallow groundwater, were collected in April, 2007. Sampling area covered nearly 80 km^2, which is inhabited by a majority of the population in the valley. Details of the sampling locations are shown in Figure 6.1.

Prior to collection of water sample, purging of wells were performed carefully to remove the stagnant water. The samples were collected in polyethylene bottles (250 ml); which were rinsed properly before filling. The filled bottles were kept immediately in an ice box. After sampling, each bottle of collected water sample (250 ml) was further separated into 3

7. MICROBIAL POLLUTION IN GROUNDWATER AND SURFACE WATER OF THE KATHMANDU VALLEY

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ABSTRACT

Water quality of wells and rivers in the Kathmandu basin was examined for ion and microbial polluation (with E. coli as an indicator) concentrations in 2007. The results showed that almost all waters of rivers and shallow wells were not suitable for drinking because of the presence of E. coli and only 29% of deep tubewells had drinkable waters. We could not find clear relationship between E. coli concentration and other concentrations of the deep tubewells except for NH_4-N. The deep tubewells were categorized in two groups; Floride (F^{--}) rich wells in the north east part and NH_4-N rich wells in the south west part. Principal component analysis suggested that the scores of principal components related with F^- and PO_4-P concentrations had relationship with E. coli concentrations, respectively.

Keywords: *E. coli, groundwater pollution, Kathmandu basin*

7.1 INTRODUCTION

In Asia, only limited number of persons can use safe drinking water and there are many children who are killed by acute diarrhoea that originates from water. Groundwater is an important water resource in Asia, but differing from Japan, microbial contamination is reported in Nepal (Warner et al., 2008), Cambodia (Watanabe, 2007) and Indonesia (Wangsaatmaja et al., 2005). In the Kathmandu Valley of Nepal, as reported in several earlier studies (JICA, 1990; Jha et al., 1997; Khadka, 1992; Karn and Harada, 2001; JICA/ENPHO, 2005; Warner et al., 2008);

- About a half of the drinking water source is groundwater, and water supply is limited to 2 or 3 hours per day, and a lot of people are using a traditional stone spouts etc. together with wells to extract potable water.
- Groundwater is contaminated with *E. coli*, nitrate, ammonia, iron, arsenic, etc.
- It is the microbial contamination such as *E. coli* that is the most serious in potable water. A lot of people have been affected by diarrhoea with polluted water from wells and taps.
- *E. coli* contamination is observed in tap water, well water or stone spout water. The residents favor the stone spouts water (*E. coli* detection rate=73%) as drinking water because of its better taste than the deep well water, though its health risk is larger than the deep well water (*E. coli* detection rate=40%).

Observations from the earlier studies motivated International Research Center for River Basin Environment of University of Yamanashi (ICRE-UY) for a continuous monitoring and assessment of groundwater quality in the Kathmandu Valley. In 2006, ICRE-UY, which is contributing to capacity development of Nepal since 2003 by training young scholars through its educational program, initiated groundwater research in the valley. In the subsequent years – with the involvement of several professors, researchers and students (both graduate and undergraduate) - it expanded its research under three broad themes, namely *groundwater hydrology*, *quality and treatment*. The groundwater *hydrology* group is working to assess the overall situation of groundwater environment, to estimate groundwater storage potential, to estimate groundwater recharge and groundwater residence time, to model groundwater flow and to assess sustainability of groundwater management. The *quality* group on the other hand is continuously monitoring groundwater quality including microbial contaminations, assessing their spatial and temporal distributions and understanding the

8. ATTACHED GROWTH SYSTEM FOR NH_4-N REMOVAL FROM GROUNDWATER IN THE KATHMANDU VALLEY

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ABSTRACT

Ammonium-nitrogen (NH_4-N) higher than standard for drinking, high Fe and low nutrient (i.e., inorganic carbon (IC) and phosphorus (PO_4-P)) in groundwater and load shedding triggered by power shortage are typical characteristics of the Kathmandu Valley. To treat NH_4-N from the groundwater, this study proposes a simple and energy-efficient "attached growth system", analyzes effect of Fe and nutrient on the NH_4-N removal efficiency at lab-scale and evaluates its performance at pilot-scale. The pilot-scale system was installed in an existing community-scale groundwater treatment system located at Chyasal area in the valley. The study results show that a high Fe (of 10 mg/L) decreases the NH_4-N removal efficiency by 30% while a low nutrient concentration (i.e., 30 mg/L of IC, 0.01 mg/L of PO_4-P) has no effect on the efficiency. Based on the findings, the pilot-scale system was set-up after pre-treatment units (i.e., aeration, sedimentation and filtration) for Fe removal. In the current preliminary phase (first 180 days of operation), the system is fed with controlled discharge of 216 L/day. The results show that 60-90% of the NH_4-N is removed, however, a high nitrate-nitrogen (NO_3-N) is observed in the treated water. For achieving complete nitrogen (NH_4-N and NO_3-N) removal and increasing the treatment capacity of the system, the study should be continued further by installing a denitrification unit and analyzing the system performance under increased flow rates.

Keywords: *attached growth system, drinking water, fiber carrier, groundwater, NH_4-N, nitrification*

8.1 INTRODUCTION

Groundwater qualities of shallow and deep groundwater in the Kathmandu Valley are reported in several literature (e.g., Khadka, 1992; Chettri and Smith, 1995; Jha et al., 1997; ENPHO, 1999, 2005; Gurung et al., 2006; Chapagain, 2009; Chapagain et al., 2010). The studies reveal that shallow aquifers are polluted by anthropogenic activities such as disposal of sewage, industrial effluents, leachate and infiltration from polluted streams whereas deep aquifers primarily from sedimentary make-up of the aquifer which consists of fluviolacustrine deposits (of Pliocene-Quaternary period) intercalated with black clay, peat and lignite (Metcalf and Eddy, 2000) and rich in organic matters (reported in Fujii and Sakai, 2001). Chapagain et al. (2009) reports that mean NH_4-N concentration in deep and shallow groundwater are 23.3 and 5.3 mg/L respectively and concentrations of several parameters (NH_4-N, Fe, Pb, Cd and As) in deep groundwater exceed standard (WHO, 2004) for drinking. The level of exceedance is the highest in case of NH_4-N, with mean concentration of more than 15 times greater than the WHO standard (i.e., 1.5 mg/L). The NH_4-N concentration varies widely (from <10 to >100 mg/L) within the core area of the valley (Figure 8.1).

Generally, the NH_4-N contamination arises either from human activities like waste disposal, fertilizer use, contaminated land and wastewater discharge or produced naturally by mineralization of organic matter *in-situ* and sorption of metal oxide (i.e., Fe and Mn) (Buss et al., 2004). Although the consumption of NH_4-N contaminated water has no direct threat to the health, it can cause effects like: (i) displeasure for drinking due to bad taste and smell; (ii) reduction of free chlorine (Cl_2) disinfection, leading to contamination of pathogenic microorganisms; (iii) corrosion of lead and copper in the water supply system, resulting in increasing lead and copper contaminations; and (iv) conversion of NH_4-N

9. ANALYSIS OF DOMESTIC WATER USE IN THE KATHMANDU VALLEY

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ABSTRACT

This chapter provides a holistic picture of domestic water use in Kathmandu Metropolitan, with particular attention to how households exercise water-use under the deficient water supply service. In the study area, water supply is often intermittent, and it forces households to cope with the deficiency by relying on alternative sources or other means. As some of the alternative sources might have health risk, the multiple water use requires households to choose appropriate sources according to purposes, and to use them in a proper manner. However, some households might have limited capacity to do so. Hence it is important to have a good picture of multiple water use for future policy making. Among a variety of water sources available, accessible, and affordable in the area, this chapter focuses on the two major sources: piped-water and groundwater.

Keywords: *household water consumption, household water sources choice, piped and non-piped water use, Kathmandu Metropolitan*

9.1 INTRODUCTION

Piped-water supply services provided by a municipal water utility, namely, Nepal Water Supply Corporation (NWSC) until 2008 and *Kathmandu Upatyaka Khanepani Limited* (KUKL) after that, have poorly performed over the past decades, burdening the public in Kathmandu Metropolitan, Nepal (ADB, 2003). The service is intermittent throughout the year and the quality is unreliable. Despite significant investments and efforts in improving the utility management, the supply service has been inefficient and poorly managed. As a result, access to safe water has been the main problem faced by households living in the area. Due to the rapid growth of population coupled with concentrated enterprise activities, both urban and rural parts of Kathmandu have been acutely affected with the water problem (CBS, 2005).

Total water demand is estimated at 320 MLD (million litres per day) as of 2010 (KUKL, 2011) and is expected to increase further. It is assumed that KUKL in the dry season has a shortfall in supply of some 60%, and in rainy season the shortfall is 30% of supply (KUKL, 2008). To manage the water shortage conditions, KUKL has applied a rationing system whereby water is allowed to flow to different sections in rotation to the service area. Water treatment plants are in existence, however, are in poor functional and maintenance state and spare parts are not available in all the plants. In some systems, water is distributed directly to the customer without treatment and/or monitoring of quality and such water contains ammonium, iron, and arsenic (Yoden and Chettry, 2010).

It is estimated that, as of 2009, there are approximately 164,000 piped-network connections, covering 67% of the urban houses in the KUKL service areas (Yoden and Chettry, 2010). Substantial and widespread leakages, illegal connections, and absence of effective repair systems are resulting in low water pressure at the consumers' taps. Consequently, households that can afford it, use electric pumps to suck water from the pipes, although it is illegal. This results in neighbourhood competition during the short supply-hours, thus accelerating the inequitable water allocation, severe deterioration of the systems and contaminated piped-water.

Inadequate capacity, poor services and poor management of the piped-water supply systems in Kathmandu Metropolitan have burdened the customers by forcing them to spend money on underground tanks, booster pumps, and water filters to retreat the supplied water and even then most of the residents boil the water before drinking. While the basic cost of piped-water in Kathmandu may be cheap, the indirect costs associated with its use are

10. GROUNDWATER USE IN THE KATHMANDU VALLEY: AN ANALYSIS OF PRE- AND POST-MELAMCHI SCENARIOS

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ABSTRACT

Water supply services in urban and semi-urban areas of the Kathmandu Valley are being provided by only one water supply operator, Kathmandu Upatyaka Khanepani Limited (KUKL), using 35 surface sources and 57 deep tubewells. The portion of groundwater contribution in the total production of KUKL is an average of 35% in dry season and 11% in wet season with an annual average of 19% in 2011. Total KUKL supply accounts for 22.5% (in March) and 37.8% (in September) of water demands only. To deal with the increasing water supply deficit and water scarcity in the valley, Melamchi Water Supply Project (MWSP) is underway to bring water from off-the-valley sources. After completion of the project, water supply quantity is expected to be improved with increasing consumption rate from 41 litres/capita/day (lpcd) in 2011 to 126 lpcd in 2025; however, groundwater contribution in total KUKL production is expected to be decreased to 7%, 4%, and 3% in 2016, 2019 and 2025, respectively. If supply system is managed with projected demand of 135 lpcd, the average supply duration is expected to increase from 7 hours/day in 2011 to 23 hours/day in 2025. Other alternate options to minimize the gap between demand and supply of the valley and consequently stress on groundwater resources could be development of urban centers outside the valley, optimum planning of land use for potential recharge, introducing micro to macro level rainwater harvesting programs and riverhead forest protection.

Keywords: *Kathmandu Valley, groundwater use, Melamchi water, water demand management*

10.1 INTRODUCTION

Shortages of surface and groundwater availability and inadequate water supply from water supply agency are identified problems in the Kathmandu Valley. Currently, *Kathmandu Upatyaka Khanepani Limited* (KUKL) is the sole water supply operator to provide water supply services in urban and many rural areas in the valley. The KUKL is supplying drinking water using 35 surface sources, 57 deep tubewells, 20 water treatment plants, 43 service reservoirs and operating about 1,300 major valves. Based on 2011 data, total KUKL supply accounts for only 22.5% (in March) and 37.8% (in September) of water demands. The total wet season supply of 106 million-litres-a-day (MLD) reduces in the dry season to 75 MLD (KUKL, 2011). The water supply services have remained poor despite various attempts through many projects during the last three decades. It was realized that the poor state of water services in the valley was a compounded result of deficiencies in water resources, weaknesses in system capacity, inadequacies in management efficiency and increasing political interferences after the 1990 political change. Projected increase in the population (Table 10.1), continuing urbanization of the valley at a similar rate to the past 10 years, and corresponding increase in water demand would suggest further aggravation of the situation. To fulfill the water demand exceeding the supply, currently, groundwater is the only source supplementary to surface water. In a bid to meet escalating water demand as well as to reduce stress on groundwater resources, the Melamchi Water Supply Project (MWSP) is underway. The MWSP is set to bring 510 MLD water to the Kathmandu Valley from off-the valley sources. It is expected to be completed in three stages (Stage I: 170 MLD from the Melamchi River, Stage II: 170 MLD from the Yangri River, and Stage III: 170 MLD from the Larke River) (MWSDB, 1998). The rivers flow through Indrawati basin, a sub-basin of Koshi river basin.

MWSP is a comprehensive multi-donor water supply mega project that aims to improve the health and well-being of the people in the valley. It will achieve this impact by diverting water from the Melamchi River to the Kathmandu Valley and thus deliver its overall

11. OVERVIEW OF WATER MARKETS IN THE KATHMANDU VALLEY

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ABSTRACT

The Kathmandu Valley has seen a long history of civilization starting from the prehistoric dependency on water. In due course of time, haphazard urbanization and population growth beyond the carrying capacity of the valley has resulted in pollution of surface water, which was the major source for quenching the thirst of the valley denizens. This ultimately led to the extraction of the hidden resources - groundwater - in a massive quantity, both at the individual and commercial levels, creating a good avenue for the water markets in the valley. Lack of regulation mechanisms is helping it to flourish further. This chapter describes the current status of water markets, which is basically based on groundwater, and the facts and figures through recent research. Along with this, the chapter also deals with the role of evolving water market operators in the valley in addressing the water needs through their services in terms of water quality and quantity.

Keywords: *groundwater, Kathmandu Valley, water market*

11.1 INTRODUCTION

Since time immemorial, the inhabitants of the Kathmandu Valley have relied on water sources like stone spouts, springs, dugwells, ponds and water holes (*kuwa*) to fulfill their water demand, which until a few decades ago were functioning very well. These traditional water sources were recharged naturally through local aquifers, which were later augmented by the artificial recharge systems from various sized ponds within the valley during different ruling periods of Nepal. The piped water distribution system was started in 1891 with the construction of *Bir Dhara* water distribution system to supply water to the Rana Palaces and the ruling elites of the country through private water connections and public stand post for the public (NGO Forum, 2008a). After 36 years of the construction of *Bir Dhara*, *Tri Bhim Dhara* came into existence to supply water to the general public in the year 1928 - another piped water supply system added to the already existing network of *Bir Dhara*. In order to organize and manage the piped water supply system in the valley, a government institution was created in 1929 and was named *Pani Goshwara*. In the course of time, this institution had undergone many reforms (as shown in Table 11.1).

At present, KUKL is responsible for all the maintenance, management and organizing water services in the valley, with a total of 1,009 (698 metered and 311 non-metered) government connections, 171,499 (155,429 metered and 16,070 non-metered) private connections and 1,196 public stand posts in the valley (KUKL, 2010), serving 78% of the valley denizens (ADB, 2010), with a leakage of 38%. About 27% of KUKL's production is covered through groundwater pumping (KUKL, 2009). The convenience and pride of having taps at homes, left the traditional water sources in isolation. On the other hand, inadequate attention in protecting natural recharge areas for the traditional sources has resulted many of them as seasonal, almost 60% of them have dried up and many are in the verge of extinction. Traditional stone spouts within all the municipalities of the valley, which were once the main sources of water, now discharges only 2.95 million-litres-a-day (MLD) of water (NGO Forum, 2008c).

Despite the tremendous pipeline connections to a majority of areas, the water received is always minimal, both in terms of quantity and quality. On the other hand, there is a wide gap between water demand and supply

This chapter is based on the results and findings of the M.Sc. research carried out by the students of Interdisciplinary Water Resources Management.

12. GROUNDWATER DEVELOPMENT AND MANAGEMENT INSTITUTIONS AND POLICIES IN NEPAL

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ABSTRACT

This chapter reviews existing groundwater development and management institutions in the Kathmandu Valley and Nepal. The institutional setups at different levels are identified and their key roles and working objectives are also discussed emphasizing the groundwater development and management. In addition, this chapter also provides a review of existing policies on groundwater development and management in the Kathmandu Valley and Nepal.

Keywords: *groundwater policy, institutions, management*

12.1 INTRODUCTION

Groundwater resources development and their use have many facets especially in a country like Nepal. Being an agricultural country, almost 52% of the total land is irrigated and the groundwater extraction has been a better option for its increasingly favored characteristics like 'limited capital requirements and low operation and maintenance costs' and the increased 'freedom' of the farmers in determining the time and quantity of irrigation for their requirements. Similarly, the changing land use patterns and increasing demand of water from the urbanization resulting to overexploitation have also affected groundwater use. Therefore, individuals, water supply agencies, industries and private sectors are dependent more on groundwater as a safe and reliable alternative since the mid-1980s (Dongol, 2010). Since then, to address the groundwater resource's sustainable use and management, various developmental approaches have also been experienced. During the same period, groundwater extraction was increased as Nepal Water Supply Corporation (NWSC) introduced groundwater in their supply system.

Use of groundwater resources for irrigation development in Nepal has a long history. As early as the seventeenth and eighteenth centuries, numerous small *Raj Kulos* (canals) were seen in and around the Kathmandu Valley. Similarly, the first large public sector irrigation canal system (the Chandra Canal System) with a net command area of 10,000 ha was constructed in 1922 and is still in operation. Similarly, Groundwater Resources Development Board (GWRDB) has been established for the enhancement of groundwater study and management of its use in 1976 under Ministry of Water Resources (now Ministry of Irrigation). Likewise, water resources development was recognized by the 8th Five Year Plan (1992-1997) for the improved management of the available supply of irrigation water.

Government of Nepal (GoN) is the owner of water resources found within her territory and also the sole governing body. However, groundwater extraction rights and ownership issues have never taken seriously and they have always had their own ambiguities and been veiled from time immemorial. Moreover, no such regulatory framework concerning the groundwater rights for its users and stakeholders exists in the country (Aryal, 2011).

The scarce groundwater of the Kathmandu Valley has enforced several stakeholders, from government to the non-government organizations to make their efforts in the management and sustainable use of groundwater. This chapter aims to provide reviews of the existing plans and policies, and the acts and regulations related to groundwater

APPENDIX

A1. RESEARCH AND PUBLICATIONS (SELECTED) RELATED TO GROUNDWATER IN THE KATHMANDU VALLEY

S.N	Title of publication	Author(s)	Year	Type	Access
1	A framework for measuring groundwater sustainability. *Environmental Science and Policy*, 14(4): 396-407.	Pandey V.P., Shrestha S., Chapagain S.K., Kazama F.	2011	Journal Paper	Online
2	Hydrogeologic characteristics of groundwater aquifers in Kathmandu Valley, Nepal. *Environmental Earth Sciences*, 62(8): 1723-1732.	Pandey V.P., Kazama F.	2011	Journal Paper	Online
3	A study on estimation of rainwater harvesting potential in the housing colonies of the Kathmandu district. M.Sc. Thesis, Pokhara University.	Sthapit M.	2010	Thesis	SchEMS
4	Assessment of deep groundwater quality in Kathmandu Valley using multivariate statistical techniques. *Water Air and Soil Pollution*, 210 (1-4): 277-288.	Chapagain S.K., Pandey V.P., Shrestha S., Nakamura T., Kazama F.	2010	Journal Paper	Online
5	Assessment of groundwater quality and quantity for sustainable water supply in core area of Lalitpur Sub-Metropolitan city. M.Sc. Thesis, Tribhuvan University.	Sapkota M.	2010	Thesis	CAS, TU
6	Development of methodology to evaluate long-term adaptation strategies in sustainable groundwater management. PhD Thesis, University of Yamanashi, Japan.	Pandey V.P.	2010	Thesis	CREEW
7	Evaluation of groundwater environment of Kathmandu Valley. *Environmental Earth Sciences*, 60 (6): 1329-1342.	Pandey V.P., Chapagain S.K., Kazama F.	2010	Journal Paper	Online
8	Groundwater quality in the Kathmandu Valley of Nepal. *Environmental Monitoring and Assessment*, DOI:10.1007/s10661-010-1706-y.	Pant B.R.	2010	Journal Paper	Online
9	Water supply situation of squatter communities of Kathmandu Valley. M.Sc. Thesis, Tribhuvan University	Shrestha S.	2010	Thesis	CAS, TU
10	Arsenic occurrence in groundwater of Kathmandu Valley, Nepal. *Desalination and Water Treatment*, 4 (2009): 248-254.	Chapagain S.K., Shrestha S., Nakamura T., Pandey V.P., Kazama F.	2009	Journal Paper	Online
11	Evaluation of groundwater quality and recharge characteristics in Kathmandu Valley, Nepal. PhD Thesis, University of Yamanashi, Japan.	Chapagain S.K.	2009	Thesis	CREEW
12	Groundwater vulnerability assessment in shallow aquifer of Kathmandu Valley using GIS-based DRASTIC model. Environmental Geology, 57 (7): 1569–1578.	Pathak D.R., Hiratsuka A., Awata I., Chen L.	2009	Journal Paper	Online
13	Study on the status of groundwater extraction in the Kathmandu Valley and its potential impacts. Final report submitted by Inter Disciplinary Consultants (IDC) to Groundwater Resources Development Board.	IDC	2009	Report	
14	Assessment of impact of solid waste dumping in shallow water quality and perception analysis of community at Gokarna landfill site, Kathmandu.M.Sc. Thesis, Tribhuvan University.	Khanal, B.	2009	M.Sc. Thesis	CDES, TU
15	Enumeration mapping and water quality assessment of traditional stone spouts in Kathmandu Metropolitan city. M.Sc. Thesis, Tribhuvan University.	Maharjan, P.	2009	M.Sc. Thesis	CDES, TU

16	Assessment of Drinking Water Quality and Socioeconomic Status of Sub-urban Region of Kathmandu Valley. M.Sc. Thesis, Tribhuvan University	Manandhar S.	2009	Thesis	CDES, TU
17	Feasibility of recharging aquifer through rainwater in Patan, Central Nepal. Bulletin *of the Department of Geology, Tribhuvan University, Kathmandu, Nepal* 11: 41-50.	Joshi H.R., Shrestha S.D.	2008	Journal Paper	Online
18	Feasibility of recharging aquifer through rainwater in Patan, Lalitpur. M.Sc. Thesis, Tribhuvan University	Joshi H.R.	2008	Thesis	NGO Forum
19	Stable isotopes as indicators of groundwater recharge system in Kathmandu Valley, Nepal: A preliminary study. In: *Proceedings of Application of isotopes tools to groundwater studies symposium*, 29, March 2007, California, USA.	Shrestha S., Nakamura T., Kazama F.	2007	Conference Proceedings	
20	The geochemical study of fluvio-lacustrine aquifers in the Kathmandu Basin (Nepal) and the implications for the mobilization of arsenic. *Environmental Geology*, 52 (3): 503–517.	Gurung J.K., Ishiga H., Khadka, M.S., Shrestha, N.R.	2007	Journal Paper	Online
21	Collection report on a study on dug well and ring manufacturing in Kathmandu Metropolitan city.	Inventory of NEWAH studies	2006	Report	NEWAH
22	Enumeration, mapping and prospects of traditional dug wells as an alternative water source in Lalitpur Sub-metropolitan city. M.Sc. Thesis, SchEMS.	Vaidya B.	2006	Thesis	NGO Forum
23	Groundwater level monitoring in Kathmandu Valley: Annual status report.	Shrestha R.	2006	Report	GWRDB
24	Status of traditional dug-wells in Lalitpur sub-Metropolitan.	NWSC	2006	Report	ISET
25	Sustainable groundwater management of Kathmandu Valley. M.Sc. Thesis, Tribhuvan University.	Mishra Y.	2006	Thesis	IOE, Pulchowk
26	Arsenic vulnerability in groundwater resources in Kathmandu Valley.	ENPHO and JICA	2005	Report	NGO Forum
27	Groundwater quality surveillances in Kathmandu and Lalitpur Municipality area.	ENPHO	2005	Report	ENPHO
28	Augmenting groundwater in Kathmandu Valley: challenges & possibilities. Nepal Water Conservation Foundation.	Dixit A., Upadhayaya M.	2004	Report	Online
29	Optimizing water use in Kathmandu Valley (ADB-TA) project, Final Report. Submitted to Government of Nepal, Ministry of Physical Planning and Works.	Acres International in association with Arcadis Euroconsult Land and Water Product Management Group, East Consult & Water Asia.	2004	Report	Melamchi Water Supply Project Office
30	Study of Ammonia releasing process in deep wells of Kathmandu Valley. M.Sc. Thesis, Tribhuvan University.	Shrestha R.C.	2004	Thesis	IOE, Pulchowk
31	Assessment of groundwater potential of Kathmandu Valley. M. Sc. Thesis, Tribhuvan University.	Ghimire G.R.	2003	Thesis	IOE, Pulchowk
32	Mapping groundwater Arsenic disaster using geospatial tools. In: Proceedings of National Seminar on "Water and Disaster".	Tandukar A., Bajracharya B.	2003	Report	CIUD
33	Quantitative & Qualitative improvement of groundwater in Kathmandu Valley: A management perspectives. M.Sc. Thesis.	Upadhaya B.M.	2003	Thesis	SchEMS

34	Risk of bacterial contamination to groundwater by on-site sanitation. M.Sc. Thesis, Tribhuvan University.	Khanal N.	2003	Thesis	IOE, Pulchowk
35	Groundwater level monitoring in Kathamandu Valley, monthly status reports (of several months). Melamchi Water Supply Development Board. Ground Water Resources Development Project.	GWRDP	2003, 2002, 2000	Report	MoI
36	Groundwater contamination assessment for sustainable water supply in Kathmandu Valley, Nepal. *Water Science and Technology*, 46 (9): 147–154.	Khatiwada N.R., Takizawa S., Tran T.V.N., Inoue M.	2002	Journal Paper	Online
37	Potential for additional groundwater withdrawal in Kathmandu Valley.	De Zanger F.A.P.	2002	Report	IRDS Nepal
38	Study of groundwater contamination transport around Manorhara well field from Gokarna landfill. M. Sc. Thesis, Tribhuvan University.	Bhattarai R.K.	2002	Thesis	IOE, Pulchowk
39	The comparative water quality assessment on ground and surface water source in the Kathmandu Valley. M. Sc. Thesis, Tribhuvan University.	Subedi P.	2002	Thesis	TU
40	A first estimate of ground water ages for the deep aquifer of the Kathmandu Basin, Nepal, using the radioisotope chlorine-36. *Ground Water*, 39: 449–457.	Cresswell R.G., Bauld J., Jacobson G., Khadka M.S., Jha M.G., Shrestha M.P., Regmi S.	2001	Journal Paper	Online
41	Assessment of hydrological changes due to land use modifications. PhD Thesis, Indian Institute of Technology, Chennai, India.	Shrestha M.N.	2001	Thesis	
42	The study of the groundwater fluctuation and its hydraulic parameters in the Kathmandu Valley. M. Sc. Thesis, Tribhuvan University.	Kharel U.	2001	Thesis	TU
43	Iron removal from hand pump groundwater under limited head condition. M. Sc. Thesis, Tribhuvan University.	Devkota R.C.	2000	Thesis	IOE, Pulchowk
44	Urban water supply reforms in the Kathmandu Valley, groundwater monitoring program, Vol. II. Annex, 6.	Metcalf and Eddy	2000	Report	CEMAT
45	Urban water supply reforms in the Kathmandu Valley, groundwater monitoring program, Vol. I Executive Summary and Main Report.	Metcalf and Eddy	2000	Report	CEMAT
46	Hydro-geological condition and water quality of deep tube wells in the Kathmandu Valley. M.Sc. Thesis, Central Department of Geology, Tribhuvan University.	Amatya S.	1999	Thesis	TU
47	Monitoring of groundwater quality in the Kathmandu Valley.	ENPHO	1999	Report	NGO Forum
48	Quality of Groundwater in the Kathmandu Valley, Nepal. In: *Proceedings of International Conference on Environment and Agriculture*, November 1-3, 1998, Kathmandu. Ecological Society (ECOS), Nepal. pp: 499-502.	Karmacharya A.P., Pariyar C.B.	1999	Conference Proceedings	
49	Urban Water Supply Reforms in Kathmandu Valley. Ground water monitoring and licensing workshop summary. Asian Development Bank. TA No 2998-Nep. Metcalf & Eddy Inc., CEMAT Consultants (P) Ltd.	Metcalf and Eddy	1999	Report	CEMAT

50	Hydrological conditions and potential barrier sediments in Kathmandu Valley. Final Report of the Technical cooperation project – Environment Geology, between HMG Nepal and Federal Republic of Germany.	Kharel B.D., Shrestha N.R., Khadka M.S., Singh V.K., Piya B., Bhandari R., Shrestha M.P., Jha M.G., Munstermann D.	1998	Report	MoI
51	The assessment of groundwater pollution in the Kathmandu Valley, Nepal. A report on joint Nepal-Australia Project 1995–96, Australian Geological Survey Organization.	Jha M.G., Khadka M.S., Shrestha M.P., Regmi S., Bauld J., Jacobson G.	1997	Report	MoI
52	Estimation of groundwater resources in Kathmandu Valley, Nepal. *Journal of Groundwater Hydrology*, 38: 29-40.	Shrestha S.D., Karmacharya R., Rao G.K.	1996	Journal Paper	
53	Shallow phreatic aquifers of Nepal.	Sharma C.K.	1995	Report	DOI
54	Groundwater quality situation in alluvial aquifers of the Kathmandu Valley, Nepal. *Journal of Australian Geology and Geophysics*, 14: 207–211.	Khadka M.S.	1992	Journal Paper	Online
55	Urban water supply and sanitation rehabilitation project for Kathmandu Valley towns: survey on private deep wells in the Kathmandu Valley. A report submitted by Consulting Engineers Salzgitter (CES) to Nepal Water Supply Corporation (NWSC).	CES	1992	Report	IRDS Nepal
56	Groundwater resources evaluation of the Kathmandu Valley. *Journal of Nepal Geological Society*, 7: 39–48.	Gautam R., Rao G.K.	1991	Journal Paper	
57	Hydro-geological conditions of dhunge dharas in the Kathmandu Valley, Central Nepal. M.Sc. Thesis, Central Department of Geology, Tribhuvan University.	Karmacharya R.	1991	Thesis	TU
58	Groundwater management project in Kathmandu Valley Final Report, Main Report and Supporting Reports, November 1990.	JICA	1990	Report	ISET-N
59	Safe yield of groundwater basin in Kathmandu Valley. M.Eng. Thesis, Asian Institute of Technology (AIT), Thailand	Shrestha M.N.	1990	Thesis	
60	Water supply for Kathmandu and Lalitpur from outside the valley. Final report on feasibility study, Appendix-L (Groundwater resources within the valley).	Binnie & Partners	1988	Report	
61	Groundwater Resources in the Terai of Nepal. Water and Energy Commission Secretariat (WECS).	Duba D.	1982	Report	ISET-N
62	Groundwater resources of Nepal, Progress Report.	Duba D.	1981	Report	ISET-N
63	Groundwater resources of Nepal.	Sharma C.K.	1981	Report	WECS
64	Groundwater investigations, Kathmandu water supply and sewerage scheme. A report submitted to the government of Nepal.	Binnie & Partners	1973	Report	
65	Groundwater resources of Kathmandu Valley.	Sharma P.N., Singh O.	1966	Report	MoI

A2. INVENTORY OF SELECTED STONE SPOUTS ORIGINATED FROM GROUNDWATER IN FIVE MUNICIPALITIES OF THE KATHMANDU VALLEY

Stone Spout

Stone spout is a traditional water system in the Kathmandu Valley of Nepal. Stone spouts are beautifully carved stone elements, in the shape of a crocodile head (considered as a holy water animal - the carrier of the Goddess Ganga) or serpent head, installed in the front or side walls of sunken and stepped platforms for the purpose of channeling water for human use. Each platform, or *hiti*, may contain one or more spouts. The spout(s) projects about 20 cm to 50 cm from the wall in which the spout is installed. The platform is usually constructed of stone slabs or bricks paved with mortar and fitted with a shallow overflow or drainage channel (generally provided with an iron screen). The surrounding wall is of brick masonry. Stone sculptures, idols and images of gods and goddesses are laid over and under the spout(s), on the surrounding wall and elsewhere in the compound. Despite their age, the underground supply and drainage lines of many old systems are still functioning, nobly characterizing the technical and engineering skills of the ancient people of Nepal.

The supply of water to the *hitis* depends both on ground and surface water. Most stone spouts receive water from either an individual spring or nearby aquifer. A single aquifer may supply water to one or many stone spouts. The stone spouts may be located within a particular, defined aquifer of known extent, or, more often, within aquifers whose locations and extent are unconfirmed. The aquifers are largely dependent on rainwater for recharge and maintenance of the groundwater table.

Stone spouts have been extensively used in the Kathmandu Valley of Nepal since ancient times. However, time and the development of new technologies for water systems has brought further construction of stone spouts to a standstill. Thus, conservation of the existing spouts has been given priority by the government, which is expected to contribute to their maintenance and optimum utilization. [Source: UNEP*]

The stone spouts were selected considering spatial coverage (in all five municipalities) and various conditions (maximum two "good to excellent" and two "bad to worst" spouts from each municipality) of the spouts. Classification of present condition was in accordance to a book "Situation of traditional water spouts in Kathmandu Valley", jointly published by ICON/UNESCO/RCUWM in 2008.

Bholadhoka Hiti
(Balkumari-9, Lalitpur)

Establishment: During Malla Period and renovated 15 years back.

Area: 88 m^2; **Depth**: 5.51m

Location of source: Bhole, overflow system

Present condition: Filthy

Description: The water is used for drinking, cooking, washing and bathing. It is decorated with steps. There is no proper collaboration between government and local people responsible for the betterment and conservation of the spout.

Cultural importance: It has religious and cultural importance that is widely celebrated on Bhandar Puja.

***www.unep.or.jp/ietc/publications/techpublications/techpub-8e/tradition.asp**

Balkumari Hiti
(Balkumari-8, Lalitpur)

Establishment: During Malla Period, renovated on May, 1946.

Area: 36 m^2; **Depth**: 1.46m

Location of source: Guitadon

Present condition: Filthy and dry

Description: The water is used for drinking, washing, bathing and even in cooking. It is decorated with stone pavement, step and railings. It is caved with image of Lord Narayan and Krishna. The water is contaminated and is drying up during winter. There has not been proper coordination between local community and municipality. However, it is watched by a *Samiitee* formed by local people.

Mangah Hiti
(Balkumari-11, Lalitpur)

Establishment: During Siddhi Narsingh Malla Period and renovated during Late King Mahendra in 1958.

Area: 189 m^2; Depth: 4.28m

Location of source: Unknown

Present condition: Excellent

Description: The water is used for all the purposes like drinking, bathing, washing and cooking. It is decorated with steps and pavement. The infrastructure of the *hiti* is good and the coordination between government and local people is admirable. The *hiti* is preserved under Mang Tole Suddhar Committiee.

Cultural importance: daily as holy water for Krishna Mandir. Also used during *Kartik Nach* to perform puja of Bhakta Pralad in Kartik month.

Saugah Hiti
(Balkumari-6, Lalitpur)

Establishment: During Lichhavi period and renovated during the Late King Mahendra.

Area: 156 m^2; **Depth**: 4.80 m

Location of source: Naricha

Present condition: Dirty

Description: The water is used for washing and bathing and is decorated with steps. The Hiti is caved with images of Lord Shankhar and Krishana. It dries ups during winter and the infrastructure is in poor condition with some waste dumped nearby. The *hiti* is cleaned up during the monsoon and there is no good coordination between government authority and local community for the betterment.

Khaltoko Stone Spout
(Baneswor-9, Kathmandu)

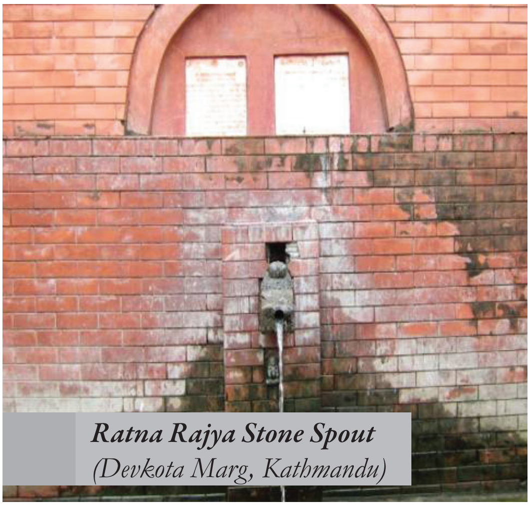
Establishment: Unknown

Area: 17 m^2; **Depth**: 1.83 m

Location of source: Unknown

Present condition: Dirty and congested

Description: Previously, the water was used for washing and bathing, but has not been in use now. There has been water contamination due to dumping of wastes in the area. The stone spout has been completely neglected by the stakeholders and also lags coordination between them.



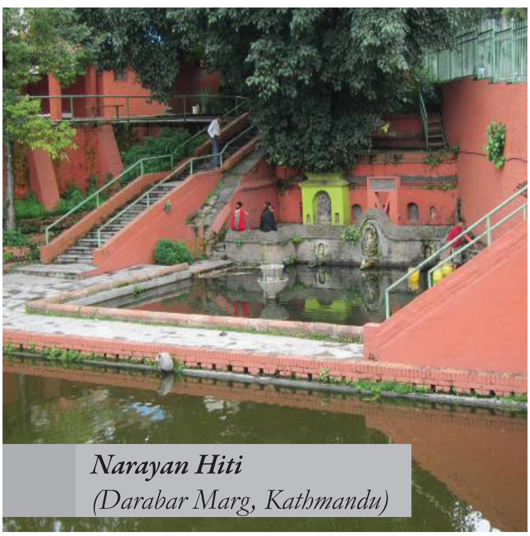
Ratna Rajya Stone Spout
(Devkota Marg, Kathmandu)

Establishment: 1959 AD.

Location of source: Unknown

Description: Water is used for drinking, washing and bathing purpose. The *Hiti* is decorated with steps and pavements. Though local people have regular cleaning and maintenance programs there is seasonal contamination and the source is drying up during winter.

Cultural Importance: Worship every morning.



Narayan Hiti
(Darabar Marg, Kathmandu)

Establishment: 1958 AD.

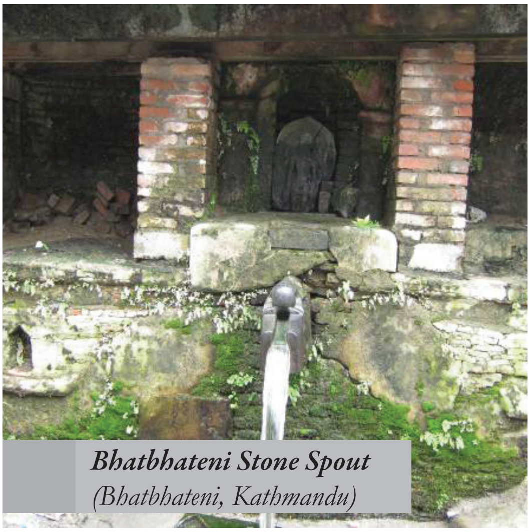
Area: 113 m^2; **Depth**: 2.63 m

Location of source: Unknown

Present condition: Good

Description: Water is used for various purposes like drinking, washing, bathing and cooking. The *Hiti* is decorated with steps and railings. Water is contaminated and infrastructure is in fair condition. There is no coordination between government and locals. However, local inhabitants have collaborated with Mercantile company for its conservation.

Cultural importance: People worship the image of Dhirnarayan. Cremation of one King was performed in that area and rituals are performed every day.



Bhatbhateni Stone Spout
(Bhatbhateni, Kathmandu)

Establishment: More than 50 years ago

Area: 45 m^2; **Depth**: 2.67m

Location of source: Pipalbot

Present condition: Bad

Description: Water is used for various purposes like drinking, washing, and bathing. The *Hiti* is decorated with steps and railings. There is no governmental intervention but a local body works for the conservation of the spout. Water is contaminated due to poor infrastructure and dries up during winter.

Cultural importance: Use in the rituals of Bhatbhateni Temple.

Bharka Hiti
(Majadega, Kirtipur)

Establishment: Not available

Location of source: Unknown

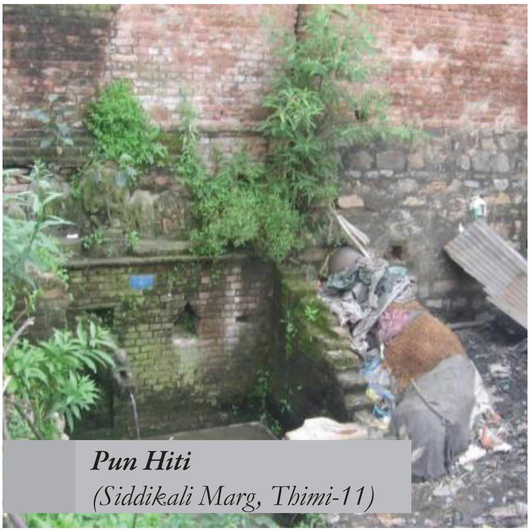
Description: The water flows mainly at rainy seasons, and is used for washing and bathing. The spout has pavements around its premises. *Kirtipur Swayam-Sewek Samaj* (KSS) manages cleanliness, reconstruction and plantation programs. Storage tank nearby minimizes the water wastage. However, there is no coordination between government and local people. Similarly, the source dries up during post- monsoon.

Hirchaphale Hiti
(Saga Tole, Kirtipur)

Establishment: Not available

Location of source: Unknown

Description: Water was used for drinking, which has now shifted to mere washing and bathing purposes. Even though some agricultural residues and open defecation upstream have contaminated the source, the concerned authorities have shown no interest to conserve the spout except clearing the blockage in the outlet.



Pun Hiti
(Siddikali Marg, Thimi-11)

Establishment: Not available

Location of source: Bagheswori Temple

Present condition: Worst

Description: Previously, the water was used for drinking purposes, but now has been limited to cooking, washing and bathing purposes. It is decorated with different idols. Even though water flows yearly, the *Hiti* is not well managed and there has been poor sanitation around. Heaps of waste dumped can be observed. Since, there is less concern from the government authority, the infrastructure has grown poor and is never renovated.

Culture importance: The water is used in *Sakimha Purnima*.

Nayaga Hiti
(Saga Tole, Kirtipur)

Establishment: Not available

Location of source: Unknown

Description: It is used for washing and bathing with few cases of water usage for cooking. Kirtipur Municipality has been conducting plantation programs for improving water percolations and cleanliness around the *Hiti*. Unlike other spouts, there is good co-ordination between government and local people.

Cultural importance: Used as holy water for morning rituals.

Gale Hiti
(Nayabazar, Kirtipur)

Establishment: Not available

Location of source: Unknown

Present condition: Good

Description: The water is used for all kinds of usages. Since, it has been fulfilling the local demands for water requirements; responsible authorities should be conserving the source by constructing wall in the adjoining side of the spout.

Cultural Importance: People use water as [holy water] in the morning.

Dhwakanpine Hiti
(Byasi, Bhaktapur-10)

Establishment: Not available

Location of source: Unknown

Present condition: Good

Description: Even though the water is used for all kind of purposes and is well managed, but the resource is not wisely used. The *Hiti* is protected with bricks wall and stone surface pavement, to make the maximum use from the year round water flow. The *Hiti* is conserved jointly by local municipality and local people. Culture importance: none

Siddikali Hiti
(Siddikali Marg, Thimi-11)

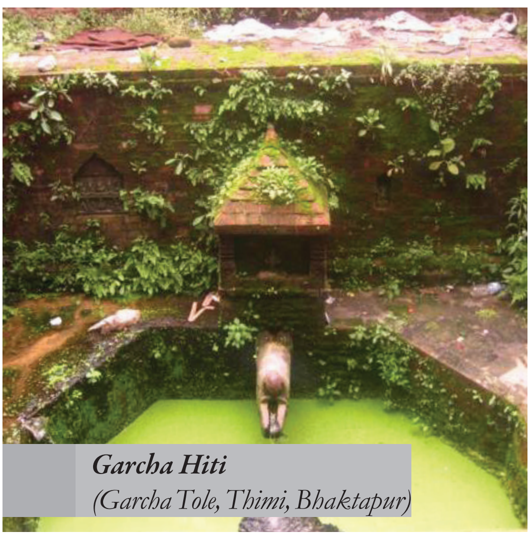
Establishment: Not available

Location of source: Bagheswori Temple

Present condition: Good

Description: Since there is yearly flow, the water is used for many purposes like drinking, washing, bathing and others. The *Hiti* is decorated with different god idols as well as protected with pavement of stone and bricks. The *Hiti* is conserved by local organization named Siddhikali Conservation Fund and there is good coordination between local users and the municipality authorities.

Culture importance: Water is also used for worshiping gods of nearby temple.



Garcha Hiti
(Garcha Tole, Thimi, Bhaktapur)

Establishment: Not available

Location of source: Unknown

Present condition: Poor

Description: Water was used for washing and bathing purposes. The *Hiti* has been poorly managed with no proper outlet and some wastes are dumped from nearby house. Previously the source was used but after the piped water supply system, the *Hiti* has been abandoned. The *Hiti* is built by bricks and paved with the stone. However, there has been some reconstruction of the stone spouts.

Culture importance: The water is used for worshiping every morning.

Khauma Stone Spout
(Khauma, Bhaktapur-3)

Establishment: Not available

Area: 40 m^2; **Depth**: 2.80 m

Location of source: Raj Kulo

Present condition: Medium

Description: The *Hiti* is decorated with steps, pavements along with idol of *Bharati* below the tap. The water was used for drinking, washing and bathing. Since 2008, there is no water supply due to blockage of its source. Unfortunately, neither government nor locals have taken initiatives for its conservation.

Cultural importance: There is no cultural significance of this stone spout.

Indrayani Stone Spout
(Mangalachhan Tole, Bhaktapur-14)

Establishment: Not available

Area: 48 m^2; **Depth**: 4.65 m

Location of source: Taleju Temple

Present condition: Bad

Description: The water was used mainly for washing and bathing, but rarely for drinking. Irrespective of decoration with steps and bricks pavement, the *Hiti* now has almost dried up. Though, the municipality is responsible for some renovations, the implementation is not regular.

Cultural importance: When Mahans take bath in Dui Majun Pokhari, blood comes out from the *Hiti* and nobody should see it. Similarly, the water is also used for washing God's idol before taking any holy ritual and animal sacrifice.

A3. ABOUT EDITORS AND CONTRIBUTORS

Prof. Gordon Young
(Advisory Editor)

Prof. Young received an M.Sc. in 1969 and a PhD in 1974 in Physical Geography with specialization in Glaciology form McGill University, Montreal. He also holds degrees of B.A. and M.A. in Geography from the University of Cambridge in 1964 and 1968 respectively. He worked as a research scientist in the Department of the Environment, Ottawa, Canada for 9 years on the hydrology of glaciers and high mountain regions. From 1981 to 1987, he served as the Chief of a Liaison Division and, since 1987 as a Professor in Geography at Wilfrid Laurier University, Waterloo, Canada. He has served as the Vice-President, International Commission on Snow and Ice, 1991-95 and as the Secretary General, International Association of Hydrological Sciences, 1995-2000. From 2000 until 2006 he was Co-ordinator, United Nations World Water Assessment Programme the Secretariat of which is housed within the Division of Water Sciences, UNESCO, Paris. In 2007 he became Emeritus Professor at Wilfrid Laurier University and in 2009 became the President of the International Association of Hydrological Sciences.

Prof. Futaba Kazama
(Advisory Editor)

Prof. Kazama belongs to International Research Center for River Basin Environment (ICRE), Interdisciplinary Graduate School of Medicine and Engineering, University of Yamanashi, Japan. Currently, she is a sub-leader of Global Center of Excellence (GCOE) Program of University of Yamanashi. She received D.Eng. in Environmental Chemistry from Hiroshima University, Japan in 1989. Her main research interest resides in water quality management of river water, groundwater and lake water. She has more than one hundred publications in journals and international proceedings in research fields not only water quality but also water treatment with chemical and/or biological methods. So she also has interest in local environmental activities, she continues to give the information of scientific topics in natural systems to local people including school students in Japan. She is a board member of Japan Society of Water Environment (JSWE), Society of Environmental Science, Japan (SES), Ecology and Civil Engineering Society, Japan (ECES) and an associate member of Science Council of Japan (SCJ).

Dr. Madan Lall Shrestha
(Advisory Editor)

Dr. Shrestha received his PhD degree from the University of Hawaii, USA. He has served as a Director General of the Department of Hydrology and Meteorology. He has represented Nepal in several International forums such as in World Meteorological Organization (WMO), Intergovernmental Panel on Climate Change (IPCC), United Nations Framework Convention on Climate Change (UNFCCC), as a chair of the National Climate Change Committee. He is the first Nepali to join Glaciological Expedition of Nepal (GEN), the First Joint Scientific Expedition between Nepal and Japan. He also spent three years as a scientist at the SAARC Meteorological Research Centre, Bangladesh and has acted as a focal point to the IPCC and contributed significantly to the Working Group II report to the Third Assessment Report of the IPCC, Climate Change 2001: Impact, Adaptation and Vulnerability. Since 2001, he has been serving as the Scientific Planning Group (SPG) Member of the Asia Pacific Network for Global Change Research (APN) and from 2011, as the co-chair of the SPG Sub-Committee. He is an Academician at the Nepal Academy of Science and Technology with expertise in climate change. He has published many papers in the international journals in the field of climate, glaciology and other environmental topics.

Ms. Yatsuka Kataoka (Advisory Editor)

Ms. Kataoka is a director of Freshwater sub-group in Institute for Global Environmental Strategies (IGES) in Japan. Ms. Kataoka gained her LLM from the Graduate School of International Cooperation Studies of Kobe University, Japan. Prior to joining IGES in 2001, she worked at the Global Environment Centre Foundation (GEC) (1992-2001), and was involved in international cooperation projects on environmental issues in Asia such as technical training of local governments and case studies of water treatment. She has focused her research activities on lawmaking and development processes in international environmental law, and on water resources management. Ms. Kataoka has a great depth of knowledge and experiences of more than 10 years on sustainable water resource management policy and institutional arrangements. She has written book chapters and papers on various issues of water resources and groundwater management. She was also involved in various sustainable water management research and network projects in East Asia. Currently she is also coordinating IGES as a regional water knowledge hub on groundwater management in Asia Pacific Region. As the regional knowledge hub for groundwater management, IGES assists national and local government organisations through research, capacity building and knowledge networking.

Dr. Sangam Shrestha (Editor/Author/Reviewer)

Dr. Shrestha is as an Assistant Professor in Water Engineering and Management (WEM) at Asian Institute of Technology (AIT), Thailand. After completing his PhD, Dr. Shrestha continued his postdoctoral research in the GCOE project of University of Yamanashi in Japan until 2007 where he was involved in development and application of material circulation model and groundwater research in the Kathmandu Valley. He then worked as a policy researcher at Institute for Global Environmental Strategies (IGES) where he was actively involved in research and outreach activities related to water and climate change adaptation and groundwater management in Asian cities. Dr. Shrestha has published more than a dozen peer-reviewed international journal papers and presented more than three dozen conference papers ranging from hydrological modeling to climate change adaptation in the water sector. Dr. Shrestha is also an associate editor of International Journal of Ecology and Development and reviewers of several International Journals. His present work responsibilities in AIT include delivering lectures in the postgraduate and undergraduate levels, supervising research to postgraduate students and providing consulting services on water related issues to government and donor agencies and research institutions. He has been conducting several projects related to water resources management, climate change impacts and adaptation being awarded from International organizations such as IFS, CIDA, IGES. Dr. Shrestha is also a Visiting Faculty at University of Yamanashi and a Research Fellow in IGES, Japan.

Mr. Dhiraj Pradhananga (Editor)

Mr. Pradhananga holds a Master of Environment (2003) from the University of Melbourne, Australia and M.Sc in Meteorology (1996) from the Tribhuvan University, Nepal. He is a Lecturer of the Department of Meteorology (DOM), Tri-Chandra Multiple Campus at the Tribhuvan University (TU) since 1998. He serves as President of The Small Earth Nepal (SEN).He served for the Government of Nepal's Meteorological Forecasting Division at the Department of Hydrology and Meteorology (DHM) as a Meteorologist from 1995-1998. In addition, he was a Secretary for the Nepal National Water Week from 2009-2011, and the General Secretary of the Society of Hydrologists and Meteorologists-Nepal (2008-2011). One of the most significant achievements that he has obtained in his career was the establishment of SEN. As the team leader/member, he has completed several campaigns and research projects of SEN on the environment, water and climate change. SEN has now become a platform for students, teachers and scientists to learn about sustainability, to develop new ideas and participate in the various activities (education/ research) on the environment and hydro-meteorology. His research interests are on the application of hydro-meteorological products and services for socio-economic benefits; climate change; glacier hydrology; climate, water and weather induced disasters; sustainable lifestyles and technologies. Currently, he is a PhD Scholar at the Centre for Hydrology, Department of Geography and Planning, University of Saskatchewan (UofS), Canada.

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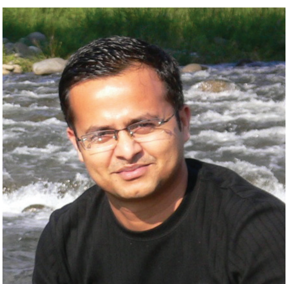
Dr. Pandey holds a PhD in Integrated River Basin Management from University of Yamanashi (Japan), M.Eng. in Water Engineering and Management from Asian Institute of Technology (Thailand) and B.Eng. in Civil Engineering from Tribhuvan University (Nepal). Currently he is a postdoctoral researcher at International Research Center for River Basin Environment (ICRE), University of Yamanashi (Japan). Dr. Pandey, a recipient of several awards, is a reviewer of peer-reviewed papers and author/co-author of more than a dozen of referred papers in international journals. His areas of contribution include water resources system analysis/modeling, vulnerability analysis of water resources system, climate change analysis and impact assessment in water resources, groundwater development and management, water footprint analysis, and GIS application in water resources management, among others.



Dr. Saroj Kumar Chapagain (Associate Editor/Author/ Reviewer)

Dr. Chapagain holds a PhD in Integrated River Basin Management (2009) from University of Yamanashi (Japan), Master degree in Physical Land Resource Management (2005) from Ghent University (Belgium) and B.Sc. in Agriculture (2000) from Tribhuvan University (Nepal). Currently he is working as Research Director at Center of Research for Environment Energy and Water (CREEW), Nepal. He is providing consultancy services as Water Monitoring Expert to Kathmandu Valley Water Supply Management Board (KVWSMB), Nepal since August, 2011. Dr. Chapagain has authored /co-authored more than 8 referred papers in international journals. His areas of contribution include analysis and mapping of groundwater quality, determination of sources of groundwater pollutants, characterization of groundwater recharge process and monitoring of groundwater resources.

Dr. Rabin Malla
(Associate Editor)

Dr. Malla holds a PhD in Integrated River Basin Management (2010) from University of Yamanashi (Japan), M.Sc. (Ag.) Soil Science (2004) from Maharana Pratap University of Agriculture and Technology, Rajasthan (India) and B.Sc. (Ag.) Soil Science (2001) from Tribhuvan University (Nepal). Currently he is a working as an Executive Director at Center of Research for Environment Energy and Water (CREEW) in Nepal. Dr. Malla has research interest on soil and water pollution and their phytoremediation, biomass modelling and also climate change issues on urban environment. He is the recipient of several awards and has authored 4 peer-reviewed papers in international journals.

Ms. Suchita Shrestha
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Ms. Shrestha has completed her M.Sc. degree in Environmental Science from Tribhuvan University. She is working as a project officer in The Small Earth Nepal (SEN). She was involved in Water Quality, Ecological Status and Bathymetric Map of Phewa Lake, Pokhara presented in National Seminar on Healthy Wetlands, Healthy People, Feb, 2008 organized by National Trust for Nature Conservation, WWF, Hindu - Kush Himalayan Benthological Society (HKH-BENSO), Resources Himalaya Foundation, KMC and LSMC. She was involved as a research member of KAPRIMO (Kathmandu Participatory River Monitoring) Segment Team of Bagmati and Bishnumati (2007) and as a facilitator of the project "Human Value based Water, Sanitation and Hygiene Education (HVWSHE)" (2009) during her involvement at Environmental Camps for Conservation Awareness (ECCA). Her core interests lies in research of Wastewater Treatment by utilizing water hyacinth and climate change impact and adaptation on water resources.

Ms. Bhintuna Shrestha
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Ms. Shrestha holds a M. Sc in Interdisciplinary Water Resources Management (2010) from Pokhara University and B. Tech in Biotechnology (2007) from Kathmandu University, Nepal. She has completed her master's thesis on Pharmaceutical Wastewater Management in Kathmandu: Documentation of Practices, Regulatory Provisions and Health Impacts. Currently, she is working at The Small Earth Nepal as a Program Officer. As a researcher, she actively participated in a Survey on 'Water Use in Kathmandu Valley' organized jointly by University of Tokyo and Asian Development Bank. She has special interest in water management activities for promoting the conservation and sustainable use of the resources in relation to environment, health and sanitation sector. Her other areas of interest include water and wastewater treatment and Integrated Water Resources Management.

Mr. Piyush Dahal
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Mr. Dahal, a final year master level student of Environmental Science at the Central Department of Environmental Science, Tribhuvan University, is working as the Research and Communication Officer in The Small Earth Nepal (SEN). He has worked on the water and climate change related research, programs and campaigns conducted through SEN. Mr. Dahal has also worked as an editor and a designer to a number of publications and workshop proceedings of SEN, and an editor to the newsletter of the Society of Hydrologists and Meteorologists-Nepal (Vol. 10, No. 1, 2010). Similarly, he was a team member for the WWF information series book publications on water and climate change for school students (Pani Prasad Ventures to Raise Climate Change Awareness, 2010 and Pani Prasad and Friends: Off to the High Altitude Wetlands, 2009), which have become very popular resources for school students and teachers. These were published in both Nepali and English languages. His areas of interest include research focused on climate change and water resource management.

Mr. Utsav Bhattarai
(Research Associate)

Mr. Bhattarai completed his M. Sc. in Water Resources Engineering (2009) and B. E. in Civil Engineering (2004) from Tribhuvan University (Nepal). He is currently working as a Research Associate in Water Engineering and Management at Asian Institute of Technology (Thailand). He has a few years of experience in teaching at the undergraduate level in Kathmandu University and different colleges of Purvanchal University (Nepal). Mr. Bhattarai has been providing services in different capacities to leading academic institutions, research centers, NGOs and consultancies in many water-related research in Nepal. He has participated and presented his research findings in a number of national and international seminars related to different sectors of water resources. His areas of interest include applied research focused on hydraulic and hydrological modeling, climate change, water induced disaster management and GIS based studies related to water resources engineering and management.

Dr. Soni Mulmi Pradhanang
(Author/Reviewer)

Dr. Pradhanang received her PhD in Watershed Hydrology and Modeling from SUNY-ESF, New York, USA in 2009 and Master's degree in Forest Ecology and Management from Yale University in 2003. She has been working as a research associate at City University of New York, USA-Institute for Sustainable Cities/Dept. of Geography, Hunter College in 2009. Her current research focuses on understanding how hydrologic processes influence water quantity and movement of sediments and nutrients through watersheds through combined effort of monitoring and modeling, aiding in the development of policies and management practices to protect water and soil. She had also worked as a lecturer at St. Xavier's College, Kathmandu University, Nepal from 1999 to 2001. Dr. Pradhanang has several publications in Hydrologic modeling. Besides her research in Northeastern USA, she is also working on hydro-climatic studies for Nepalese Rivers and developing precipitation and temperature climate grids for Nepal. She is also a reviewer of several journals such as Journal of Environmental Quality, Journal of Natural Resources and Life Sciences Education and Journal of Sustainable Forestry.

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Dr. Shrestha holds a D.Sc. in Groundwater Geology (1996) from Osaka City University (Japan), Master in Science in Geology (1992) from Shimane University (Japan). He was a Fulbright Post Docotoral Fellow (2003/04) at University of Texas at Dallas (USA). Dr. Shrestha is an Associate Professor at Central Department of Geology, Tribhuvan University, Nepal. He has supervised eighteen master thesis works for various universites and one Ph.D thesis. He has authored more than six referred papers in both national and international journals. He currently serves as a member of Climate Change Council headed by Rt. Honorable Prime Minister of Nepal and various other committees of Minsitry of Environment, Government of Nepal. He also served as an advisor to the Minsiter of Environment , Government of Nepal from 2009 to 2011. His area of contribution includes climate change issues, groundwater policy formulation, Arsenic contamination in groundwater, rainwater recharge of groundwater and groundwater managemnt in Nepal.

Dr. Takashi Nakamura (Author)

Dr. Nakamura holds a PhD in Integrated River Basin Management (2008) from University of Yamanashi (Japan), M.Eng. in Ecosocial System Engineering (2005) from University of Yamanashi (Japan) and B.Sc. in Environmental Biology and Chemistry (2003) from University of Toyama (Japan). Currently he is an Assisttant Professor at International Research Center for River Basin Environment (ICRE), University of Yamanashi (Japan). Dr. Nakamura's research expertise is in the area of isotope hydrology, groundwater quality and nitrogen dynamics. His research are basically field- and lab-based and cover groundwater recharge and contamination processes.

Prof. Yasushi Sakamoto (Author)

Prof. Sakamoto received M.Eng. and D.Eng. in Urban Engineering from The University of Tokyo. His career was started as an Assistant Professor in University of Yamanashi in 1979 and then advanced as an Associate Professor in 1991 and Professor in 2001. Currently he is the Director of International Research Center for River Basin Environment (ICRE), Interdisciplinary Graduate School of Medicine and Engineering, University of Yamanashi, Japan. His research interest lies on the movement of pollutants in water cycles, vertical seepage in unsaturated soil, and estimation of groundwater flow based on analysis of pollutant sources, among others.

Dr. Wilawan Khanitchaidecha (Author)

Dr. Khanitchaidecha received her B.Sc. degree in Environmental Chemistry from King's Mongkut Institute of Technology Ladkrabang (Thailand) in 2004. In 2005, she was awarded the Royal Thai Government Scholarship to study her M.Sc. in Environmental Engineering and Management, Asian Institute of Technology (Thailand). In 2007, Dr. Khanitchaidecha was granted the Japan Ministry of Education, Culture, Sports, Science and Technology (MEXT) scholarship to study her PhD at University of Yamanashi (Japan). She completed her PhD in Environmental Engineering in 2010. Dr. Khanitchaidecha's research expertise is in the area of Water and Wastewater Treatment, specifically the design of reactor for water treatment through bioprocess. Her research cover nutrient and heavy metal removals, aerobic and anaerobic processes, and suspended and immobilized bacteria. Currently, Dr. Khanitchaidecha is a researcher at International Research Center for River Basin Environment, University of Yamanashi, Japan.

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Dr. Yoden holds a PhD in Civil Engineering (2010) from University of Tokyo (Japan) and M.E. in Civil Engineering (2003) from University of Tokyo (Japan). She worked as a Research Associate/Assistant Professor at the University of Tokyo (Japan) from 2003 to 2011. She has more than 6 years of specialized knowledge and work experience in infrastructure planning, especially water supply services, in Nepal, India, Indonesia, Philippines, Japan and others. Her specific areas of expertise include infrastructure development, provisions for the poor/vulnerable, public-private-partnership, and social communications and mediation for infrastructure development projects. As a team leader, she worked for water supply services development projects in Kathmandu, Nepal, funded by Asian Development Bank and Public-Private Infrastructure Advisory Facility (World Bank), and initiated water demand estimates, built baselines of water supply services, and formulated plans for benchmarking system development.

Dr. Madhav Narayan Shrestha (Author/ Reviewer)

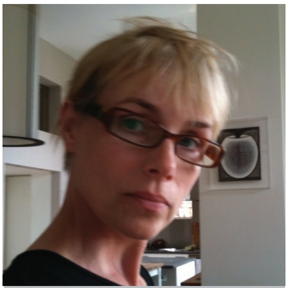
Dr. Shrestha holds a PhD in Environmental Water Resource (2002) from Indian Institute of Technology Madras (India), M.Eng. in Water Resource Engineering (1990) from Asian Institute of Technology (Thailand) and B.Eng. in Civil Engineering (1988) from University of Roorkee (IITR) Roorkee (India). Currently he is working as Team Leader in Secondary Towns Urban Environmental Improvement Project/Kavre Valley Integrated Water Supply Project, Nepal. Dr. Shrestha, a recipient of several awards, is a reviewer of peer-reviewed papers and author/co-author of more than 20 referred papers in international and national journals. His areas of contribution include environmental water resources system analysis/modeling, water supply operation and management system, climate change adaptation and mitigation analysis in water management system, groundwater development and management, GIS and remote sensing application in water resources management, and research proposal reviewer/evaluator, among others.

Mr. Robert Dongol (Author)

Mr. Dongol holds Masters Degree in Environmental Engineering and Management (2007) from Asian Institute of Technology with specialization in water and wastewater engineering, Bachelor Degree in Environmental Sciences (2004) from Kathmandu University. Currently, he is engaged with Nepal Engineering College, as a research coordinator in M.Sc. Interdisciplinary Water Resources Management Program. He holds more than three years of teaching and research experience in the field of integrated water resources management. So far he has successfully co-supervised 6 master's thesis and supervised two student's research on water quality funded by CREEW. He has co-authored four papers based on research findings. He was one of the Executive Editors of the Fourth South Asia Water Research Workshop Proceeding. He has actively participated in many training such as interdisciplinary field research methodology, integrated water resources management. His research interest is on water and wastewater treatment systems, integrated water resources management.

Dr. Bhanu R Neupane (Reviewer)

Dr. Neupane is the Regional Hydrologist/Programme Specialist of UNESCO based in New Delhi, India since September 2004. He has previously worked in Nepal, USA, and France and has consulted in 13 countries in North America, Asia and Europe. Holder of PhD in Water Resource Management (Hydro Systems) from Canada and a doctorate in Business Administration from France/USA, Dr. Neupane is also responsible for overseeing UNESCO's other science programs in Ecological and Earth Sciences, basic and engineering sciences, science analysis and policy. Dr. Neupane serves with several Universities in India and abroad as visiting professor in the area of water resource management and hydrosystems. Dr. Neupane has over 100 publications to his credit (16 refereed journals, 42 conference papers and three book chapters, rest reports). He has also edited 7 books and is referee to 11 international journals.



Ms. Maureen Papas (Reviewer)

Ms. Papas hold a Bachelor of Arts (Hons) and a Master of International Relations with a Master of International Environmental Law from Macquarie University, Sydney, Australia. In the past few years, she has developed a very strong interest in international politics and in particular the interface between politics and the law. Her main area of interest is in international and national water law, policy issues, governance and sustainable practices. She has published a research paper on Australian water law in Macquarie Journal of International and Comparative Environmental Law (MqJICEL) and a research paper on the international regulation of groundwater in the Journal of Water Law. She presented and published on the management of transboundary aquifers for the international ISARM conference which was held at UNESCO Headquarters in Paris (France) in December 6 -8- 2010. She started her PhD in 2010. Her research topic aims to identify best practice approaches to water resources management in a developed country context, drawing upon both the underlying international policies and principles and the practical experience identified across two jurisdictions. More recently, she has been invited to contribute to the Specialist Group Newsletter on Watershed and River Basin Management, International Water Association (IWA), March 2011.

Mr. Naba Raj Shrestha (Reviewer)

Mr. Shrestha holds an M.Sc. Degree in Geophysics (1974) from Banaras Hindu University, India, Post Graduate Diploma in Exploration Geophysics (1982) from Institute of Aerial Survey and Earth Sciences, Delft Netherlands and another Post Graduate Diploma in Petroleum Exploration and Management (1990) from Technical University, Trondheim, Norway. He served government agencies from 1975 to 2009 in different capacities. He worked in government projects of mineral exploration, groundwater, irrigation, petroleum exploration, etc. He also worked in bilateral projects and World Bank and ADB/N funded projects during 1975-2009 period. Currently he is working as the Managing Director of Three D. Consultants (P.) Ltd. Mr. Shrestha is a reviewer of peer-reviewed papers and author/co-author of some papers in international journals. His areas of contribution include groundwater development and management, water resources system analysis, climate change analysis and impact assessment, vulnerability analysis of water resources system, rain water harvesting, landslide vulnerability, and hydropower development, among others.

Dr. Jaya Kumar Gurung (Reviewer)

Dr. Gurung received doctoral degree from Shimane University, Japan in 2007 for his research on a heavy metal contamination mechanism in groundwater. Prior to join his research Dr. Gurung did his professional practice through Ministry of Water Resources, Government of Nepal, in the capacity of Hydrogeologist for eight years. Dr. Gurung is honored with awards both nationally and internationally for his research endeavors. He had given invited presentations in the scientific forums in Nepal, Japan, USA, Vietnam, Korea, Bangladesh in water related challenges and its pragmatic solutions. Dr Gurung has a number of peers research paper published in international journals and quite number of non-peer articles on water issues, policy imperatives and environmental advocacy. He is contributing as reviewer in several national and international journals. Currently he is working as the Executive Director in Himalayan Alliance for Climate Change (HIMCCA). Research and study on fresh water pollution, the impact of Climate Change on fresh water, water quality assessment, treatment and engineering, strategic design of water resource management and conservation measure and tranboundary environmental issues are major areas of interest of Dr. Gurung. He has been providing consulting services both national and international organizations in the field of research based development intervention in the above mentioned sectors.

Dr. Bandana K Pradhan (Reviewer)

Dr. Pradhan holds a PhD in Applied Natural Science from the University of Natural Resources and Applied Life Sciences - BOKU, Vienna, Austria (1998), M.Sc. Botany (1982) from Tribhuvan University (Nepal), Postgraduate in Limnology from the Institute of Limnology, Mondsee, Austria (1992), Postgraduate in Women Study (2000), Tribhuvan University (Nepal) and Postgraduate in Health Care Management (2008) from Pokhara University (Nepal). Currently she is working as an Associate Professor at the Department of Community Medicine and Public Health, Institute of Medicine, Tribhuvan University, Nepal. Dr. Pradhan has hitherto supervised over dozen of Masters' and PhD students in various fields of environment and public health. She has specialized in water quality, environment and health and contributed to the development of communities and nation through producing scientific reports, the few and the most important are surface water and groundwater quality assessment and classification for public health, status of environment Nepal, etc. She has publication in national and international peer review journals. She has served as an editor in several national and international journals.

Dr. Mahesh Raj Gautam (Reviewer)

Dr. Gautam has a PhD in Hydrology (2000) from Saitama University (Japan), M. Eng. in Water Resource Engineering (1997) from Asian Institute of Technology (Thailand), and B.Eng. in Civil Engineering (1990) from Panjab Engineering College, Chandigarh (India). Currently he is a research fellow at Division of Hydrologic Sciences, Desert Research Institute, Las Vegas (United States). At present, he is a reviewer of seven peer-reviewed International Journals, and author/co-author of more than two dozen referred papers. He researches at the broad interface of water and environment. His current research include watershed modeling, climate change impact and vulnerability assessments, flood and drought forecasting and management, urban water management and stream restoration, sustainable urban infrastructures, and decision support system.

Dr. Dhundi Raj Pathak (Reviewer)

Dr. Pathak is a founding director and principal researcher of the Engineering Study & Research Centre, a geo-environmental consulting company based in Kathmandu, started in 2011. Currently, he is also working as geo-environmental consultant in Solid Waste Management Technical Support Centre, Government of Nepal and other different organizations. Before return to Nepal in March 2010, he was a research assistant and PhD scholar in Osaka Sangyo University, Japan from October 2006 for 3.5 years. He has published many papers in peer reviewed international journals and has delivered many presentations at international conferences in many countries. He is an editorial board member of Journal of Water Resource and Protection and has served as reviewer of several reputed international journals. Dr. Pathak was awarded a gold medal for the first position in M.Sc. in Geotechnical Engineering in 2005 from Institute of Engineering, Tribhuwan University, Nepal. He was appointed technical expert member of field verification team of Government of Nepal for Integrated Solid Waste Management project in Kathmandu Valley. His research interests include geotechnical investigation and analysis, aquifer vulnerability, groundwater quality/quantity assessment and pollution control, environmental risk assessment, solid waste management, GIS mapping and planning, climate change and other environmental issues.

ABOUT KATHMANDU VALLEY GROUNDWATER OUTLOOK

Groundwater is an important source of water for communities and industries in the Kathmandu Valley. Unfortunately, uncontrolled extraction and use of groundwater and improper management of both solid waste and wastewater from urban centres have increased the vulnerability of groundwater to depletion and degradation. A lack of appropriate documentation as well as insufficient dissemination of results from studies on groundwater carried out by various stakeholders over the decades has also resulted in problems with both baseline data loss and knowledge redundancy. In response to these current circumstances, this book aims to prioritize present issues related to groundwater in the Kathmandu Valley, reclaim available information and baseline data from earlier studies, compile the latest scientific understandings of relevant pressing issues, and organize those issues as well as potential approaches to contending with them within a single volume. As such, this book also provides a scientific foundation to advocate for appropriate policies as well as for the need of subsequent institutional and legal arrangements for sustainable development and management of the Kathmandu Valley's groundwater resources. In this way, it is hoped that the papers within this publication will benefit not only high-level policymakers in the government and affiliates in INGOs, NGOs and civil society but also academicians and researchers as well as practitioners and professionals from diverse areas of groundwater development and management.

The book has been authored by and subsequently undergone a process of extensive review by experts in the respective fields. …Though the book features specific case studies at the local level, I strongly believe that the issues dealt, approaches followed, and conclusions drawn will be interesting and beneficial to the readers globally (Prof. Said Irandoust, President, AIT)

… the information in the book shall help a lot to implement the Strategic Action Plan (2008-2025) and Groundwater Regulation and Management Policy 2011 prepared by the KVWSMB (Hari Prasad Dhakal, Executive Director, KVWSMB)

The best part of this publication is that it has not only indicated problems but also highlighted several possible solutions to help overcome current issues of water scarcity and to protect groundwater resources in the valley from further degradation (Dr. Roshan Raj Shrestha, UN-HABITAT/UNDP)

… is the first publication of its kind for Kathmandu Valley and Nepal, and as such is a milestone for understanding the role of this important resource. The book is an important contribution to sustainable development, management, and governance of the groundwater resource in the valley (Dr. David James Molden, Director General, ICIMOD)