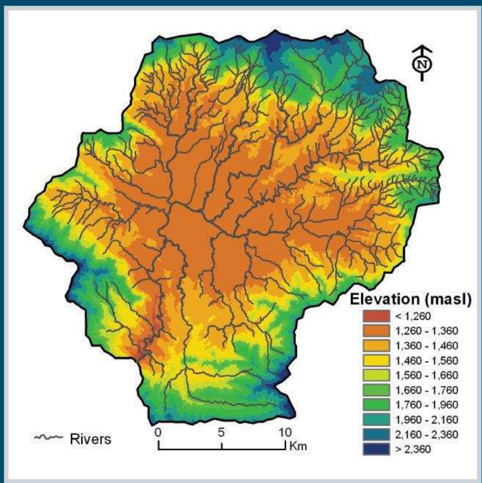
KATHMANDU VALLEY GROUNDWATER OUTLOOK



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Sangam Shrestha
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ABOUT PUBLISHING ORGANIZATIONS

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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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Telephone No. 977 (1) 4782738 | E-mail: info@smallearth.org.np | www.smallearth.org.np

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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.

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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.

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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

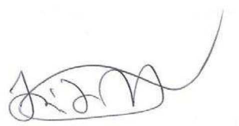
FOREWORD

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.

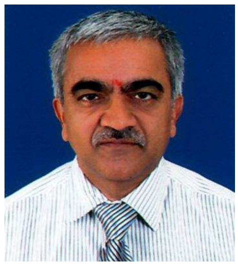
I am confident that the book will benefit a wide range of readers from policy-makers in governments, affiliates of INGOs, NGOs and civil societies, researchers to graduate students from universities and academic institutions in the area. Though the book features specific case-studies at the local level, 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

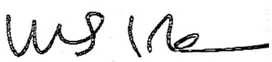


Management and protection of the groundwater resource in the Kathmandu Valley has long been an issue of wide public concern. In 2006, the Kathmandu Valley Water Supply Management Board (KVWSMB) was established by the government through the Water Supply Management Board Act, to look after groundwater 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

SECTION IV: GROUNDWATER USE

SECTION I

INTRODUCTION

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

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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 water for both drinking and non-drinking purposes. These systems are also known to be contaminated by pollutants and pathogens (Table 2.1).

The objective of this chapter is to provide a detailed description of the Kathmandu Valley, summarize current status of groundwater research in the area based on available literature and reports, and suggest further research needs in the area. Compilation of past research, methodologies, and major findings that are relevant to groundwater systems in the Kathmandu Valley is presented in Table 2.1 and discussed in the following sections.

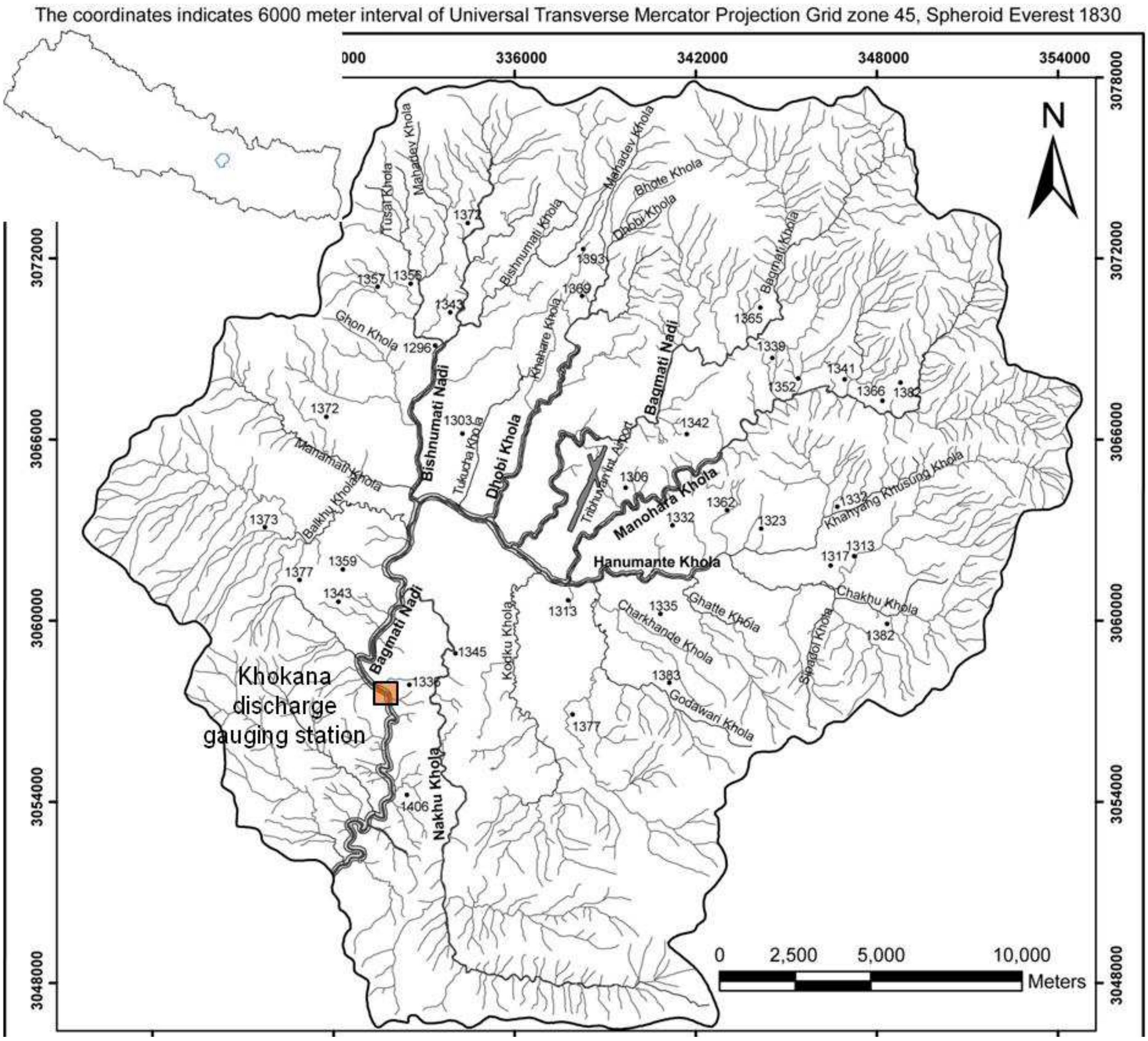

Figure 2.1 Kathmandu Valley watershed with drainage networks (modified after IDC, 2009)

2.2 OVERVIEW OF THE KATHMANDU VALLEY

2.2.1 Physiography and climate

The Kathmandu Valley lies between 27°32'13"-27°49'10"N latitudes and 85°11'31"- 85°31'38" E longitudes in central Nepal. The Kathmandu Valley watershed has an area of approximately 664 km^2 (GoN/World Bank, 1994). The valley has the capital city Kathmandu along with four other municipal towns; Lalitpur, Bhaktpur, Kirtipur and Madhyapur-Thimi. It is a roughly circular intermontane basin (Figure 2.1) with a diameter of 25 km and an average altitude of 1,350 m (above sea level); the surrounding hills are approximately 2,800 m in elevation.

There are two major aquifers within the consolidated sediments of the valley separated vertically by clay aquitard layer (Figure 2.2). They provide residents with drinking water. The upper aquifer is composed of up to 50 m of Quaternary sand, with some discontinuous, interbedded silt and clay of the Patan and Thimi Formations

(Yoshida and Igarashi, 1984). The surficial sediments that compose the upper aquifer are underlain by an aquitard (a bed of permeability) of interbedded black clay and lignite that reaches up to 200 m in thickness in the western valley. The Pliocene sand-and-gravel, with interbedded lignite, peat, and clay, lies beneath the clay aquitard and constitutes the deeper confined aquifer used by several hotels, private companies, and municipalities (Jha et al., 1997). Recharge areas are located in the northeast part of the valley where the thick confining unit of clay is not present.

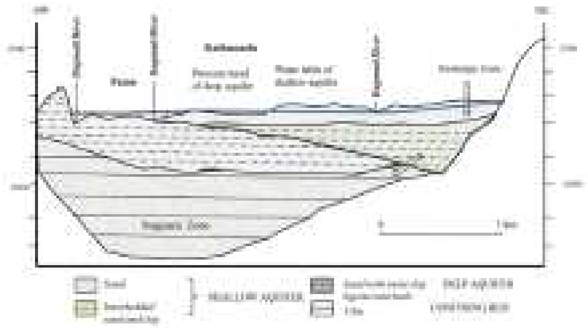

Figure 2.2 Groundwater aquifers in the Kathmandu Valley, with vertical exaggeration, adapted and modified from Cresswell et al. (2001)

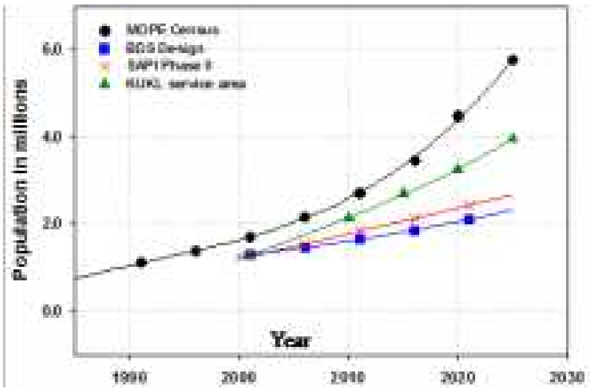

Figure 2.3 Population census and projection for the Kathmandu Valley (prepared with data from MOPE (2000), ADB (2006), Dixit and Upadhyaya (2005)). MOPE is 'Ministry of Physical Planning and Works; BDS is 'Bulk Distribution System'; SAPI is 'Special Assistance for Project Implementation'; KUKL is 'Kathmandu Upatyaka Khanepani Limited'

The climatic condition of the valley is sub-tropical primarily influenced by the southwest monsoon during summer. The summer average temperature is 24°C while the average winter temperature is about 13°C; the annual average is 18°C based on 21 years (1988-2008) of temperature records from Kathmandu Airport Station. The weather in the valley exhibits distinct seasonality with four major periods; 1) pre-monsoon (Mar-May), 2) summer monsoon (Jun-Sep), 3) post-monsoon (Oct-Nov), and 4) winter (Dec–Feb). Monthly precipitation ranges from 9 mm in November to 364 mm in July. The average annual precipitation is 1,700 mm, 80% of which falls during the monsoon season between June and September (DHM, 2009).

2.2.2 Hydrology and water resources

The rivers in the valley show a strong discharge correlation with precipitation. The dry months usually result in very low streamflow. The Bagmati River, which drains most parts of the valley, flows through a total length of abou 163 km with estimated average annual (1992-2006 average) runoff of 564.3 million m^3/year at Khokana, a station located at the valley's outlet (please refer Figure 2.1). As there are many fine networks of rivers, tributaries as well as ponds and spring sources, their river bed conductance and quality of water flowing in them will highly influence the groundwater resources (quantity and quality). This will in turn influence the water (quantity and quality) supplied by *Kathmandu Upatyaka Khanepani Limited* (KUKL) (the water supply agency) to the consumers.

2.2.3 Population dynamics and groundwater use

With over two million people, the Kathmandu Valley is the most important urban concentration in Nepal. Population is expected to grow at a rate of 5% (Figure 2.3). Municipal water supplies are being inadequate to meet increased water demands due to increasing population as well as changing life styles. The inadequate and inefficient supply systems have led the population at large to supplement their water supply by tapping into traditional water sources, i.e., stone spouts, spring sources, shallow aquifer waters, etc. Unfortunately, many stone spouts are now converted into temporary refuse dumps that need proper rehabilitation.

2.3 GROUNDWATER RESEARCH STATUS

The groundwater of the Kathmandu Valley is under immense pressure as it is being heavily extracted for several purposes. Although groundwater overuse is recognized as a serious problem (Cresswell et al., 2001), until the mid 1990s, groundwater resource development received greater attention. The approaches of groundwater resource development coupled with monitoring, management and research is still developing. There are a number of research that address the potential impacts of groundwater overuse on both quantity and quality (Table 2.1), however, such research are usually bound through contractual agreements to keep data confidential from public access, suggesting lack of transparency and capacity building. Availability of such information will not only help to develop scenarios on groundwater use spatially and temporally, but also allow researchers to evaluate vulnerability of groundwater usage addressing availability and water quality. This section presents a review of research/studies related to groundwater quantity and quality in the valley with focus on their approaches and findings.

2.3.1 Groundwater quantity

In the last four decades, several studies have been carried out to understand quantitative aspects of groundwater resources in the Kathmandu Valley (Table 2.1). They were focused on estimation of groundwater recharge, modeling, sustainable withdrawal, storage potential, extractions, among others. The primary basis for assessment of groundwater resources is based on the relationship between pumping and annual replenishment which is based on the aquifer characteristics. An aquifer is the natural unit within which groundwater occurs. Aquifer characteristics, such as storage and transmissivity are not being studied well; though some of the studies have documented the data available so far (Metcalf and Eddy, 2000; Pandey and Kazama, 2011). The geological diversity in the Kathmandu Valley warrants detailed study on the characteristics and behavior of aquifers which primarily dictate the approaches to managing groundwater resources and addressing vulnerability at local level.

The groundwater resource estimates are still sparse for all the regions of Nepal. Recharge to the valley's main aquifer has been variously reported to be 15 million m^3/year (i.e., 165 mm/year) (Binnie and Partners, 1988) to less than 5 million m^3/year (i.e., 55 mm/year) (Gautam and Rao, 1991). A study by CES (1992) reported that almost 50% of the valley's water supply is derived from groundwater. The extraction rate is reported to be 20 million m^3/year. Systematic and regular monitoring of water table to confirm the actual recharge volume has not been carried out until recently (IDC, 2009). Large inconsistencies in reported recharge and extraction rates warrant a standard protocol of research.

Table 2.1 A list of peer reviewed literature related to groundwater in the Kathmandu Valley

Author(s)	Objectives	Methods	Major findings
Cresswell et al. (2001)	*Quantification of groundwater recharge rates and residence times*	*Radioisotope study*	*Current recharge rate is about 5 to 15 mm/year (0.04 to 1.2 million m^3/year); extraction rate is 20 times of this amount; and reserves will be used up within 100 years at current rate of extraction.*
Dixit and Upadhyaya (2005)	*Summarize existing knowledge on groundwater conditions and identify potentials for development*	*Compilation of relevant literature and analysis*	*Substantial opportunities may exist for increasing municipal supplies by conjunctive management of surface and groundwater sources including direct and indirect recharge and rainwater harvesting.*
Pattanayak et al. (2005)	*Test the coping costs and stated preferences for willingness to pay for improved services*	*Household survey of 1500 randomly sampled households; develop profile of sample households.*	*Coping costs arise from behaviors such as collecting, treating, storing and purchasing (1) are equivalent to 1% of current incomes, 2) are lower than the willingness to pay, and 3) vary across household with different socio-economic backgrounds.*
Villholth and Sharma (2006)	*Present major issues related to groundwater in South and South East Asia*	*Summary of literature*	*Groundwater depletion can be tackled by integrating environmental, social and economic factors. Effective groundwater management requires an optimum balancing of the increasing demands of water and land users with the long-term maintenance of the complex natural resource.*

Gurung et al. (2007)	*Examine geochemistry of Kathmandu aquifer sediments, the elution behavior of arsenic (As) and evaluate the mechanism causing mobilization of As in groundwater*	*Elution analysis to determine potential leaching of As from the aquifer sediment*	*Arsenic concentration in the sediments of the Kathmandu Valley average 8 mg/kg, similar to typical modern sediments (5-10 mg/kg). The mobilization of As in the sediment is mainly related to change in redox conditions resulting from iron oxide rich sediment along with high organic content.*
Kannel et al. (2007)	*Assessment of water quality variation, classification of monitoring networks and identification of sources*	*Water quality analysis of important physical, chemical and biological parameters*	*Upstream river water qualities in the rural areas are affected mostly due to sewage disposal and transport of fertilizers and manure applied to agricultural fields. Urban water is mostly polluted due to untreated municipal sewage and can have impacts on shallow aquifers.*
Warner et al. (2008)	*Identify common drinking water contaminants; compare water quality between sources; evaluate relationship between water quality parameters and site characteristics.*	*Water sampling prior to monsoon season, lab analyses for bacterial pollution, inorganic pollutants and heavy metals; household surveys using questionnaire; statistical analyses using non-parametric statistics.*	*Pathogens (coliform, both total and fecal) were found in 72% of the water sampled. Nitrate-N and ammonium-N exceeded the Nepali guidelines for 45% of the samples, arsenic and mercury exceeded WHO standards for 10% of the samples.*
Pathak et al. (2009)	*Development of groundwater vulnerability map*	*GIS based DRASTIC model; sensitivity analysis*	*Aquifer vulnerability map was developed to reflect an aquifer's inherent capacity to become contaminated based on pollution index. The vulnerability index indicated high susceptibility to contaminations.*
Chapagain et al. (2010)	*Assess the current state of water quality and identify the major factors affecting water quality of deep groundwater in the valley.*	*Physico-chemical analysis of major cations and anions; Principal Component Analyses, Factor Analyses and Cluster Analyses of all water quality parameters.*	*Groundwater is classified as Ca-HCO_3 and (Na^+ K)- HCO_3 types with concentration of NH_4^+-N, Pb, As, Fe, Cd found at most of the sampling locations. Water quality of deep aquifer is affected primarily by hydro-geochemical properties and less by the human activities.*
Pant (2010)	*Assess quality of groundwater in the Kathmandu Valley.*	*Groundwater samples from shallow, deep-tubewells from October to December 2004 were analyzed for physical, chemical and biological properties.*	*Groundwater contaminated with iron (1.5-1.9 mg/L) and coliform bacteria (129 cfu/100 mL and 148 cfu/100 mL in tubewell and deepwell respectively). Study showed high electrical conductivity and turbidity.*
Kannel et al. (2011)	*Chemometrics in assessment of seasonal variation of water quality in fresh water systems.*	*Multivariate statistical analysis*	*Seasonal variation in water quality was observed especially for parameters such as, temperature, DO, EC, COD, Cl, Ca, alkalinity, PO_4-P and TP.*

JICA (1990) carried out modeling of deep aquifer system to estimate sustainable withdrawal from it. The study suggested the sustainable withdrawal as 0.027 million m^3/day, which differs with the estimates from Stanley (1994) as 0.0263 million m^3/day and from Metcalf and Eddy (2000) as 0.0586 million m^3/day. The differences could probably be due to approaches used and aquifer layers considered. However, it is unclear whether the later two withdrawal rates are for shallow or deep or both the aquifers. Complexity of geological formations and lack of adequate and reliable datasets are partly to be blamed for the discrepancies in the estimates. Despite of suggested sustainable withdrawal, due to lack of adequate management measures, groundwater resources in the valley are already over-exploited (Metcalf and Eddy, 2000; Pandey et al., 2011). The study by Metcalf and Eddy (2000) showed a drop in pumping water level from 9 m to 68 m over the few years. However, in some areas level of extractions are expected to be lower than availability of the resource.

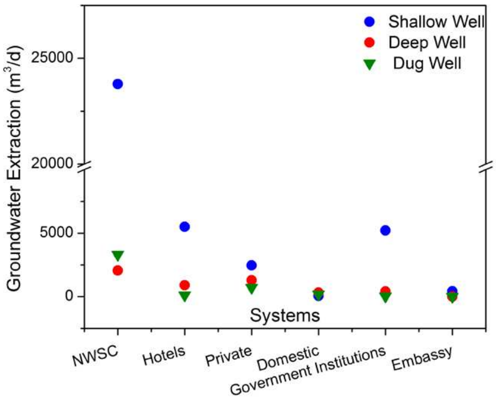

Figure 2.4 Groundwater extraction rate in the Kathmandu Valley for different systems (prepared with data from HMG (2004))

The over-exploitation of groundwater resources has resulted several impacts. The impacts as detailed in Pandey et al. (2011) are both negative and positive. The negative impacts include depletion of groundwater levels, decline in production capacity of wells, possibility of land subsidence, among others; whereas the positive impacts include institutional and policy reforms, initiation of groundwater-focused collective discussions (e.g., national groundwater symposiums, groundwater expert meeting), etc. The literature also showed time trend of water demand, supply, groundwater extraction, and groundwater level decline in an easy-to-understand way. As reported in the study, total groundwater extraction was less than 0.04 million m^3/year in the early 1970s, which went up to around 12.2 million m^3/year in the late 1980s with another 90% increase in the late 1990s. The study also classified the period from the 1970s to the late 1990s as 1) the early 1970s as the baseline situation where groundwater availability was high with less being supplied to the public, 2) the early 1980s as the low impact period with inception of groundwater development and extraction systems, 3) mid and the late 1980s as the period when Nepal Water Supply Corporation (NWSC) started well fields and impacts of extraction became visible, 4) the early 1990s when a number of private wells increased (Table 2.2) and impacts increased, and 5) the late 1990s as the period where haphazard pumping occurred resulting in groundwater table to decline considerably. Over-exploitation of groundwater has certainly lowered the groundwater levels and raised concerns on risks of land subsidence in areas with high compressible clay and silt layers. This does not necessarily mean that the pumping should entirely focus on shallow aquifer systems. It also indicates that groundwater development and extractions need to be monitored and evaluated across all types of aquifers.

In 2004, a study (HMG, 2004) reported distribution of groundwater extraction from shallow, deep and dugwells by different systems (e.g., NWSC wells, hotels, private, domestic, government institutions and embassies) and revealed that NWSC (currently KUKL) has a major stake on the groundwater extraction (Figure 2.4). The estimate was based on data of 1999/2000. Regularly updated data are probably not available even with the authorities responsible for groundwater management.

ADB (2006) reported that many of the deep wells, which are the main means of extracting groundwater for use in water supply system, may not be in good conditions. Out of 73 existing deep tubewells, only ~74% were in operation. Most of the tubewells' electro-mechanical parts were considered to be in non operable condition with flow meters missing or broken suggesting lack of maintenance or inadequacy in fund allocation and manpower. Tubewells were used to be operated only in the dry season in order to supplement reducing surface water sources, but, due to demand exceeding supply, the general public is now

Table 2.2 Water balance components and groundwater extraction rates from 1991-1993 (IDC, 2009)

Parameters	1991	1992	1993	Remarks
A) Total rainfall (P)	*785.66*	*835.22*	*967.59*	
B) Surface water loss				
1.River discharge(RQ)	*311.89*	*308.11*	*455.38*	
2. Evapotranspiration (ET)	*476.31*	*476.31*	*476.31*	
3. Irrigation requirement (I)	*22.09*	*23.00*	*23.61*	*20% return to river*
4. NWSC distribution	*22.60*	*22.60*	*22.60*	*30% return to river*
C) Recharge to aquifers (RA)	*14.60*	*14.60*	*14.60*	
D) Groundwater abstraction (GA)	*31.61*	*32.77*	*34.29*	*30% return to river*
1. Tubewells	*18.94*	*20.10*	*21.62*	
NWSC wells	*14.30*	*14.30*	*14.30*	
Private wells	*3.59*	*4.75*	*6.27*	
DMG wells	*1.05*	*1.05*	*1.05*	
2. Stone spouts	*1.45*	*1.45*	*1.45*	
Kathamndu	*0.27*	*0.27*	*0.27*	
Lalitpur	*1.17*	*1.17*	*1.17*	
Bhaktapur	*0.01*	*0.01*	*0.01*	
3. Natural springs	*11.22*	*11.22*	*11.22*	
E) Water balance	*-58.21*	*11.98*	*-22.71*	

NWSC: Nepal Water Supply Corporation; DMG: Department of Mines and Geology; All the units are in million m^3/year

forced to use this alternative source of water supply even during wet seasons. Deep wells usually have a very slow recharge capacity. Further studies are needed to explore other sources of groundwater systems.

Pandey et al. (Chapter 4 of this book) estimated groundwater storage potential in the Kathmandu Valley and reported that groundwater storage potential of the valley's shallow and deep aquifers is equal to 2.1 Billion m^3 (BCM); with shallow aquifer alone accounting for 1.5 BCM. The estimate, however, was a static one without considering groundwater recharges and flow dynamics. Actual storage potential considering groundwater flow and recharge dynamics, and mass balance of storage and abstraction of groundwater in the valley, however, are yet to be studied. Another study by the same author (Pandey et al., 2010) evaluated groundwater environment in the Kathmandu Valley by separating both natural (environmental needs) and social systems (human consumption, economic states), analyzing their extent and interrelationships. The study used indicators representing the drivers, pressures, state, impacts and responses and concluded that the anthropogenic factors are the major drivers exerting pressure on groundwater environment.

Cresswell et al. (2001), by analyzing isotope tracers, suggested that the basin's deep aquifer has been confined for the past 200,000 to 400,000 years. Recharge from the surrounding hills contributes to the groundwater capacity of the deep aquifer, but at the rate that is very small relative to the rate of removal of water by pumping. The study further estimated that at least 20 times the amount of recharge is actually being pumped from these deep aquifers and suggested that groundwater resource will be depleted below present extraction levels within 100 years. This analysis might hold true for the current situation. Although without further research and additional findings, the current results may not be sufficient to form a definitive opinion. The extrapolation of the numbers to distant years might need more research that focus on how recharge capacity of shallow aquifer is affected through pumping. Forest and vegetation cover has been long recognized as a major factor influencing run-off, infiltration and evapotranspiration from shallow water tables (Dingman, 2002). Although the Kathmandu Valley is surrounded by forested hills, the valley floor itself has very limited vegetation cover. The high rate of urbanization has increased impervious surface that contributes to no infiltration and high runoff. The message is thus clear; there is definite evidence on increased pressure on aquifers and the race to abstract groundwater through wells and pumps to meet the demands of the growing population. The impervious surface created from building, infrastructures and roads lowers the infiltration rate reducing water that can be otherwise stored in shallow aquifers. Research that address issues of effect of urbanization on infiltration rates will provide insights on understanding groundwater dynamics in the Kathmandu Valley which is undergoing dramatic urbanization.

2.3.2 Groundwater quality

While considering the level of groundwater development, issue of groundwater quality should also be considered. Even though the valley might be in marginal situation in terms of quantitative availability of groundwater, earlier studies indicate a high incidence of water quality problems (Table 2.1). The studies conducted by Jha et al. (1997) showed that the concentration of ammonium-N (NH_4-N), even in the deep well, is above the World Health Organization (WHO) standards (Table 2.3). Other studies (JICA, 1990; Khatiwada et al., 2002; JICA/ENPHO, 2005) have reported the occurrence of high levels of ammonia, nitrate and *E. coli* in shallow aquifer in the valley. Chapagain et al. (2010) used multivariate statistical analyses of water quality from 42 deep wells of the Kathmandu Valley. The major water quality variables such as NH_4^+-N, Fe, Pb, As, and Cd exceeded the WHO standards for drinking water (Table 2.3) for most of the samples. The water quality of deep groundwater, however, is less influenced directly by human activities and affected mostly by the natural hydro-chemical environment. Groundwater quality studies by Pant (2010) showed higher iron and coliform content in all the samples tested. Other physical parameters such as electrical conductivity and turbidity were found to be 875 μS/cm and 55 NTU respectively exceeding the WHO limits for drinking water. The geochemical analysis of fluvio-lacustrine aquifer sediments of the the Kathmandu Valley was studied by Gurung et al. (2007) to assess arsenic mobilization. Elution test of 15 sediment core samples showed that the greater amounts of As are eluted from the fine sediments at varying rates. They attributed the As contamination of groundwater to the redox condition and high organic content of underlying sediments. Groundwater resources are particularly vulnerable to a build-up of arsenic because of their interaction with arsenic bearing aquifers (Panthi et al., 2006; Chapagain et al., 2009). Arsenic is mobilized preferentially under reducing conditions, but oxidizing groundwater with high pH and alkalinity are also vulnerable.

Wastewater and solid waste management practices have a great influence in quality of shallow as well as deep aquifers (if they are connected somehow to the surface). Karn and Harada (2001) reported that Kathmandu generates ~272,000 kg/day of solid waste, out of which less than 60% (i.e., ~150,000 to 190,000 kg/day) are collected. With deteriorating management systems and political instability, the collection of domestic and industrial waste might have gone even less than the earlier estimates. There are several landfill sites that are located near the river banks that contain highly permeable sediment beds (Shrestha et al., 1999). The wastewater treatment systems for both domestic and industrial wastes are not enough and effective. In such circumstances, direct disposal of waste into the nearby rivers often lead to the deterioration of surface water systems and even groundwater in the valley. Often groundwater wells are located in the agricultural fields. Manure, fertilizers, and herbicides spread in agricultural lands may eventually reach shallow aquifer systems contaminating them with excess coliform, phosphorus, nitrogen and other organic compounds that can have health implications. The wide extent of on-site sanitation septic tank

Table 2.3 National and WHO guidelines for drinking water quality (WHO, 2004; and MoLRM/GoN, 2005)

Parameter	Unit	Maximum concentration limit	Maximum concentration limit
		National drinking water quality standards (2062 B.S.)	*WHO drinking water quality standards*
pH	*pH units*	*6.5-8.5*[a]	*No guideline*
Specific Conductance	*mS/cm*	*1.5*	
NO_3-N	*mg/L*	*11.3*[b]	*50.0 for total nitrogen*
NH_3-N	*mg/L*	*1.24*[c]	
SO_4^{2-}	*mg/L*	*250*	*500.0*
Al	*mg/L*	*0.2*	
As	*mg/L*	*0.05*	*0.01*
Ca	*mg/L*	*200*	
Cd	*mg/L*	*0.003*	*0.003*
Cu	*mg/L*	*1*	*2.0*
Cr	*mg/L*	*0.05*	*0.05*
Fe	*mg/L*	*0.3*	*No Guideline*
Pb	*mg/L*	*0.01*	*0.01*
Mn	*mg/L*	*0.2*	*0.05*
Hg	*mg/L*	*0.001*	*0.001*
Zn	*mg/L*	*3*	*3.0*
E.coli bacteria	*cfu/100 ml*	*0*	*0.0*
Total coliform bacteria	*cfu/100 ml*	*0*	*0.0*

[a]*Levels are the minimum to the maximum;*
[b]*Based on* NO_3^- *standard of 50 mg/L;* [c]*Based on* NH_3 *standard of 1.5 mg/L; cfu = colony-forming units*

systems and poor disposal of septage pollutes shallow groundwater. It is estimated that there are over 10,000 dugwell which are used to supplement the KUKL water supply (Dixit and Upadhyaya, 2005). Biological contamination problems causing enteric diseases are present throughout the country and probably constitute one of the major problems of concern. However, no clear estimates are available on the impact of this problem. It must be noted, however, that this summary is based on available data for the valley and represents only the tip of the iceberg of water quality problems.

Given the waste disposal practices and breadth of contamination sources, a broad examination of possible contaminants from sewage, agriculture, and industry is deemed necessary. Pollutants such as nitrates, phosphorus and pathogens need to be monitored at a regular basis. Pathak et al. (2009) assessed vulnerability of shallow aquifers to nitrate contamination using DRASTIC model (Aller et al., 1987). The study incorporated the major hydro-geological factors that affect and control groundwater contamination. The vulnerability maps could be valuable and serve as important resource to begin further impacts and vulnerability assessments. Beyond the inherent vulnerability of aquifers to contamination, much depends on the nature of pollutant sources. Contaminant behavior varies greatly with respect to the specific transport properties in each aquifer system.

2.4 GROUNDWATER DEVELOPMENT AND MANAGEMENT

Groundwater development in the Kathmandu Valley started from the early 1970s. It took momentum from the mid-1980s after NWSC introduced groundwater into its water supply system. With the objective of groundwater development, JICA (1990) has divided groundwater basin in the valley into three districts; northern, central and southern districts (please refer Chapter 3 for details). The northern groundwater district forms the main aquifer in the valley. According to the sedimentary development, the area suitable for recharging aquifers is located mainly in the northern part of the valley, along the rivers, and along the gravel fans near the hillside in the southern part. Though some knowledge about groundwater environment and its recharge system exists, management interventions are yet to be imposed citing their inadequate evidences. This is partially true, because many studies are focused primarily on groundwater development and fewer research address issues of monitoring, management and regulations. The lack of systematic and reliable data and information pertinent to groundwater development, management and research is another potential barrier for appropriate action to take place. The absence of data often limits the degree to which researchers are able to quantify and describe aquifer dynamics and the vastness of groundwater related issues. In addition, management and responses to groundwater related issues are complicated by variations in resource characteristics and social conditions. Hydrogeologic complexities relate to the changes in groundwater dynamics that exist both between and within aquifer systems. Natural variation in climatic conditions is also important since precipitation characteristics greatly influence management options. The ability to capture run-off for aquifer recharge, for example, depends not only on the intensity and duration of precipitation events, but also on infiltration capacity of the soils. Social and economic variation may present some challenges to the development of groundwater management systems (Burke and Moench, 2000), but regulatory agencies need to pay greater attention for managing this resource.

Harvesting rainwater during wet months may reduce stress on groundwater resources (Dixit and Upadhyaya, 2005) to some extent. An integrated effort of mapping, monitoring and modeling is necessary to predict the impacts of water resource management interventions on key environmental, social and economic services. Information essential for coming up with science-based management interventions include the following;

- Hydrogeologic maps identifying aquifers, the characteristics of geologic formations and major surface-water features need to be developed in greater details.
- Location of wells need to be geo-referenced along with their formation characteristics and water quality variations at depth
- Major water-use patterns, key environmental features, cities, agricultural areas and industries along with potential points of contamination.
- Safe pumping rates must be determined. Reliable water supplies will reduce the need for groundwater pumping at individual households, thus helps for using it sustainably.
- Climatic parameters, including precipitation, evapotranspiration, cloud cover, solar radiation, wind speed and humidity data must be collected, evaluated and made accessible for future research.
- Regular monitoring of groundwater quality parameters must be carried out.
- The primary cause of pathogens contamination in groundwater and surface water systems are due to unregulated disposal of domestic wastes to the water bodies. Regulators must focus on developing proper waste management schemes that will help lower nitrate, ammonium, arsenic and mercury pollution in addition to pathogen contamination. Measures must be taken to monitor arsenic contaminations. Lessons must be learnt from the problems that the neighboring countries are facing with these contaminants.
- Water-planning models capable of integrated analysis of water demand, use and supply systems need to be evaluated. Hydrologic and ecologic models for detailed analysis of groundwater flow patterns, specific aquifer conditions and surface stream hydrology and water resource management will help better understand the groundwater dynamics.

2.5 CONCLUSIONS

Conservation and management of groundwater resources need to focus on the ability of the resource to produce environmental, societal, and economic services. Water-level declines greatly increase the probability of impacts on streams, wetlands and the occurrence of subsidence, effecting environmental services. As levels decline, drilling and pumping costs increase. Water may still be physically available, but the cost of extraction can be sufficiently high affecting these services. Groundwater resources and its use are much more difficult to monitor. But the ability to monitor resource use is often critical for the effective development and management of these resources. Public and policy-maker's perceptions of groundwater represent another important problem. Groundwater is often viewed as an inexhaustible resource, cleaned by the filtering action of aquifers. These perceptions do not reflect reality, and often result in use patterns that cause unanticipated problems. The focus must therefore be given to educate general public or users the importance of this valuable resource.

The impacts of groundwater pollution on environment, society and economy of the country have never been comprehensively assessed. The growing number of wells, uncontrolled pumping and unregulated disposal of pollutants are all proximate causes of emerging groundwater problems in the area. Current levels of groundwater abstraction over and above the natural rates of replenishment are already significant, but aquifer systems exhibit a variety of responses to anthropogenic activities that require in-depth study. Water quality issues of the valley are apparent from the literature. This calls for the more research that will address an integrated approach on availability and quality of groundwater for past, current and future scenarios.

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SECTION II
GROUNDWATER QUANTITY

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,

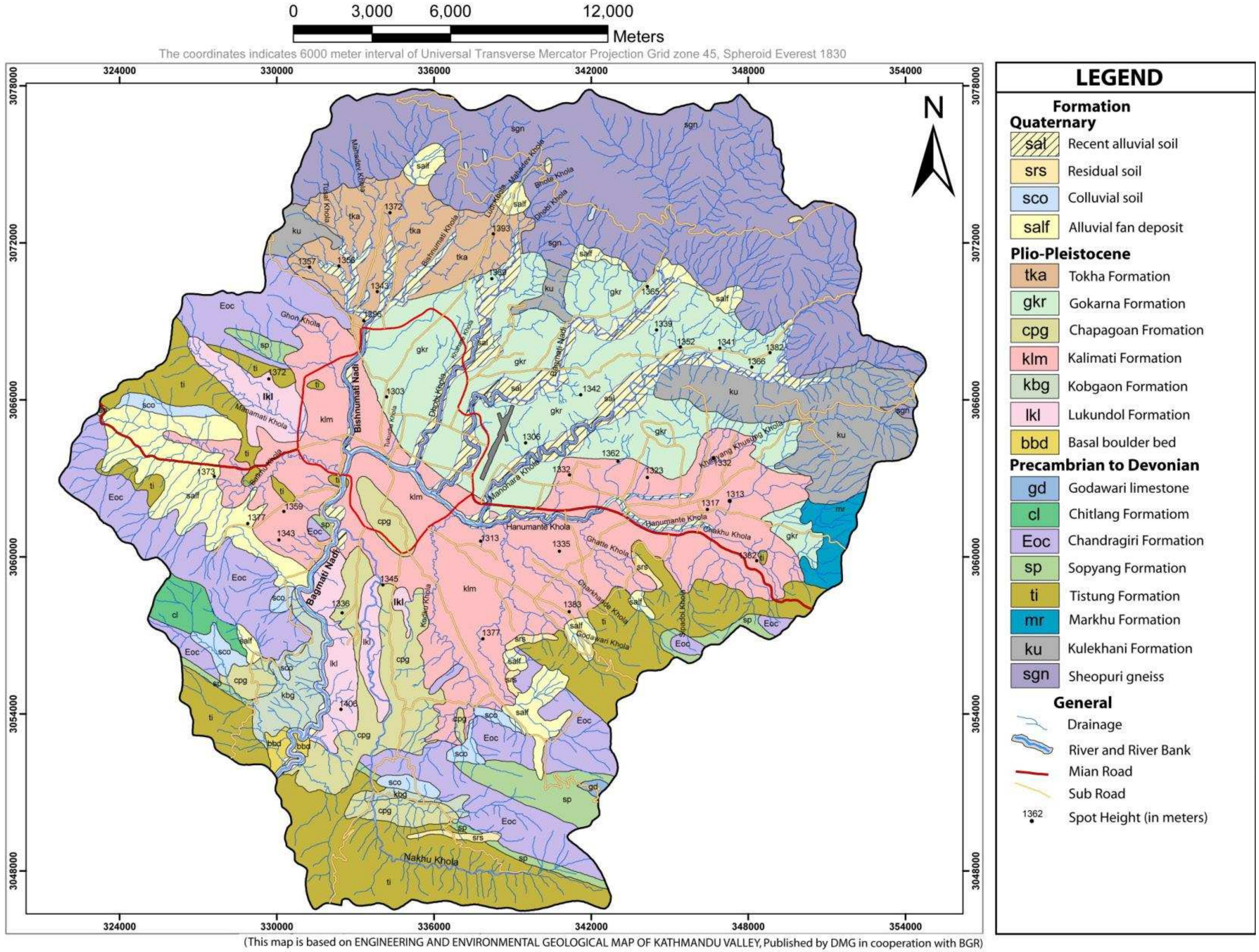

Figure 3.1 Geological map of the Kathmandu Valley (DMG/BGR/DOI, 1998)

shale and crystalline limestone belonging to *Paleozoic Phulchauki Group* (Table 3.1). Description of Geological Formations of the rocks and consolidated to semi-consolidated sedimentary deposits in the Kathmandu Valley are given hereunder in Tables 3.1, 3.2 and 3.3.

Table 3.1 Stratigraphic subdivision of the rocks of the Kathmandu Valley and its surroundings (Stöcklin and Bhattarai, 1977; Stöcklin, 1980)

Group	Formation	Main lithology	Thickness (m)	Age
Phulchauki Group	*Godavari Limestone*	*Crinoidal limestone, dolomitic limestone*	*300*	*Devonian*
	Chitlang Formation	*Sandstone, siltstone and violet grey slate*	*1000*	*Silurian*
	Chandragiri Limestone	*Finely crystalline limestone*	*2000*	*Cambrian to Ordovician*
	Sopyang Formation	*Argillaceous and marly slate and calc-phyllite*	*200*	*Cambrian*
	Tistung Formation	*Metasandstone, siltstone and phyllite*	*3000*	*Early Cambrian to Precambrian*
---------------------------------Transitional Contact---------------------------------				
Bhimphedi Group	*Markhu Formation*	*Marble, schist with granite intrusion*	*1000*	*Precambrian*
	Kulekhani Formation	*Quartzite and schist*	*2000*	*Precambrian*

Table 3.2 Classification of Quaternary unconsolidated sediments of the Kathmandu Valley (DMG/BGR/DOI, 1998)

Formation	Description
Recent Alluvial Soil (sal)	*Recent sediments of flood plains and lower alluvial terraces. In the Northern part, sand and gravel deposits up to boulder size. In central and southern part, clay, sand and fine gravel. Hydrologically the formation has high potential of groundwater with periodic change of shallow groundwater level, high infiltration and high risk of pollution of groundwater and surface water.*
Residual Soil (srs)	*Humic silty loam to sandy gravels of thickness 1-3 m, at places and occur on slopes. High Infiltration and potential for groundwater.*
Colluvial Soil (sco)	*Inhomogeneous deposit at foot slopes with constituents of humic clay silt and sand, at places boulders. Variable thickness>1 m, increasing towards the center of the deposit. High infiltration and low potential for groundwater.*
Alluvial Fan Deposit (salf)	*Gravel, sandy gravel, sand and silt. Thickness increases towards the center of the fan. Finer grained material towards the margin of the fan. High infiltration of surface water and Perched water table may be present.*

Table 3.3 Classification of Plio-Pleistocene slightly consolidated sediments of the valley (DMG/BGR/DOI, 1998)

Formation	Description
Tokha Formation (tka)	*The formation mainly consists of dark grey clay, brownish grey sand and poorly sorted, sub angular to rounded sandy gravel with occasional peaty clay and lignite layers. The thickness of the formation is up to 200 m or more. This formation may act as good aquifer materials for the groundwater abstraction from shallow depth. Most of this formation is highly permeable.*
Gokarna Formation (gkr)	*It comprises light grey; fine laminated and poorly graded silty sand, intercalation of clay of variable thickness as well as in upper part Thimi diatomite (1 m) present. The total thickness is up to 300 m and more. The sediment of this formation is considered to be fluvio-deltaic facies. In the contest of hydrology, the formation has medium groundwater potential and moderate to high groundwater infiltration.*

Chapagoan Formation (cpg)	*It consists of sub-rounded to rounded silty sandy gravel, occasionally with boulder beds sometime within (<1 m) clayey silt and silty sand, and at places lignite pockets. The total thickness is up to 110 m. The cpg has moderate to high permeability and high groundwater potential. Groundwater level is moderately deep and highly vulnerable to groundwater pollution. The formation is potential for groundwater recharge.*
Kalimati Formation (klm)	*The formation is exposed in the central part of the valley around the main cities of Kathmandu, Lalitpur and Bhaktapur. It consists of grey to dark silty clay and clayey silt, at places calcareous nature and phosphate mineral (vivianite). Organic clay, fine sand beds and peat layers are common. Occasionally, lignite seams up to 20 m also occur. In Kharipati area, quartzite and biotite schist boulder beds with sandy gravel and minor clayey and sandy silt layers are present. The total thickness of the formation is 450 m or more. This formation shows purely a lacustrine facies and it acts as an aquiclude or aquitard material having extremely low permeability.*
Kobgoan Formation (kbg)	*It is exposed along the western bank of the Bagmati River and Nakhu Khola in the southern part of the valley around Yutiki, Pharping, Bansbari and Tika Bhairab area. The formation consists of light grey to grey laminated fine sand, occasionally with sandy clay, silty sand and sub rounded to rounded, poorly graded gravel. The thickness is up to 50 m or more. The formation has moderate groundwater potential with moderate to deep groundwater level and has moderate to high permeability.*
Lukundol Formation (lkl)	*It is exposed around the Sunakothi, Bungmati, Khokana and Saibhu Bhaisepati area. It is composed of semi-consolidated sandy, clayey silt interbedded with gravel and clayey sand, peat and lignite of up to 3 m thickness. The total thickness of the formation is up to 80 m. The formation has low groundwater potential with deep groundwater table and has low permeability.*
Basal Boulder Bed (bbd)	*It is the oldest basin fill sediments which unconformably overlie the basement rock of the valley. The formation is exposed at the south western part of the valley near Katuwal Daha around the Bagmati River. It consists mainly of compact boulder conglomerate mixed with silt and sand. Boulders are of quartzite, granite, gneiss and meta-sandstone. The thickness of this formation is up to 300 m. It has high groundwater potential and permeability.*

The valley floor sediments consist of mainly unconsolidated to semi-consolidated sand, gravel, peat, silt, clay and carbonaceous black sticky clay locally known as 'Kalimati' brought from the surrounding hills (Table 3.2, 3.3). The total thickness of the sediment is about 550 to 600 m in the central part of the valley (DMG/BGR/DOI, 1998) with coarse grains in the periphery and finer sediments towards the centre. The sedimentary beds are gently inclined to about 2-9 degrees due North at the southern margin of the Basin (Sah, 1999).

3.3 GROUNDWATER AQUIFERS

The groundwater system of the valley is considered as a closed and isolated groundwater basin, with irregular and discontinuous aquifers. Sand and gravel beds are the principal aquifers within the fluvio lacustrine sediments. They are predominant along the northern and northeastern parts of the valley and occur along with alluvial fans and intercalated with clays and silts (Figure 3.1, 3.2). In the central parts of the valley, sand and gravel units are overlain by a thick (about 200 m) sequence of lacustrine clay. Similarly, sand and gravel units are interbeded with silt and clay layers in the south and southwestern part. Hills along the southwestern, southern and south eastern margins of the valley consisting of carbonate rocks have been classified as aquifers by Binnie and Partners (1973). A general cross-sectional view of subsurface geology and hydrogeological system of the Kathmandu Valley is presented in Figure 3.2. Classifications of aquifer systems are discussed hereunder.

3.3.1 Classifications of aquifer system

According to Binnie and Partners (1973), the aquifer system in the valley can be classified into seven types as in the following:

- Interbedded: lateral extensive aquifers, more numerous towards the north
- Liner: old river channel deposits
- Bedrock: limestone (karst) of the South-East and South-West rims of the valley
- Basal gravel: deep gravel overlying the

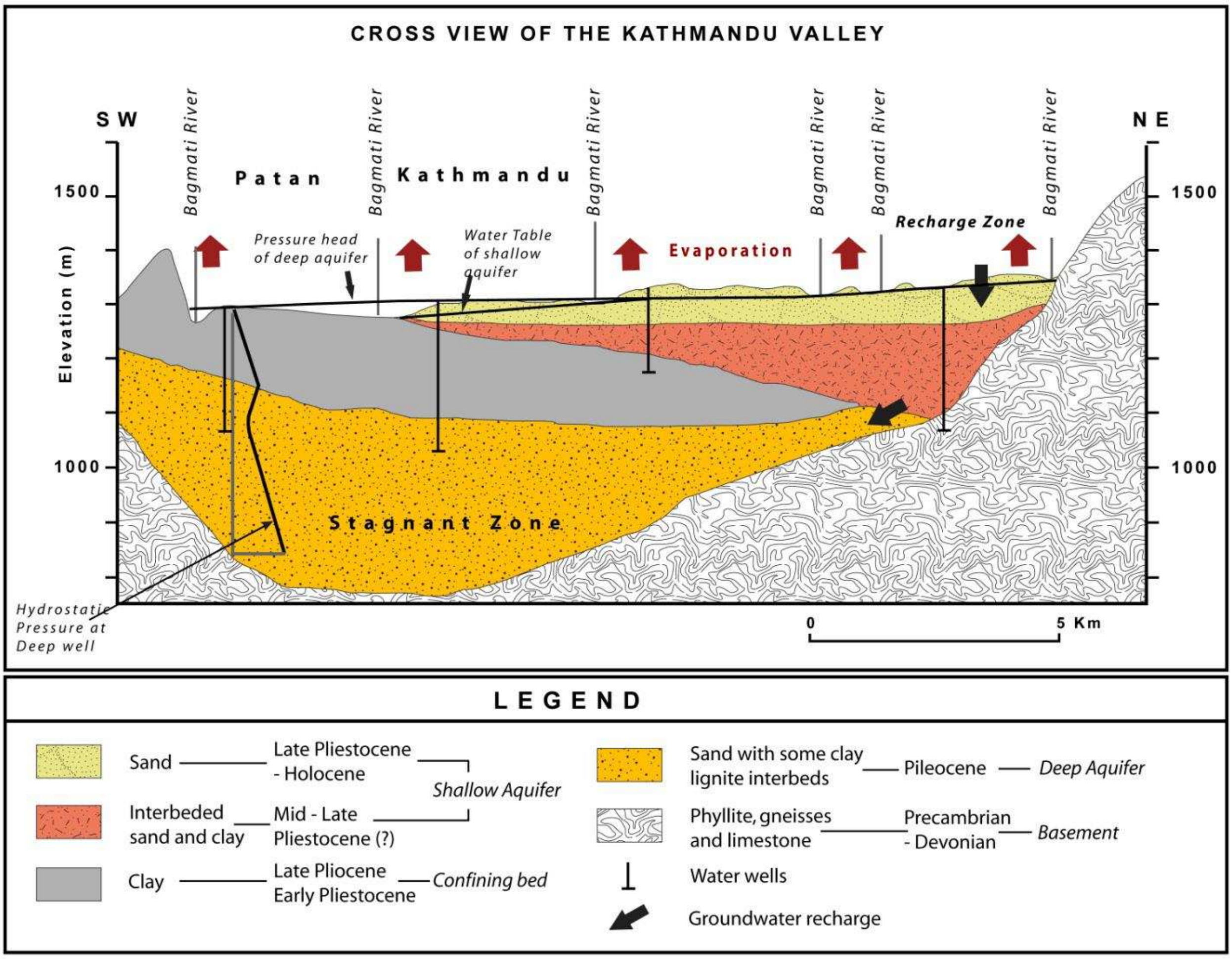

Figure 3.2 Cross-sectional view of subsurface geology and hydrogeological system of the Kathmandu Valley (modified from GWRDB, 2009)

bedrock in the southern part of the valley

- River deposits: recent alluvial material
- Gravel fans: from the hilly rim towards the valley
- Gravel near surface: usually small thickness, locally widespread occurrence

Gautam and Rao (1991) classified the aquifer system in the valley into four zones as (a) Unconfined aquifer zone, (b) Two aquifer zone, (c) Confined aquifer zone, and (d) No groundwater zone.

The unconfined zone lies north of Maharajgunj and Boudha and west of Gorkarna extending to western and northern foot hills of the valley. Medium to coarse grained sand, gravelly sand and silty sand comprises the major aquifer material. Besides the above mentioned areas, other unconfined aquifers are found on terraces in other parts of the valley but with limited potentiality. The shallow aquifers in the north central part at Dhobi Khola well field have been tapped for municipal water supply (DMG/BGR/DOI, 1998). These shallow perched aquifers are generally composed of clayey sand, silt, gravelly sand with limited local extension.

Similarly, the two aquifer zone constitutes sandy deposits forming the shallow aquifer and deep confined aquifers consisting of gravel deposits are separated by thick clay beds. The two aquifer zone is found in the region between Manohara River and Bishnumati River in the central part of the valley. The thickness of the top shallow aquifer increases towards north and northeast up to 44 m while it is only 5 m thick in the central part. Recent alluvial deposits along the rivers also form a shallow groundwater system. The rest of the central part constitutes only the confined aquifer zone with confining clay layer exposed on the surface.

Coarse to very coarse sand, pebble, cobble and gravel are the chief constituents of the confined aquifers which form the main aquifer system within the valley. The piezometric surface in the confined aquifer area is said to decrease in the central part of the valley indicating the flow direction from periphery to the center. Similarly, the piezometric head increases with the depth of the aquifer which is in conformity with the hydraulic principle. The confined aquifer zone lies south of Maharajgunj and Boudha but extends all the way to southern and western boundaries from Bode in the east. However, the aquifer in the southern part of the valley is considered a no groundwater zone.

Collectively the greatest proportion of aquifer units occurs in the north and northeastern areas of the valley. Little is known about the hydraulic connections within these aquifer units, however, presence of relatively impermeable silts/clays and buried bedrock ridges suggest the presence of hydraulic barriers, localized aquifer systems or basins probably isolated from each other.

3.3.2 Rock aquifers

Hills from the southeastern to the southwestern part of the valley consists of interbedded limestone, sandstone, shale, and siltstone that are highly jointed, fractured and porous (limestone terrain). Under weathered conditions they become favorable for the formation of groundwater reservoir with the development of underground drainage system. Some industries have developed exploration tubewells in the rock aquifers. The areas along the foothills of the southern part of the valley like Pharping, Thapagaun can also be considered as the rock aquifer zone. In the Phulchoki–Chandragiri range, spring water gushes out from faulted and fractured limestone layers. In the Nagarjun-Naichal range major springs emerge from layers of conglomerates.

Numbers of NW-SE trending ridges extend to the valley bottom from the surrounding hills. Similarly, exposures of basement rocks at the surface near temples like Pashupati, Gokarneswor, Bijeswori and the occurrence of basement rocks at shallow depths in locations like Sanepa, airport and Department of Water Induced Disaster Prevention in Pulchowk suggests a number of buried ridges hidden beneath the fluvial and lacustrine deposits in the valley. Possibility of a number of groundwater sub-basins isolated or connected to the main basin warrants further study.

3.3.3 Aquifer tapping

The sedimentary deposits contain a number of aquifer horizons which can be identified from the existing lithologs and the placement of screens in the wells. The lithologs of wells MH3 in Mulpani and GK1 at Nayapati show screens placed at nine different aquifer horizons. In well BB9 at Budanilkantha, the first screen has been placed at the depth of 6 m below ground level and other screens placed at 102-123,132-142 m below ground level thus linking both shallow and deep groundwater aquifers.

3.3.4 Spring sources

Springs are located mainly in the southern parts of the valley. These springs could be an indication of a huge reservoir of groundwater hidden inside the fractured, jointed carbonate rocks. There could be substantial groundwater storage in the limestone below the spring line which occurs generally along or above the level of the top of the basin fill deposits (Metcalf and Eddy, 1999). An inventory of discharge of 7 major spring sources by JICA in 1990, reported discharge of 34,000 m^3/day in dry season (Feb/March) and 50,000 m^3/day in wet season (Aug/Sept) (Metcalf and Eddy, 1999). HYM Consult in 1997 reported cumulative discharge of 396 litres/second (lps) from seven spring sources in February/March, dry season. In 1999, abstraction from spring sources reportedly contributed 13.9 MLD to the city water supply (Metcalf and Eddy, 1999). Recent studies show even higher discharge from the spring sources totaling 43 MLD (Maharjan, 2008).

3.4 HYDROGEOLOGICAL PARAMETERS

3.4.1 Hydrogeological districts

Based on physical and chemical characteristics of the groundwater and geological conditions, JICA (1990) divided the deep part of the Kathmandu basin into three groundwater districts (refer Figure 3.3).

Northern Groundwater District (NGD): This zone lies in the northern part of the valley from the foothills to Pashupati in the South encompassing an area of 156 km^2 and includes principal water supply well fields of Bansbari, Dhobi Khola, Gorkarna, Manohara and the Bhaktapur (West to East). The sediments are composed of unconsolidated highly permeable materials of micaceous sand and gravel. The unconsolidated coarse sediments are as thick as 60 m. However, several impermeable fine layers are interbedded with these coarse sediments. This coarse sediment is the main aquifer that supplies groundwater to NWSC wells. Groundwater occurs generally in unconfined to semi-confined, conditions becoming confined in the south. Binnie and partners (1973) reported that interbedded layer of sand/gravel and clay layers is over 330 m thick but the upper 50-80 m has the greatest potential. The study also identified Dhobi Khola- Jorpati areas as a separate sub-district having shallow aquifers of only 20-35 m in thickness. Water quality in the NGD is characterized by low

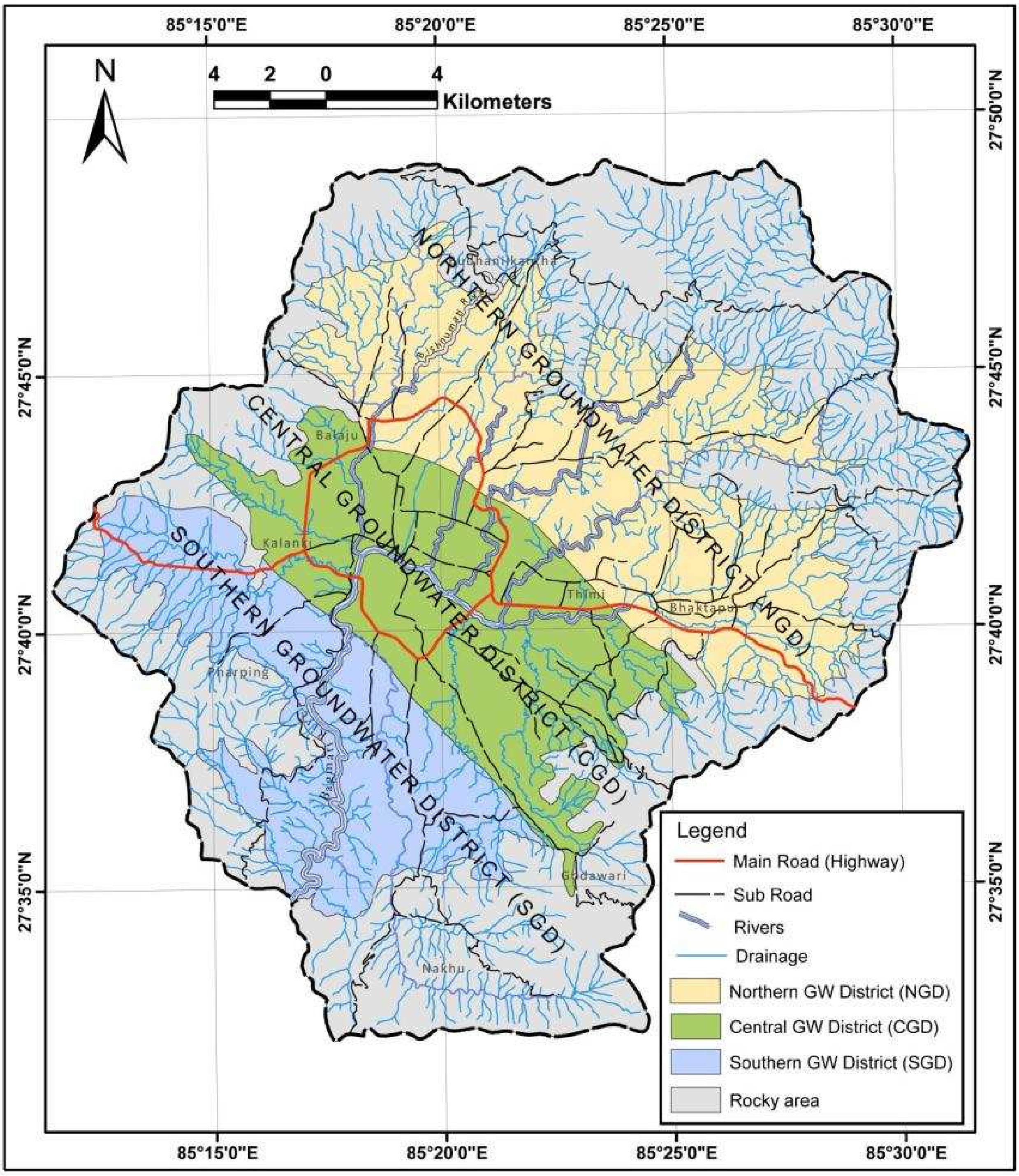

Figure 3.3 Hydrogeological districts in the Kathmandu Valley *(JICA, 1990)*

electrical conductivity such as 100 to 200 μS/cm.

Central Groundwater District (CGD): The central groundwater district consists of very thick impermeable (about 200 m) black 'Kalimati' clay accompanied by some lignite and peat. Unconsolidated coarse sediments of low permeability underlie this thick black clay and form the aquifer unit in the CGD. Though most of the aquifers are in confined conditions, in southeastern part near Godavari, sand and gravel extend towards surface from where recharge also takes place. Collectively the coarse sediments are about 80 m thick. A shallow layer up to the depth of 20 m overlies the thick clay. The total area is 114 km^2. The groundwater quality in the CGD is characterized by high electrical conductivity (1000 μS/cm in some tubewells near Tripureswor). The age, 28000 years (JICA, 1990), and the presence of methane gas indicate non-rechargeable or with limited recharge, stagnant fossil groundwater. The Transmissivity (T) of the aquifer ranges from 32 to 960 m^2/day (JICA, 1990; DMG/ BGR/ DOI, 1998). Most of the private tubewells are located in the central part of the valley where water contains high quantity of ammonia and nitrogen and are mainly used only for sanitary purposes (JICA, 1990).

Southern Groundwater District (SGD): In general, the aquifer is not well developed except along the Bagmati River between Chobhar and Pharping. Like in the CGD, the area is characterized by a basal gravel of low T, covered by a thick impermeable clay formation. The aquifer surfaces near Pharping. The total area of this district is only 56 km^2.

3.4.2 Hydrogeological parameters

Table 3.4 Hydraulic parameters of deep wells in the valley (Metcalf and Eddy, 1999)

Well no.	Locations	Depth (m)	Cumulative aquifer thickness (m)	T (m^2/day)	Specific capacity (lps/m)	Storage coefficient	Year of drilling
Northern well-field							
Dhobi Khola							
DK1	*Mahankal Chaur*	*72*	*21*	*1963*	*4.3*	-	*1984*
DK46	*Dhobi Khola*	*163*	*46*	*3.36*	*0.09*	-	*1998*
Bansbari							
BB2	*Galfutar*	*190*	*79*	*44*	*0.63*	*0.017*	*1984*
BB7	*Gongabu*	*253*	*135*	*561*	*5.57*	-	*1985*
Gokarna							
GK1	*Nayapati*	*289*	*117*	*291*	*2.85*	-	*1985*
GK2	*Nayapati*	*149*	*90*	*83*	*1.35*	-	*1985*
Manohara							
MH 4	*Mulpani*	*237*	*144*	*861*	*3.18*	5.61×10^{-2}	*1985*
MH3a	*Mulpani*	*323*	*166*	*162*	*2.51*	-	*1984*
Bhaktapur							
BH4	*Bode*	*161*	*80*	*646*	*3.85*	-	
BH2b	*Bode*	*266*	-	*62.55*	*0.65*	5.5×10^{-3}	*1998*
Southern well field							
Pharping							
PH2	*Bungmati*	*90*	*37*	*70.62*	*0.75*	7.05×10^{-3}	*1977*
JW3	*Sundarighat*	*284*	*30*	*1.6*	*0.03*	-	*1989*

Transmissivity (T): The T values calculated from earlier studies for various aquifer units show wide variation in values indicating heterogeneous nature of the sediment distribution. According to Metcalf and Eddy (1999), shallow aquifers in the north have higher T values ranging from 3.36 (well DK4) to 1963 m^2/day (well DK1). In comparison, deep wells of northern groundwater district have T values in the range of 44 and 561 m^2/day in the wells BB1 and BB7. In general, T is highest (>300 m^2/day) in NGD and CGD. Deep wells in SGD have the maximum T of 70.62 m^2/day (Table 3.4). The T in general decreases towards CGD and SGD from the NGD indicating change from unconfined/semi-confined to confined conditions.

Storage coefficient (S): Storage coefficient in the deep wells of NGD ranges from 5.5 x 10^{-3} to 0.017 while in the SGD, only one value of 7.05 x 10^{-3} is available.

Hydraulic conductivity: Hydraulic conductivity also shows a similar pattern, with shallow aquifers in the NGD having higher values compared to deep aquifers (Metcalf and Eddy, 1999). Hydraulic conductivity measured in shallow borings along river channels of Dhobikhola, Bishnumati, and Bagmati rivers in Northern parts ranged from 10^{-2} to 10^{-4} cm/s with the average value of 2 x 10^{-3} cm/s for shallow zones of less than 20 m.

Specific capacity (SC): SC values are associated with T values. SC values range from 0.03 to 0.75 lps/m in SGD, 0.09 to 5.57 lps/m in the deep wells of NGD and 0.041 to 1.34 lps/m in CGD. However, the values are low in wells of Pharping in SGD.

Specific Yield: Specific Yield for shallow unconfined layer has been calculated by a study carried out by Acres International. According to the report, the specific yield of the unconfined aquifer in the Kathmandu Valley ranges from 0.1 to 0.19 (MoPPW, 2004).

3.5 SUMMARY AND CONCLUSIONS

Groundwater system in the valley consists of three components: a) shallow groundwater system, b) deep groundwater system, and c) rock aquifer system in the valley rims. Shallow groundwater system is the major source of water supply at household level while deep groundwater is the principal source of water supply for the municipal, industries, hotels and other large volume users. In terms of groundwater potential and water quality, the Kathmandu Valley has been divided into three groundwater districts. The northern groundwater district consisting of coarse sediments is the most potential among the three districts in the valley with higher values of Transmissivity/Hydraulic conductivity. As little monitoring works are being carried out, changes in the groundwater system are little understood. Complication arises from the fact that most wells tap multiple aquifer units having variable hydrogeologic parameters. Piezometric level decline of 1-4 m/year since 1984 has been reported in deep wells with the greatest abstraction in the north. Though artificial recharge of deep aquifer system is hindered by the presence of Kalimati layer, shallow aquifer system has potential for recharge as evident from yearly water level fluctuation taking place. The natural recharge, however, is believed to be declining due to increase in surface sealing from urbanization. Thus rainwater harvesting holds some potential as a means of recharge.

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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 throughout the valley. Its thickness is more than 200 m in the central part and gradually decreases towards the edges and diminishes to minimal in some area towards north and southeastern part of the valley (Metcalf and Eddy, 2000). Those areas are expected to be recharge areas (Figure 4.2) for the deep aquifer since they have less amount of clay layer barrier to interrupt percolation of infiltrated water. Along with clay, the distribution of shallow and deep aquifer layers is also irregular with discontinuities occurring vertically and horizontally.

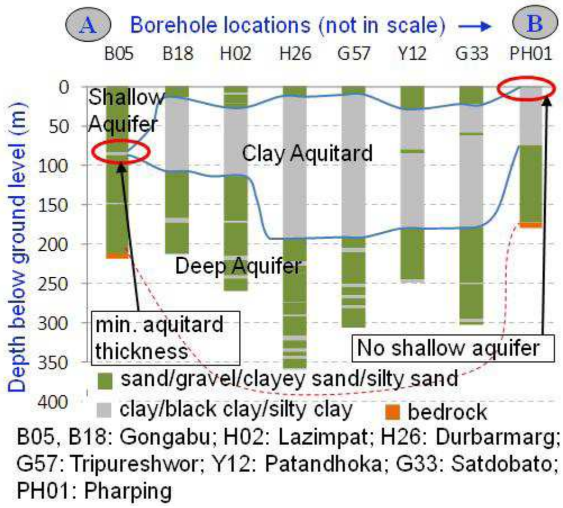

Figure 4.1 North-South x-section at selected locations Locations of the points are shown in Figure 4.2

A few earlier studies suggest that northern part of the groundwater basin have high percentage of aquifer units (e.g., Metcalf and Eddy, 2000; KC, 2003). However, they have neither shed light on actual depths of the aquifer layers and spatial extent within the entire basin, nor have estimated volume of aquifers, groundwater storage potential and its spatial distribution. Estimating dynamics of groundwater storage potential requires a three-dimensional numerical modeling of groundwater system with aid of several data and information and demands advanced knowledge and expertise. However, an acceptable static estimate of groundwater storage potential could be made at relatively less resources based on readily available secondary data and information using Geographic Information System (GIS). The GIS technique has advantages in terms of prediction capability, visualization strength, and resource efficiency (less time and money); and therefore it is widely being used as a tool for estimating groundwater storage potential (e.g. Johnson and Njuguna, 2002; Singh and Prakash, 2002; Jorcin, 2006; Wahyuni et al., 2008; etc). This study aims to provide an acceptable estimate of groundwater storage potential and its spatial distribution in the Kathmandu Valley's shallow and deep aquifers.

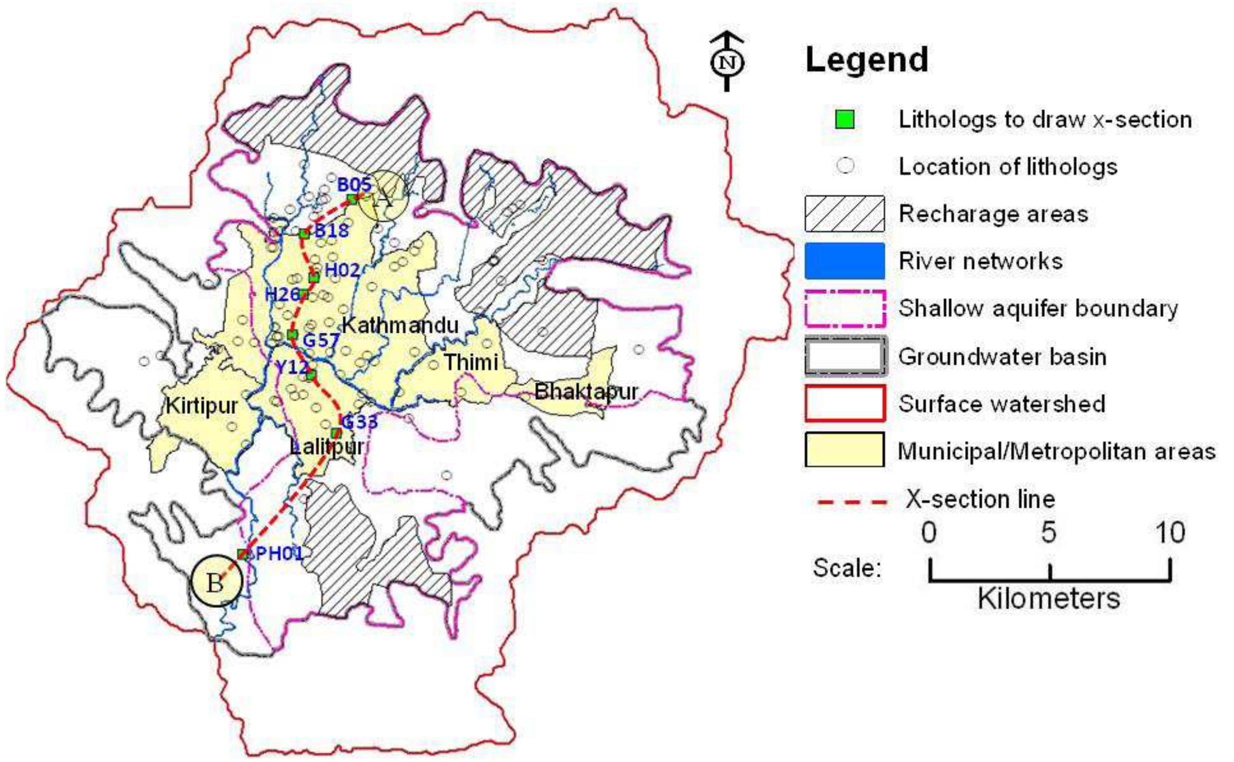

Figure 4.2 The Kathmandu Valley groundwater basin (surface and groundwater basin boundary and recharge areas from JICA (1990); river networks from department of survey in Nepal; sources of lithologs are outlined in Table 4. 1)

4.2 METHODOLOGY

The 'groundwater storage potential' in this study refers to the volume of groundwater that can theoretically be extracted if the aquifer were completely drained. It can be calculated by multiplying aquifer volume (= aquifer thickness x surface area of a grid cell) with storage coefficient (refer to Figure 4.3). This, therefore, needs information about spatial distribution of three parameters: aquifer thickness, storage coefficient (called as specific yield, Sy, in case of the shallow aquifer) and surface area of *grid cells*. For calculating distribution of aquifer thickness, a Digital Elevation Model (DEM) of ground surface is also needed. The DEM (20 m resolution) was generated in ArcGIS using digital elevation points, 20 m interval contour lines, and river networks using "*Topo to Raster tool*" in ArcToolbox. Accuracy of the newly created ground surface DEM was evaluated by extracting elevation of top of boreholes and comparing them with the elevations collected as a part of borehole datasets.

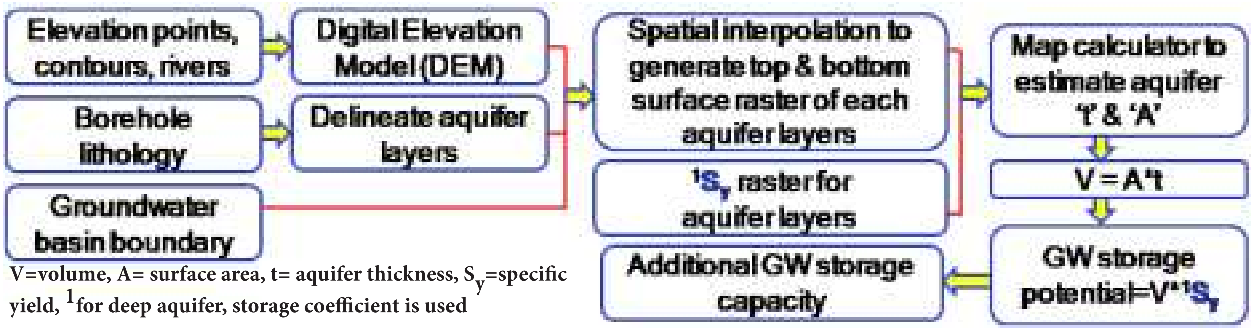

Figure 4.3 Flow chart to estimate groundwater storage potential and its spatial distribution

Following sub-sections detail the calculation of the parameters required to estimate the groundwater storage potential.

4.2.1 Aquifer thickness

The thickness, from the perspective of estimating groundwater storage potential, stands for the distance from an assumed upper limit of groundwater level to the top of the underlying layer. In this study, the upper limit of groundwater level was assumed at 0.5 metres below ground level (mbgl) for both shallow and deep aquifers. Though, actual upper limit for deep aquifers may vary depending upon hydraulic head, in some areas in deep aquifer, the heads were found to be more than atmospheric pressure. In the absence of detailed data throughout the aquifer, upper limit for deep aquifer was assumed the same as that of shallow aquifer. Afterwards, actual groundwater level data was used to estimate the space available for additional groundwater storage.

To delineate the thickness of aquifer layers, the groundwater basin boundary digitized from JICA (1990) and 112 borehole lithologs collected from a large number of sources (outlined in Table 4.1) were used. Borehole records consisted of location (X,Y), elevation, and lithological information beneath the ground. The lithological information (sand, gravel, clay, etc.) were not uniform throughout the study area. However, three general hydrogeologic layers in descending order - shallow aquifer, aquitard and deep aquifer – above the bed rock were delineated from the borehole records based on available knowledge in the published reports (e.g. Metcalf and Eddy, 2000)and based on authors' knowledge of the study area. The reclassified borehole information (reclassification in terms of hydrogeologic layers), means thickness of the hydrogeologic layers, was then converted into a GIS database.

Elevations of bottom of hydrogeologic layers (shallow aquifer, aquitard, and deep aquifer) in each borehole were calculated by subtracting 'layer thicknesses' from the DEM of ground surface. Only thirty boreholes were drilled up to the bed rock. A bed rock raster was generated by *spline* interpolation of those thirty data points. The bottom elevations of the deep aquifer for other boreholes were extracted from that *bed rock raster*. The *spline* method was selected because our data points were unevenly distributed

Table 4.1 Data and sources

S.N.	Data	Source
1.	*Borehole lithology*	*Department of Mines and Geology, National drilling company, Sagarmatha drilling company, Metcalf and Eddy (2000), Acres International (2004), NISAKU drilling company, JICA (1990), Groundwater Development Project/ Department of Irrigation*
2.	*Storage coefficient (S) and specific yield (Sy)*	*Metcalf and Eddy (2000), Binnie and Parttners (1973), JICA (1990), Acres International (2004)*
3.	*Water level in deep aquifer*	*Groundwater Development Project/Department of Irrigation, Nepal*
4.	*Water level in shallow aquifer*	*Personal communication with Dr. Dhundi R. Pathak, Osaka University*

and relatively small in number. The extracted elevations were evaluated by comparing with bottom elevation of the boreholes. In some cases, extracted elevations were above the bottom elevation of the boreholes (i.e. underestimated). To overcome those errors, it was assumed that bottom of borehole coincides with that of the deep aquifer in that particular borehole. Finally, elevation raster of bottom of each geological layer was generated using *spline* interpolation and thickness raster of each hydrogeologic layer was generated by subtracting top and bottom layer elevation raster of the respective hydrogeologic layers using "*Raster Calculator*" tool in ArcGIS.

4.2.2 Storage coefficient

Water storage and release ability of a deep aquifer is expressed in terms of storage coefficient (S), while that of a shallow aquifer is expressed in terms of specific yield (Sy). The S describes the compressibility of the mineral skeleton of the aquifer matrix and the expansion of the water. It accounts for percentage of aquifer area that is available for storing water. The S (or Sy) distributions around the data point were considered to vary according to Thiessen polygon extent.

4.2.3 Surface area of grid cells

Surface area of grid cells of each raster (thickness- and S-raster) were 20 m x 20 m (i.e., 400 m^2). This value was multiplied by aquifer thickness in each grid cell to calculate spatial distribution of 'aquifer volume' throughout the groundwater basin.

Finally, after calculating the potential groundwater storage volume using the three parameters described above, *the space available for groundwater storage above groundwater level* were estimated based on available aquifer depth for an additional storage; which is the difference between the current and the assumed upper limit of groundwater level (i.e., 0.5 mbgl in this study) in each aquifer. The additional groundwater storage potential in shallow and deep aquifers, thus, becomes:

In Shallow Aquifer (SA) = {(GL-0.5) – water level in SA} x Sy x surface area

In Deep Aquifer (DA) = {(GL-0.5) – water level in DA} x S x surface area

where, GL is ground level elevation, S is storage coefficient, Sy is specific yield.

4.3 RESULTS AND DISCUSSION

4.3.1 Thickness distribution of hydrogeologic layers

Thickness of shallow aquifer varies from 0 to 85 m, clay aquitard (that vertically separates shallow and deep aquifer) from nearly 5 m to more than 200 m, and that of deep aquifer from 25 m to 285 m (Figure 4.4). There is no distinct shallow aquifer layer in some parts of the groundwater basin (Figure 4.4), however, perched aquifers which are not considered in this study, may exist in those areas. The shallow aquifer is thicker towards the northern part of the groundwater basin while the deep aquifer is thicker towards the southern part. The result about shallow aquifer is consistent with earlier reports that northern part has a high percentage of aquifer units (Metcalf and Eddy, 2000; KC, 2003). The clay layer (i.e., aquitard) has a minimum thickness (<10 m) towards northern and north-eastern part of the basin. Those areas closely matched with potential recharge areas (shown in Figure 4.2) suggested by JICA (1990). The shallow aquifer surface extends over 240 km^2 area while clay aquitard and deep aquifers extend to the entire area of the groundwater basin (i.e. 327 km^2). The total volumes of shallow and deep aquifers are estimated at 7.26 Billion-Cubic-Metres (BCM) and 56.8 BCM, respectively.

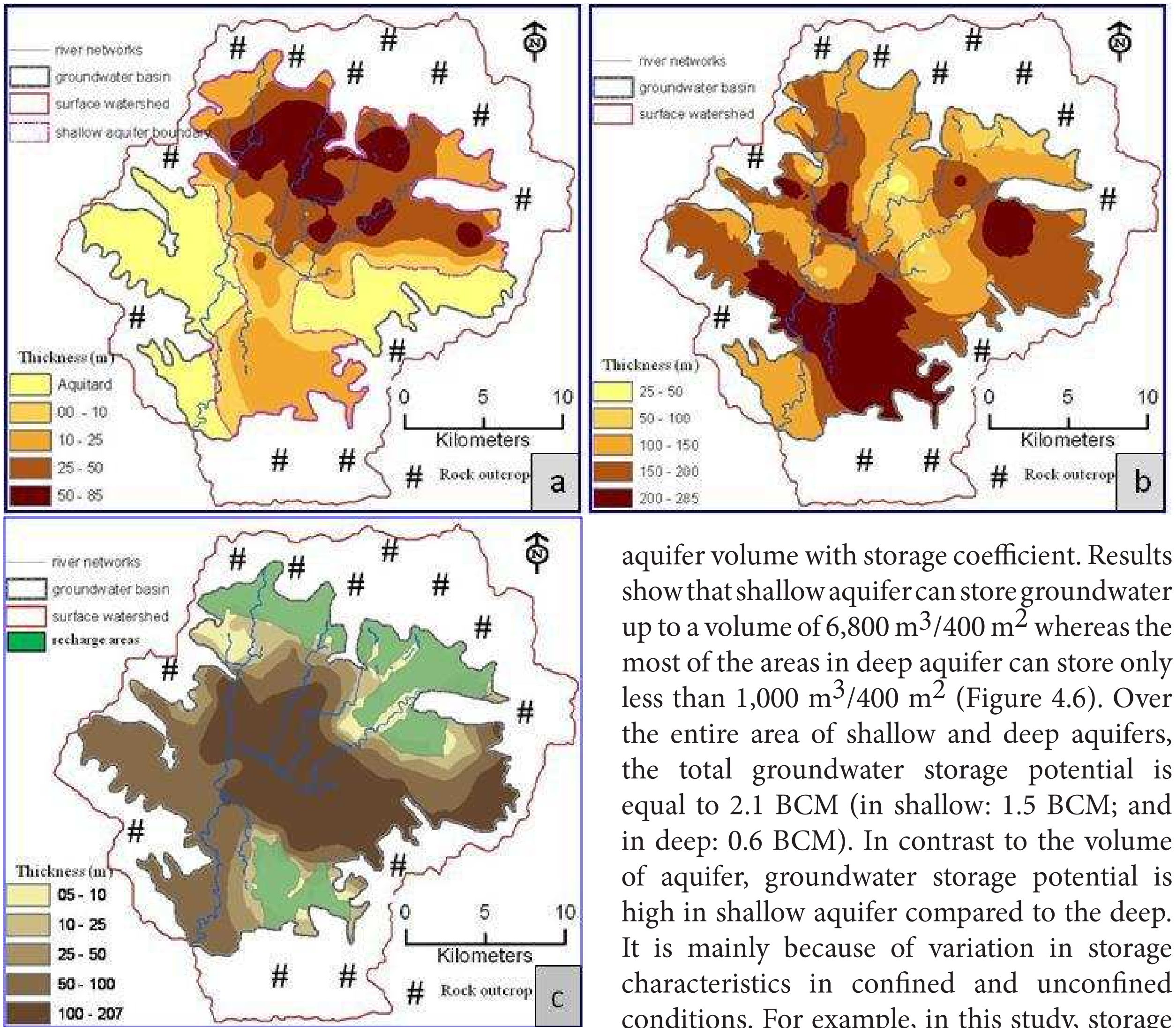

Figure 4.4 Thickness distribution: (a) shallow aquifer (b) deep aquifer (c) clay aquitard

4.3.2 Storage coefficient distribution

The storage coefficients of deep aquifer were available at 12 locations (Figure 4.5b, for data source, please refer Table 4.1) whereas no such data (Sy) were available for shallow aquifer. In the absence of data, it was assumed as 0.20 throughout the shallow aquifer. One of the earlier studies (Acres International, 2004) has also used 0.20 as an approximate value of Sy throughout the study area. Though distribution of available data is relatively uneven and large data gaps do exit, values of S are much lesser than Sy. Storage coefficients in deep aquifer vary from 0.00023 to 0.07000 (Figure 4.5b).

4.3.3 Spatial distribution of groundwater storage potential

Groundwater storage potentials in shallow and deep aquifers were estimated by multiplying aquifer volume with storage coefficient. Results show that shallow aquifer can store groundwater up to a volume of 6,800 m^3/400 m^2 whereas the most of the areas in deep aquifer can store only less than 1,000 m^3/400 m^2 (Figure 4.6). Over the entire area of shallow and deep aquifers, the total groundwater storage potential is equal to 2.1 BCM (in shallow: 1.5 BCM; and in deep: 0.6 BCM). In contrast to the volume of aquifer, groundwater storage potential is high in shallow aquifer compared to the deep. It is mainly because of variation in storage characteristics in confined and unconfined conditions. For example, in this study, storage coefficient in deep aquifer varies from 0.00023 to 0.07 which is lower by a few to several orders compared to the assumed storage coefficient in shallow aquifer (i.e. 0.20). High storage potential per pixel as well as total over the entire shallow aquifer suggests the prospects of shallow aquifer to play an important role as storage reservoir if plans for artificial recharge could be prepared and implemented effectively. However, analysis for cost and benefit should be carried out separately (which is outside the scope of this paper) before deciding to go for such recharge projects. If using Kathmandu Valley's groundwater reserve is continued at the same rate as in 2001, i.e. 21.56 MCM/year (as discussed in Pandey et al., 2010), shallow and deep aquifers in the valley will be emptied in less than 100 years. This analysis based on estimated storage volume and rate of extraction is consistent with that of Cresswell et al. (2001) based on recharge and extraction rates.

Further analysis of estimated total storage volumes in shallow and deep aquifers within municipal areas (there are five municipal areas in the Kathmandu Valley) reveals that groundwater storage per unit area is the highest in Kathmandu municipality, whereas per capita storage is the lowest in Bhaktapur (Table 4.2). But, Bhaktapur municipality has the highest population density. These scenarios reflect the possible inter-municipality conflict in underground water use in future if groundwater extraction and user right is not wisely defined.

4.3.4 Empty space available in shallow and deep aquifers

Water level in deep aquifer (based on data of July 2008 in 22 monitoring wells) ranges from 5.3 to 98.9 mbgl. The volume of space above the water level and assumed upper limit of storage (i.e., 0.5 mbgl) is equivalent to 8.2 MCM of groundwater storage in deep aquifer. In case of shallow aquifer, water level (based on water level data in 90 shallow wells) ranges from 0.5 to 25.0 mbgl with mean value of 5.2 mbgl. Assuming upper limit of storage elevation is

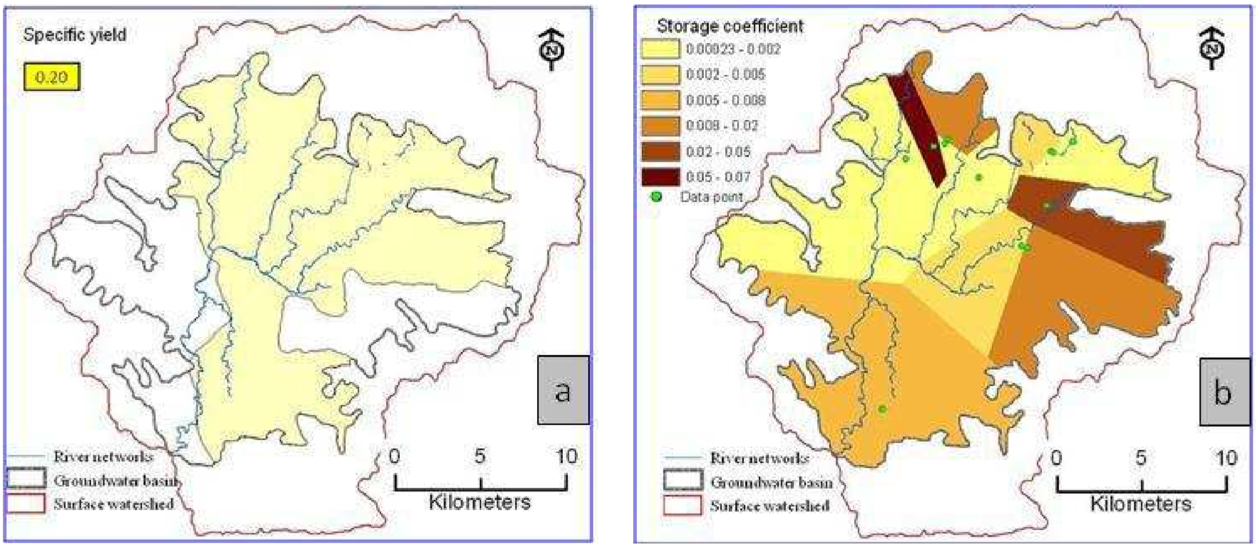

Figure 4.5 Storage coefficient distribution of: (a) shallow aquifer, (b) deep aquifer

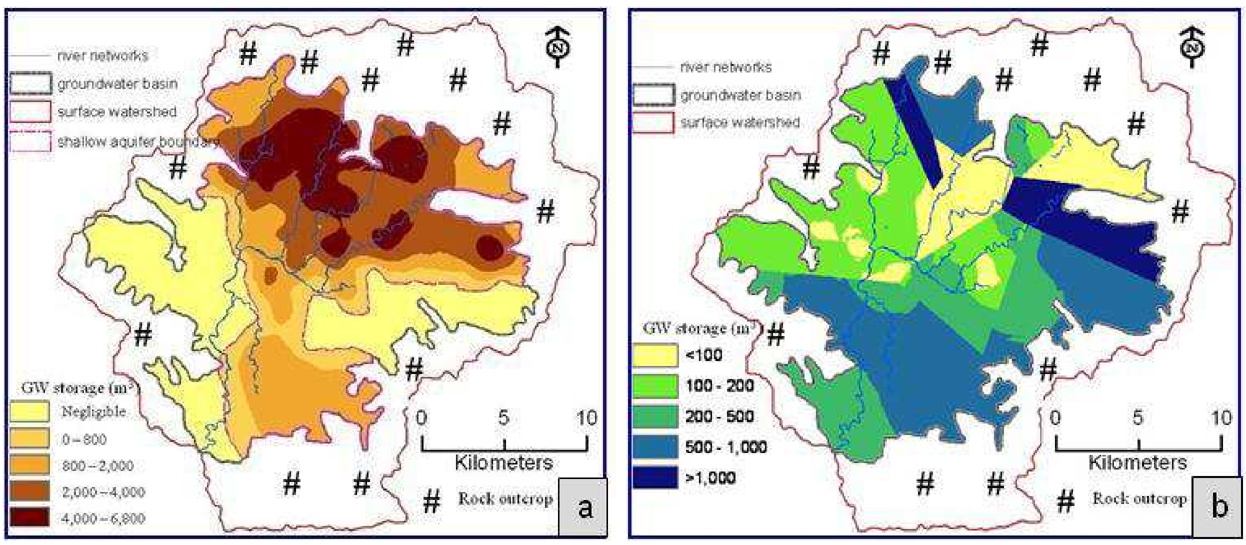

Figure 4.6 Groundwater storage potential per 20 m x 20 m cell: (a) shallow aquifer, (b) deep aquifer

Table 4.2 Groundwater storage potentials of municipal areas in the Kathmandu Valley

Municipal name	Area (km^2)	GW storage capacity(MCM)			Pop. (2001)	Pop. density (Number/km^2)	Storage/area (MCM/km^2)	Storage per capita (m^3)
		SA	DA	Total				
Kathmandu	*49.9*	*313.8*	*31.5*	*345.3*	*421,258*	*8,445.4*	*6.9*	*819.6*
Lalitpur	*15.2*	*32.3*	*12.2*	*44.5*	*115,865*	*7,617.7*	*2.9*	*384.0*
Bhaktapur	*6.4*	*9.5*	*11.7*	*21.2*	*61,405*	*9,654.9*	*3.3*	*344.4*
*Thimi**	*11.2*	*46.6*	*6.5*	*53.1*	*31,970*	*2,862.1*	*4.8*	*1,661.2*
Kirtipur	*14.6*	*0.00*	*16.7*	*16.7*	*31,338*	*2,145.0*	*1.1*	*533.2*

** Madhyapur Thimi; Pop. is population, MCM is million cubic metres; GW is groundwater SA and DA are shallow and deep aquifer*

0.5 mbgl, mean thickness above current water level becomes 4.7 metre. The space with 4.7 metre thickness in shallow aquifer can store 226.5 MCM of groundwater. Summing up total groundwater storage potentials of the available spaces (above current water level) in shallow and deep aquifers, the available spaces can store 234.7 MCM of groundwater. The strong seasonality of monsoon rainfall and the availability of huge space beneath the ground surface suggest the prospects for artificial or managed aquifer recharge possibilities. If all the available spaces could be filled in with water, it can meet Kathmandu Valley's groundwater demand for 11 years assuming future groundwater extraction at the same level as in 2001 (i.e., 21.56 MCM/year).

4.4 CONCLUSIONS

The static groundwater storage potential of shallow aquifer in the Kathmandu Valley is higher than that of deep aquifer. Total storage potential of the shallow one is 1.5 BCM where as that of the deep is only 0.6 BCM. There is a wide spatial variation in the storage potential in both the aquifers. In shallow, it varies from less than 100 to 6,800 $m^3/400\ m^2$. In contrast, the maximum storage in major parts of the deep aquifer is less than 1,000 $m^3/400\ m^2$ only. If the groundwater use is continued in the same rate as that of 2001 (i.e., 21.56 MCM/year), the shallow and deep aquifers will be emptied in less than 100 years. On the other hand, a large (226.5 MCM) empty space is available above groundwater level in shallow aquifer. If all the empty space of the shallow aquifer could be filled in, one cycle of the filling can meet the valley's groundwater demand for 11 years assuming future groundwater extraction at the same level as in 2001 (i.e., 21.56 MCM/year). Therefore, if the recharge potentials of the shallow aquifers and their locations could be delineated and rainwater could be harvested and used for recharging the shallow aquifer, water supply in the valley could be augmented.

The estimates of groundwater storage potentials could be improved by considering dynamics of groundwater flow and recharge characteristics. Three-dimensional numerical modeling of the groundwater system is needed for that purpose. Therefore, it is recommended to develop a numerical model of groundwater flow and contaminant transport characteristics to enhance the understanding of the groundwater environment. The model can also be used to assess climate change impacts on groundwater resource availability and their spatial distribution and to evaluate effectiveness of several artificial recharge possibilities.

4.5 ACKNOWLEDGEMENTS

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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 of δD (and $\delta^{18}O$) in a particular area can help estimate average altitude from where recharge to groundwater aquifer(s) takes place. As of now, such equations for the Kathmandu Valley are not published.

In addition, one of earlier studies (JICA, 1990) reported some patches of surface at northern and southern areas in the valley as locations of potential recharge areas for the valley's aquifers. It was based on generalized geology and groundwater level information. After a detailed surface geology of the Kathmandu Valley (Shrestha et al., 1998) became available in 1998, it revealed the possibility of wide spatial variation in shallow groundwater recharge system. But, there are no studies/reports focused to that end. The objective of this study is to establish equations to reveal depletion of isotope values with altitude for the Kathmandu Valley and infer spatial distribution of shallow groundwater recharge altitudes based on D and ^{18}O values in groundwater samples.

5.2 MATERIAL AND METHODS

The methodology consists of selecting sampling locations, field visit for sampling and laboratory analysis of the water samples. Thirty-five shallow groundwater samples (for location refer Figure 5.1) were collected during two consecutive seasons, i.e. pre-monsoon (January) and monsoon (August), in 2009. The wells were purged over 15 min until pH, temperature and electric conductivity (EC) became stable. Nine spring water samples from 1,300 to 1,700 m elevations at Mt. Jamachowk (located in south-west of the Kathmandu Valley) were collected in August 2006. The samples were stored in polyethylene bottles (250 ml), which were rinsed properly before filling. The filled bottles were kept immediately in an ice box.

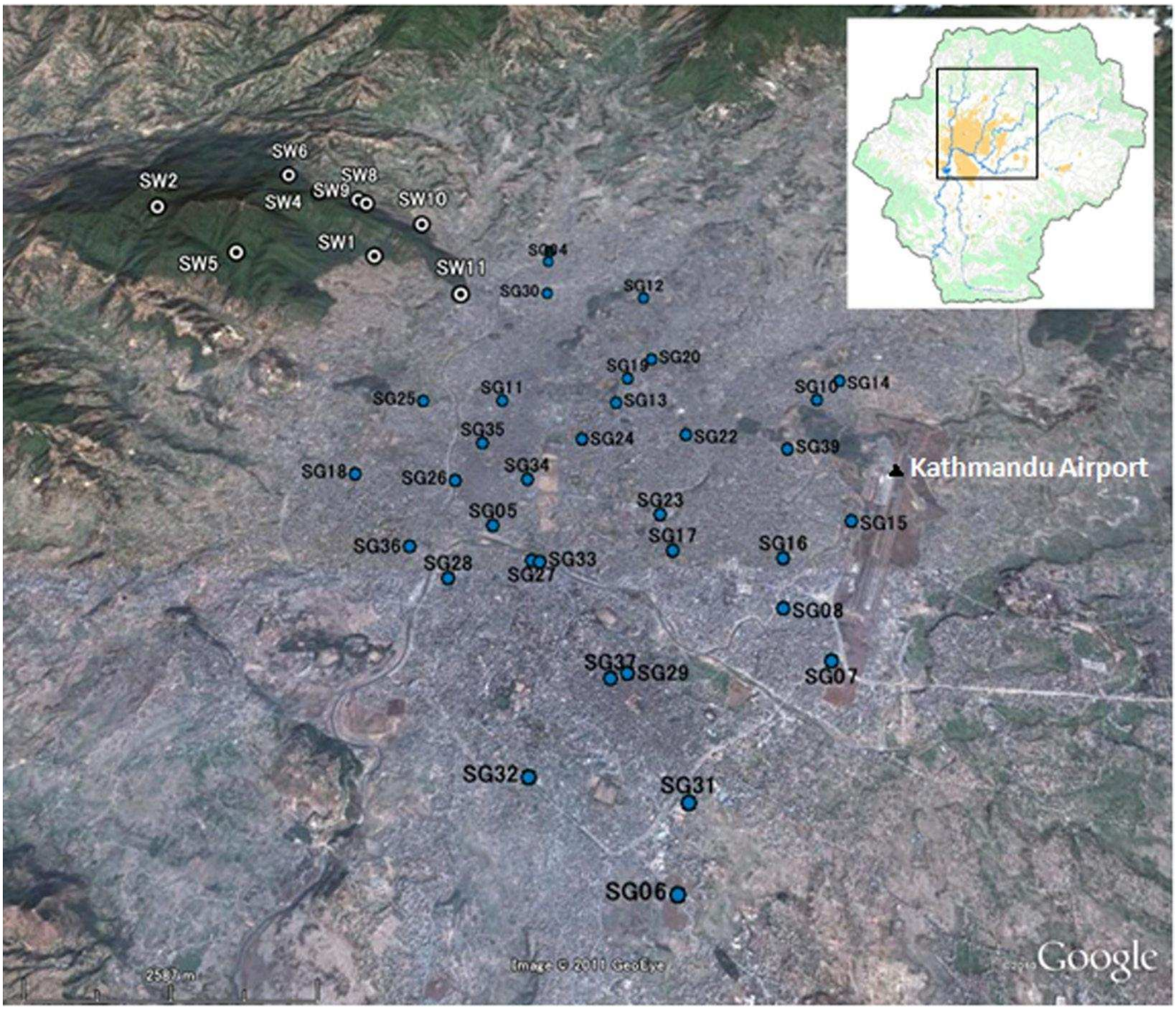

Figure 5.1 Groundwater (SG) and spring water (SW) sampling locations in the Kathmandu Valley

Stable isotope analyses were performed using water equilibration system (Sercon,WES) and isotope mass spectrometer (Sercon, Hydra20-20) in the laboratory of the International Research Center for River Basin Environment-University of Yamanashi (ICRE-UY), Japan. The analyses were standardized with the international references Vienna Standard Mean Ocean Water (V-SMOW), Greenland Ice Sheet Project (GISP), and Standard Light Anarctic Precipitation (SLAP), as well as internal standards. For $\delta^{18}O$, 1 ml of each standard and samples were flushed for CO_2, then left to equilibrate at 35 degree on the hot block in the WES for 8 h before being analyzed. For δD, 1 ml of each standard and samples were transferred into individual exetainers containing platinum bead and flushed by H_2. The samples were then left to equilibrate in a hot block in the WES for 3 h at 35 degree before analysis.

According to standard conventions, all isotopic compositions are given in per mill (‰) units and δ notation relative to the V-SMOW standard (Craig, 1961):

$$\delta D \text{ or } {}^{18}O = (R_{sample} - R_{V\text{-}SMOW}) / R_{V\text{-}SMOW} \times 1000 \ (‰)$$

where R indicates the ratio $^{2}H/^{1}H$ or $^{18}O/^{16}O$. Stable isotope values are reported in the usual notation in units of ‰, vs. V-SMOW for hydrogen and oxygen. Analytical uncertainties are ±0.1‰ for $\delta^{18}O$, and ±1‰ for δD.

5.3 RESULTS

To analyze the isotope depletion rate with altitude, δD and $\delta^{18}O$ values of spring water samples were plotted against the elevation of the sampling site (Figure 5.2). The study results showed that spring water isotope values and elevation in metres (h) are related by a linear equation as shown in Equation 1 and Equation 2, thus reflecting local altitude effect on the isotope values. The δD and $\delta^{18}O$ lapse rate for the spring water are -0.15 permil/ 100 m and -0.22 permil/ 100 m, respectively. The value is within the reported $\delta^{18}O$ lapse rate range of Himalayan regions (altitude: <5,000 m) which is -0.14 to -0.24 permil/ 100 m (Bartarya et al., 1995; Bahadur, 1976; Jinsheng et al., 1984).

$$h\ (m) = -51.4 \times \delta D - 1380 \quad r^2 = 0.81 \text{ ---- } (1)$$
$$h\ (m) = -361.8 \times \delta^{18}O - 1590 \quad r^2 = 0.80 \text{ ---- } (2)$$

After establishing the relationships (Equation 1 and Equation 2), the δD and $\delta^{18}O$ values of spring water and shallow groundwater were compared to find the elevation of spring water sample having the same δD and $\delta^{18}O$ values as that of the shallow groundwater.

The δD and $\delta^{18}O$ values of shallow groundwater samples collected during the pre-monsoon and the monsoon seasons of 2009 (sampling locations are shown in Figure 5.1) are detailed in Table 5.1. The δD ($\delta^{18}O$) values range from -60‰ (-8.6‰) to -42‰ (-6.4‰) with a mean

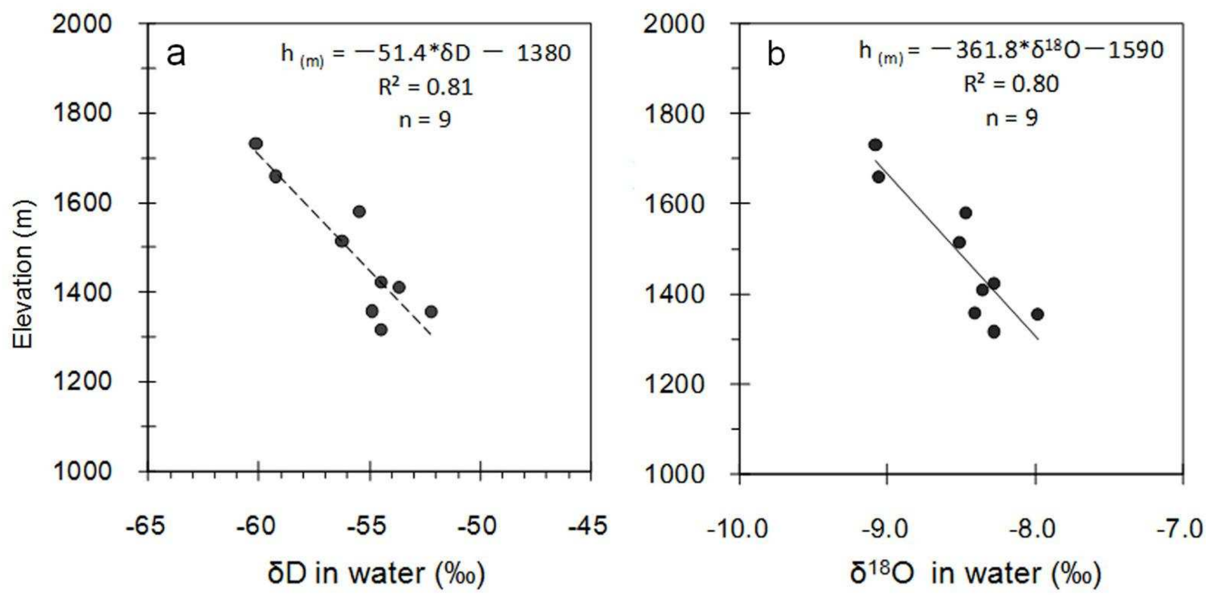

Figure 5.2 Altitude effects of hydrogen (a) and oxygen (b) isotopes defined from spring water collected from Mt. Jamachowk at the western part of the Kathmandu Valley

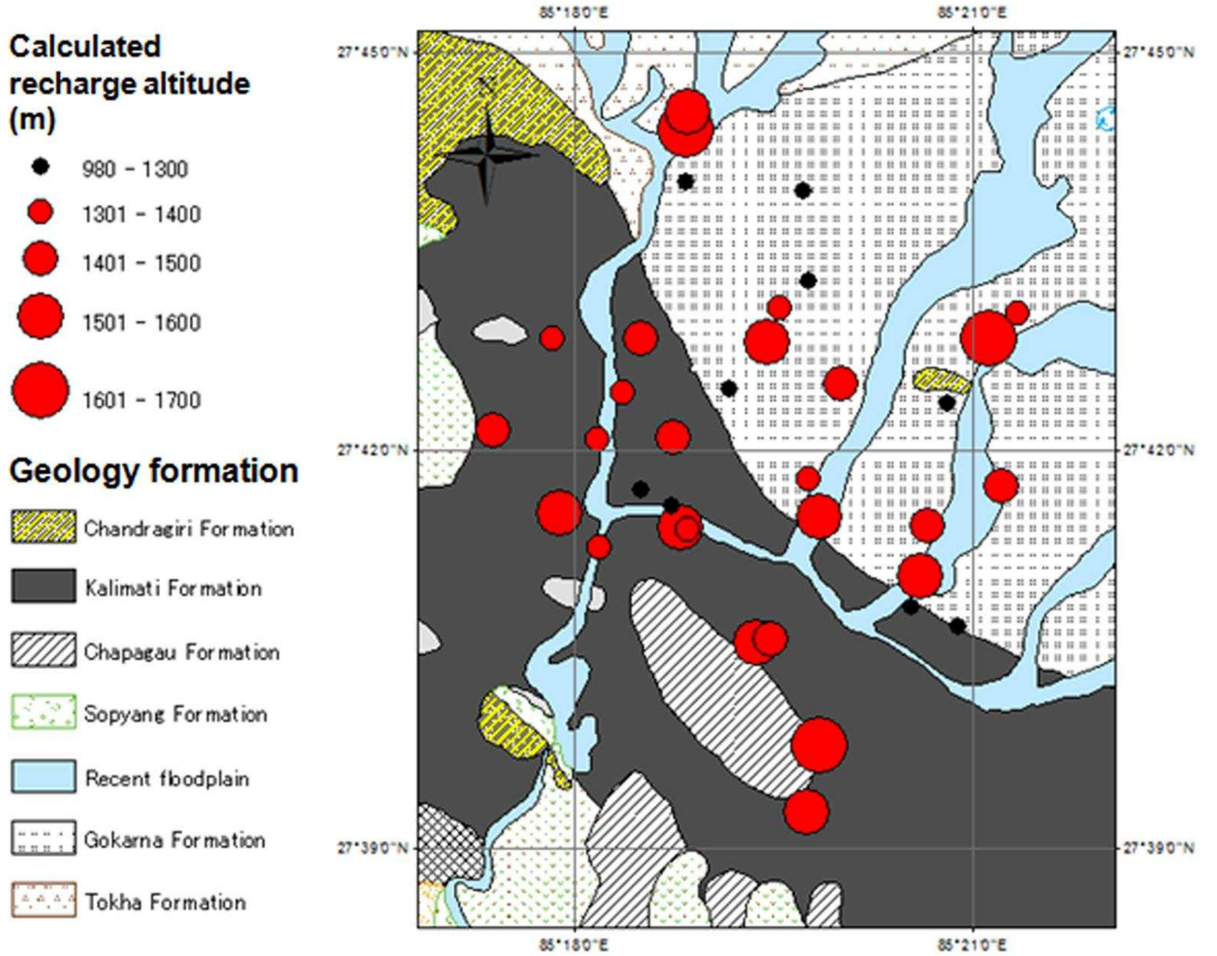

Figure 5.3 Spatial distribution of estimated recharge altitude at sampling locations

value and standard deviation of -54±4‰ (-7.8±0.5‰) in the pre-monsoon whereas in monsoon, it ranges from -62‰ (-8.8‰) to -46‰ (-6.9‰) with a mean value of -54±3 ‰ (-7.9±0.4 ‰). The δD and $\delta^{18}O$ values of pre-monsoon and monsoon rain water samples for the Kathmandu Valley was established by Gajurel et al. (2006). This study suggests the rain water isotope value shows a significant seasonal fraction which is relatively depleted rain water occurred in monsoon season. And pre-monsoon rain water has positive isotope values. Weighted mean δD and $\delta^{18}O$ values of rainwater calculated using the data reported in Gajurel et al. (2006) for the period of July 2001-May 2002 show a distinct seasonal variation. The weighted mean δD ($\delta^{18}O$) values of pre-monsoon (January-May) and monsoon (June-September) rainwater are 15‰ (0.3‰) and -67‰ (-11.4‰) respectively with a difference between the seasons as Δ68‰ (Δ8.3‰). On the other hand, difference between the δD ($\delta^{18}O$) values of shallow groundwater in the two seasons range from Δ0‰ (Δ0‰) to Δ6‰ (Δ1.2‰), which is very low compared to the average difference in rain water samples (i.e., Δ68 ‰ for δD and Δ8.3‰ for $\delta^{18}O$). This result shows that rainwater seasonal fraction has not affected the groundwater isotope composition throughout the year.

5.4 DISCUSSION

The recharge altitude range calculated using Equation 1 and δD values of groundwater (-60‰ ~ -42‰) is found about 600 ~ 1,700 m. However, the groundwater samples were collected from 1,278 ~ 1,346 m. Some samples are calculated lower than the sampling location. This mismatching in estimation of groundwater recharge altitude might be due to higher proportion of pre-monsoon rainwater in total groundwater recharge (as discussed above). The groundwater recharge altitude, which was calculated using average δD values of groundwater (Table 5.1), it was found to be about 1,370 m. This result indicates that lower elevation areas (i.e., valley floor itself rather than mountains surrounding the valley) as potential

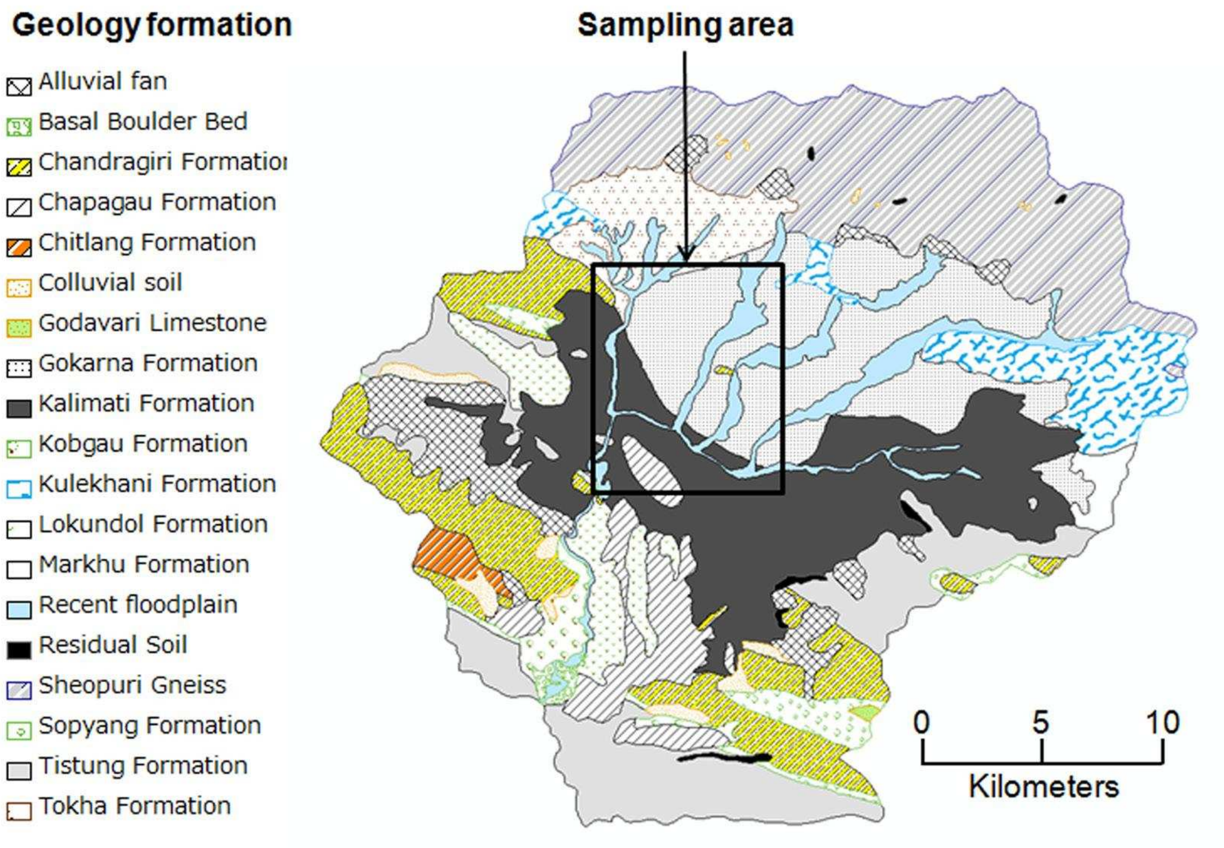

Figure 5.4 Surface geological conditions in the Kathmandu Valley (Shrestha et al., 1998)

recharge areas for the shallow groundwater.

Spatial distribution of calculated recharge altitude at sampling locations is plotted in Figure 5.3. It shows that groundwater in southern part of the sampling area and at few sampling locations at northern part is recharged from altitudes higher than 1,500 m; whereas many groundwater samples located at central part of the sampling area are recharged from less than 1,500 m altitude. The surface geology (Figure 5.4), which is a controlling factor for infiltration and recharge of the shallow groundwater, shows that foots of southern and northern mountains have alluvial deposits located at altitudes higher than 1,500 m. Those alluvial deposits could be potential recharge areas. This surface geological condition shows that the shallow groundwater of southern and northern part might have been recharged from altitudes higher than 1,500 m; similar to the finding of this study based on isotope analysis. Regarding central part of the sampling area, major parts of the surface geology consists of Gokarna formation which is characterized by large proportion of sand and gravel favorable for infiltration and recharge to the aquifers. The area under Gokarna formation could be potential recharge areas for the sampling points in central areas which are recharged from elevations lower than 1,500 m.

Based on these discussions, it can be concluded that northern shallow groundwater in the Kathmandu Valley is recharged from different altitudes in the valley floor.

5.5 CONCLUSIONS

The intent of this study was to use stable isotopes to infer potential altitude for shallow groundwater recharge in the Kathmandu Valley. For that, relationship of stable isotopes of spring water samples with altitude were analyzed and local altitude effect on isotope values of surface water was established. The δD and $\delta^{18}O$ lapse rate for the spring water showed a significant gradient with elevation; -0.15 permil/100 m for δD and -0.22 permil/100 m for $\delta^{18}O$. The potential altitude range for shallow groundwater recharge was calculated using the relationship between δD and altitude and δD values of groundwater samples. The calculated altitude for each groundwater sampling locations shows a wide range (600 ~1,700 m) of recharge altitude. A higher

Table 5.1 Hydrogen and Oxygen isotope data for groundwater in the Kathmandu Valley

ID	Location	Latitude	Longitude	Elevation (m)	Depth (m)	Pre-monsoon			Monsoon			Difference between pre-monsoon and monsoon	
						Collection date	δD (‰)	δ¹⁸O (‰)	Collection date	δD (‰)	δ¹⁸O (‰)	ΔδD (‰)	Δδ¹⁸O (‰)
SG01	Radhavawan	27°41'34.7"	85°18'44.1"	1295	6	2009/1/8	-50	-7.2	8/29/2009	-49	-7.1	1	0.1
SG03	Manamaiju	27°44'32.9"	85°18'50.8"	1319	6	2009/1/6	-57	-7.9	8/31/2009	-56	-8.0	1	0.1
SG04	Gongabu	27°44'25.1"	85°18'50.4"	1309	6	2009/1/6	-60	-8.2	8/31/2009	-59	-8.2	2	0.1
SG05	Teku	27°41'41.9"	85°18'29.6"	1287	8	2009/1/6	-51	-7.1	8/30/2009	-49	-7.3	2	0.2
SG06	Khumaltaar	27°39'16.1"	85°19'44.9"	1326	12	2009/1/13	-59	-8.4	8/30/2009	-58	-8.3	1	0.1
SG07	Koteshowr	27°40'39.9"	85°20'53.4"	1300	5	2009/1/6	-55	-7.4	9/2/2009	-50	-7.4	5	0.0
SG08	Tinkune	27°41'2.7"	85°20'36.5"	1287	9	2009/1/6	-55	-8.0	8/29/2009	-58	-8.3	3	0.3
SG10	Gaurighat	27°42'50.3"	85°21'7.2"	1346	9	2009/1/6	-58	-8.0	8/31/2009	-58	-8.0	0	0.1
SG11	Chhetrapati	27°42'50.9"	85°18'29.9"	1305	6	2009/1/8	-56	-8.0	9/1/2009	-56	-8.1	0	0.1
SG12	Maharajgunj	27°43'57.5"	85°19'43"	1341	11	2009/1/6	-42	-6.4	8/31/2009	-46	-6.9	4	0.5
SG13	Naagpokhari	27°42'49.3"	85°19'26.8"	1308	—	2009/1/8	-57	-8.1	8/29/2009	-57	-8.1	0	0.0
SG14	Chuchepati	27°43'1.9"	85°21'20.4"	1337	6	2009/1/6	-58	-8.6	9/1/2009	-53	-7.8	5	0.8
SG15	Sinamangal	27°41'43.5"	85°21'12.7"	1312	6	2009/1/6	-52	-7.6	8/29/2009	-55	-7.8	2	0.2
SG16	Shantinagar	27°41'25.5"	85°20'39.3"	1295	21	2009/1/6	-57	-8.1	8/31/2009	-54	-7.9	2	0.1
SG17	Bijuli Bazar	27°41'29.6"	85°19'50.7"	1295	3	2009/1/6	-52	-7.5	8/31/2009	-58	-8.1	6	0.6
SG18	Tahachal	27°42'8.6"	85°17'22.8"	1304	5	2009/1/6	-53	-7.4	9/1/2009	-55	-7.9	2	0.4
SG19	Gairidhara	27°43'4.1"	85°19'32.9"	1298	6	2009/1/8	-55	-7.7	8/29/2009	-54	-7.8	1	0.0
SG20	Bhatbhateni	27°43'16.3"	85°19'45.6"	1300	—	2009/1/8	-51	-7.5	8/29/2009	-51	-7.5	0	0.0
SG22	Gyaneshowr chowk	27°42'30"	85°20'0.4"	1300	14	2009/1/8	-57	-8.1	8/29/2009	-55	-8.1	2	0.1
SG23	Anamnagaar	27°41'47.4"	85°19'45.9"	1306	6	2009/1/8	-55	-8.0	8/31/2009	-54	-7.9	2	0.1
SG24	Kamaladi ganesthan	27°42'28.1"	85°19'9.9"	1305	7	2009/1/8	-50	-7.2	8/29/2009	-49	-7.2	1	0.0
SG25	Sovavagwati	27°42'50.3"	85°17'50.4"	1305	6	2009/1/8	-53	-7.8	8/30/2009	-53	-7.8	1	0.0
SG26	Vimsenthan	27°42'5.3"	85°18'10.3"	1281	7	2009/1/8	-56	-8.1	8/29/2009	-54	-7.8	2	0.3
SG27	Kupandole	27°41'24.8"	85°18'47.9"	1278	6	2009/1/13	-56	-8.2	8/30/2009	-57	-8.2	1	0.0
SG28	Sanepa, Lalitpur	27°41'16.4"	85°18'11.6"	1279	10	2009/1/13	-49	-7.3	8/30/2009	-53	-7.8	4	0.5
SG29	Patan Campus Around	27°40'34.8"	85°19'29"	1326	9	2009/1/13	-57	-8.3	8/30/2009	-56	-8.2	1	0.1
SG30	Samakhusi	27°44'1.7"	85°18'50.4"	1305	8	2009/1/15	-51	-7.4	8/31/2009	-52	-7.6	1	0.2
SG31	Voldhoka	27°39'46.3"	85°19'50.9"	1292	6	2009/1/13	-58	-8.2	9/2/2009	-60	-8.4	2	0.2
SG32	Afaldole	27°39'55"	85°18'50.2"	1319	20	2009/1/13	-57	-8.2	9/2/2009	-62	-8.8	5	0.6
SG33	Kupandole	27°41'24.1"	85°18'51.4"	1285	12	2009/1/13	-58	-8.5	8/30/2009	-52	-7.6	6	0.9
SG34	Sankata	27°42'5.8"	85°18'44.3"	1313	9	2009/1/15	-54	-8.1	9/2/2009	-55	-8.0	0	0.2
SG35	Tamogalli	27°42'25.7"	85°18'21.7"	1307	10	2009/1/15	-50	-7.6	8/30/2009	-53	-7.7	3	0.1
SG36	Kuleshowr	27°41'31.6"	85°17'52.9"	1280	6	2009/1/15	-55	-8.1	8/29/2009	-56	-7.9	1	0.2
SG37	Nukabahal, Lalitpur	27°40'32.6"	85°19'22"	1308	—	2009/1/15	-44	-6.8	8/30/2009	-46	-8.0	2	1.2
SG39	Gaushala	27°42'21.6"	85°20'48.6"	1291	6	2009/1/15	-54	-7.7	9/1/2009	-52	-7.8	2	0.1
Min				1278			-60	-8.6		-62	-8.8	0	0.0
Max				1346			-42	-6.4		-46	-6.9	6	1.2
Mean				1304			-54	-7.8		-54	-7.9	—	—
SD				±17			±4	±0.5		±3	±0.4	—	—

(>1,500 m) recharge altitude was found for sampling locations at northern and some part of southern area within the sampling area whereas central areas are potentially recharged from lower (<1,500 m) altitude. These analyses coupled with surface geological conditions helped to conclude that northern shallow groundwater in the Kathmandu Valley are recharged from different altitudes in the valley floor itself rather than mountains surrounding the valley.

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SECTION III

GROUNDWATER QUALITY

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

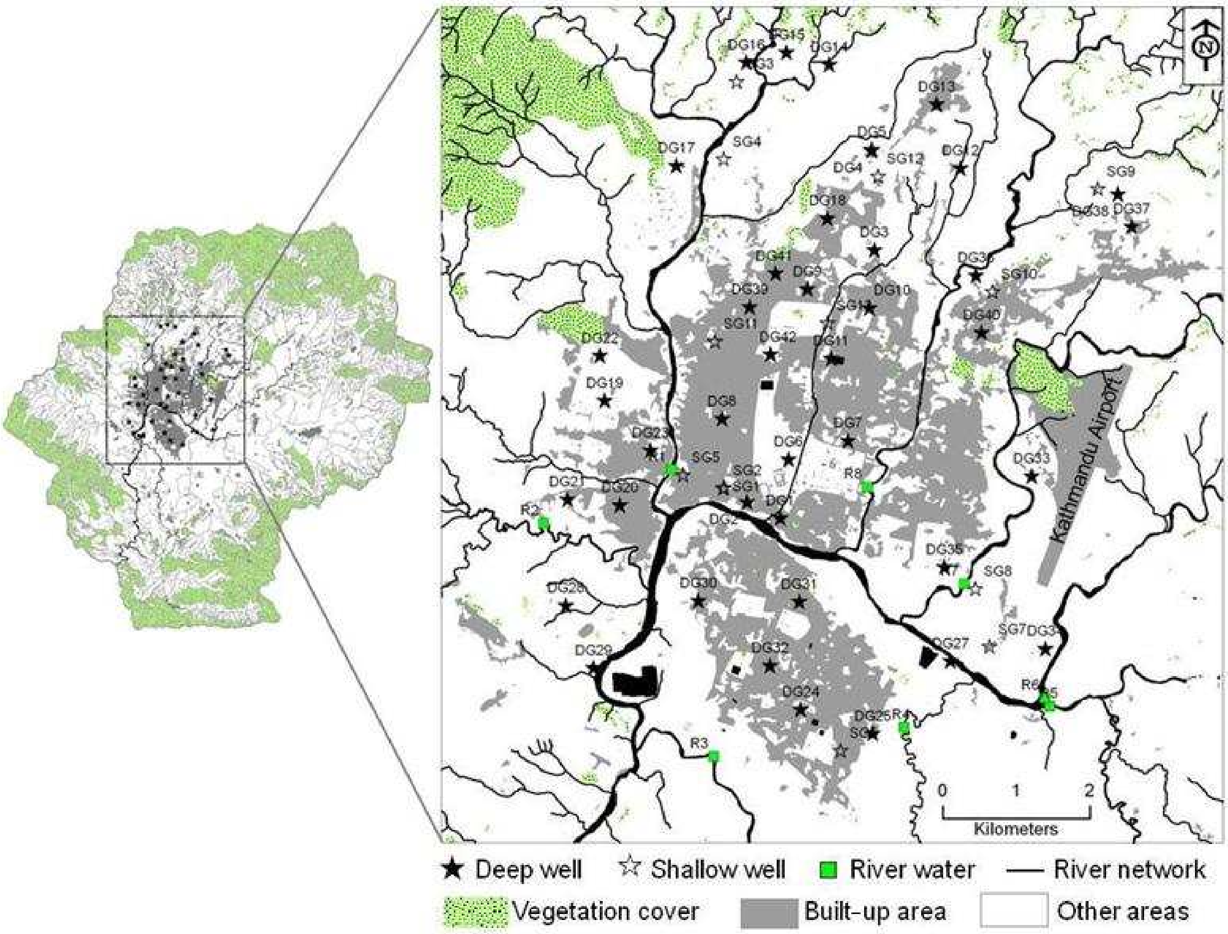

Figure 6.1 Details of sampling locations

polyethylene bottles (*i.e.* 100 ml, 80 ml and 50 ml); which were analysed differently. Firstly, 100 ml of the total water sample was filtered using 0.45 μm filter and the filtered sample was kept in 100 ml bottle. This was stored at room temperature and used for the measurement of dissolved heavy metals. In the next step, 80 ml of sample was poured directly (without filter) into a 100 ml bottle and kept in frozen condition; which was filtered (0.45 μm) for the analysis of basic cations, anions, dissolved organic and inorganic carbon. The remaining water sample was poured into a 50 ml bottle and stored at room temperature; which was analyzed for total arsenic and total heavy metal concentrations. The samples were transported to laboratory using ice box and coolant gel.

6.2.2 Physicochemical analysis

Electrical conductivity (EC), pH and water temperature (WT) were measured on-site using a portable tester (Hanna Combo Tester, HI 98129). The oxidation reduction potential (ORP) was measured on-site using ORP tester (Oakton Waterproof ORPTestr BNC 10) and values are reported as electrical potential of the water sample relative to the reference electrode. These testers were calibrated on each sampling day using the respective standards. The major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+-N) and anions (SO_4^{2-}, Cl^-, F^-, PO_4^{3-}-P, NO_3^--N) were determined by ion chromatography (761 Compact IC, Metrohm). The dissolved organic carbon (DOC) and inorganic carbon (DIC) were determined by total carbon analyzer (Shimadzu TOC-VCSH). Bicarbonate (HCO_3^-) was indirectly calculated based on pH, IC and water temperature. Heavy metals (Cu, Cd, Zn, Cr, Pb, Fe, Mn) and Si were analyzed by inductively coupled plasma optical emission spectrometer (ICP-OES) (ULTIMA 2 HORIBA Jobin Yvon). Arsenic (As) was measured by using atomic absorption spectrophotometry with hydride generation (AAS-HG) (SOLAAR, UK). All chemical analysis of water samples were carried out at University of Yamanashi, Japan. The statistical analysis was performed using Microsoft Excel.

Table 6.1 Summary of physicochemical parameters of groundwater

Parameter	Unit	Deep groundwater (n=42)				Shallow groundwater (n=13)			
		Ave	Min	Max	SD	Ave	Min	Max	SD
WT	℃	25.1	19.7	28.0	1.8	21.1	19.5	24.8	1.5
pH		6.6	6.1	7.3	0.2	6.3	6.0	6.8	0.2
ORP	mV	-82	-135	30	30	9	-73	130	80
EC	µS/cm	586	111	1722	379	621	269	1169	263
DOC	mg/L	5.5	0.1	16.4	4.4	2.1	0.5	4.6	1.3
IC	mg/L	77.0	12.4	219.3	53.2	50.1	20.4	78.1	19.6
NH_4^+-N	mg/L	23.3	0.0	119.8	27.3	5.3	0.0	12.3	4.4
Na^+	mg/L	36.2	2.7	93.9	23.3	35.8	7.7	79.0	19.2
K^+	mg/L	2.5	0.2	6.4	1.8	13.3	1.4	49.7	12.9
Mg^{2+}	mg/L	8.4	2.2	31.3	6.6	12.6	2.8	22.0	6.9
Ca^{2+}	mg/L	33.7	7.2	77.3	21.7	38.8	7.5	71.4	19.4
Cl^-	mg/L	2.3	0.2	32.0	5.2	47.1	11.8	82.7	24.3
PO_4^{3-}-P	mg/L	2.5	0.0	8.7	2.6	0.1	0.001	0.4	0.2
SO_4^{2-}	mg/L	1.2	0.0	31.0	4.9	22.0	0.0	60.0	20.3
HCO_3^-	mg/L	314	36	941	217	177	68	302	84
NO_3-N	mg/L	0.0	0.0	0.1	0.0	1.4	0.001	5.3	2.1
F^-	mg/L	0.3	0.0	2.3	0.4	0.2	0.1	0.4	0.1
Fe	mg/L	2.9	0.0	10.7	3.0	4.8	0.1	17.1	5.8
Mn	mg/L	0.4	0.0	1.7	0.3	0.5	0.0	1.4	0.4
Si	mg/L	28.5	4.6	40.1	7.6	14.5	6.6	26.6	5.4
Cd	µg/L	5.1	0.0	10.0	3.5	9.9	9.0	10.4	0.4
Cr	µg/L	9.6	0.0	33.0	14.3	31.5	29.8	32.4	0.7
Pb	µg/L	19.1	0.0	75.0	22.7	52.4	41.5	62.7	8.1

(Note: Ave: average, Min: minimum, Max: maximum, SD: standard deviation, WT= water temperature)

6.3 RESULTS AND DISCUSSION

6.3.1 Physicochemical properties of groundwater

A summary of physicochemical parameters of groundwater is presented in Table 6.1. The groundwater was nearly neutral, with pH ranging from 6.1-7.3. Electrical conductivity (EC) in deep groundwater varied from 111 to 1722 µS/cm with average value of 586 µS/cm. EC was relatively higher (average 621 µS/cm) in shallow groundwater, with range of 269 to 1169 µS/cm. The major anions were dominated by HCO_3^- followed by PO_4^{3-}-P and Cl^- and lower concentrations of SO_4^{2-} and NO_3^--N in deep groundwater, but the dominance of HCO_3^- was followed by Cl^- and SO_4^{2-} and NO_3^--N and lower concentration of PO_4^{3-}-P in shallow groundwater. Deep groundwater had a high content of DOC (average 5.5 mg/L); whereas, the value was lower (average 2.1 mg/L) in shallow groundwater. The higher organic matter content in the lower sediment may have increased the DOC level in deep groundwater. All samples from deep groundwater (except DG 17), showed negative value of ORP, which apparently reveals the reducing environment of the groundwater. It was also demonstrated by lower concentrations of NO_3^--N (average 0.02 mg/L), SO_4^{2-} (average 1.2 mg/L) and higher concentration (average 23.3 mg/L) of NH_4^+-N. The reducing environment of groundwater is possibly due to microbial degradation of organic matter. Whereas, a relatively high concentration of NO_3^--N (mean 1.4 mg/L) and SO_4^{2-} (average

22.0 mg/L) indicates the existence of lower reducing environment of the shallow groundwater.

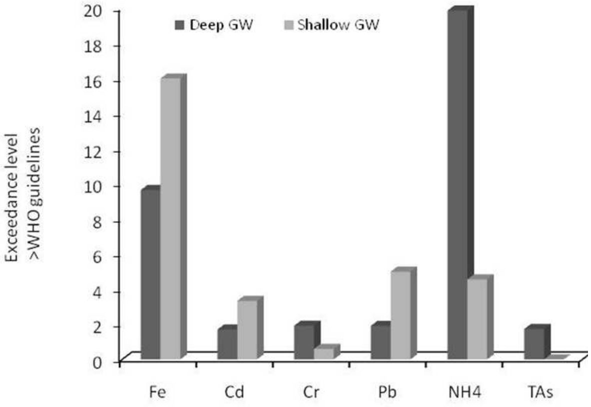

Figure 6.2 Exceedance levels of water quality parameters with respect to WHO guidelines

6.3.2 Evaluation of water quality variables based on WHO guidelines

To evaluate suitability of the groundwater quality for drinking, concentration levels of major water quality variables are compared to WHO guidelines (WHO, 2004). The average concentrations of Fe, Cd, Pb, As and NH_4^+-N as NH_3 are higher than the WHO guideline levels (guideline levels for Fe=0.3 mg/L, Cd=0.003 mg/L, Pb=0.01 mg/L, As=0.01 mg/L, NH_3=1.5 mg/L). The extents of concentration exceeding the WHO guideline are expressed as exceedance levels. This level is calculated as a ratio of mean concentration of each water quality variable to the respective guideline level and expressed as unitless value. This approach is an effective method for visualizing the concentration levels of different water quality variables in relation to the non uniform guideline levels. The highest exceedance level was for NH_4^+-N, followed by Fe, Pb, Cd and As respectively (Figure 6.2). The occurrence of high levels of NH_4^+-N, Fe and As are consistent with the earlier reports; whereas, the higher concentrations of Pb and Cd occurrences have not been previously reported in the study area.

6.3.3 Arsenic occurrence

Arsenic contamination has drawn high attention due to a huge dependency on groundwater in the valley and adverse health effects from the arsenic exposure, such as, dermal changes, cardiovascular, reproductive, mutagenic and carcinogenic (Mandal and Suzuki, 2002). Arsenic concentration varied distinctly between shallow and deep groundwater. The average arsenic concentrations were 1 and 17 µg/L in shallow and deep groundwater respectively (Figure 6.3). This study revealed a wide range (<1 to 73 µg/L) of arsenic occurrence in deep groundwater and the spatial variation is represented in Figure 6.4. However, an earlier study reported the concentration up to 265 µg/L (JICA/ENPHO, 2005). This discrepancy is likely due to the difference in sampling locations suggesting a wider spatial variation of arsenic occurrence.

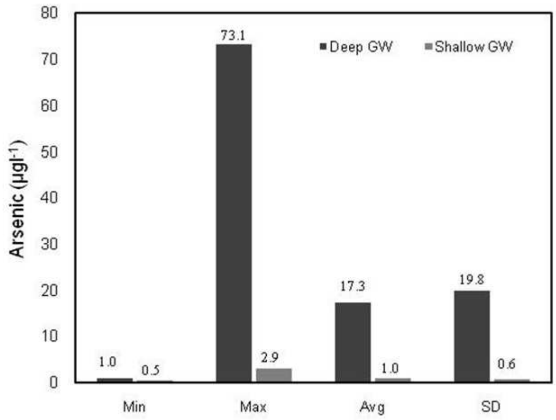

Figure 6.3 Mean As concentration

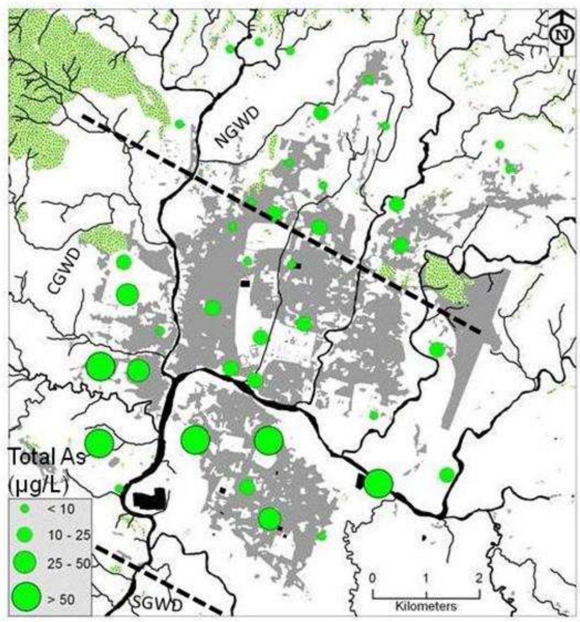

Figure 6.4 Spatial distribution of As in deep wells

For a better understanding the arsenic occurrence, the relationship and overall coherence of the water quality variables are examined by Spearman R coefficient (Table

Table 6.2 Correlation matrix of physicochemical variables

Variable	pH	ORP	EC	As	Na^+	NH_4^+-N	K^+	Mg^{2+}	Ca^{2+}	F^-	Cl^-	PO_4^{3-}-P	SO_4^{2-}	Cd	Cr	Fe	Mn	Pb	Si	Zn	Ni	DOC	NO_3^--N	HCO_3^-
pH	1.00																							
ORP	-0.09	1.00																						
EC	-0.13	*-0.38*	1.00																					
As	0.15	*-0.31*	*0.32*	1.00																				
Na^+	-0.14	-0.20	*0.48*	*0.28*	1.00																			
NH_4^+-N	-0.20	*-0.37*	*0.92*	*0.23*	*0.27*	1.00																		
K^+	-0.20	*-0.30*	*0.90*	*0.31*	*0.60*	*0.80*	1.00																	
Mg^{2+}	-0.17	*-0.35*	*0.92*	0.20	*0.34*	*0.93*	*0.85*	1.00																
Ca^{2+}	0.03	*-0.32*	*0.80*	*0.33*	*0.35*	*0.65*	*0.76*	*0.75*	1.00															
F^-	-0.03	0.12	*-0.34*	-0.21	0.12	*-0.30*	*-0.27*	*-0.34*	*-0.42*	1.00														
Cl^-	0.19	-0.09	0.03	0.05	-0.18	0.01	0.03	0.03	0.00	-0.18	1.00													
PO_4^{3-}-P	*-0.35*	-0.22	*0.45*	*0.24*	*0.42*	*0.50*	*0.46*	*0.40*	*0.30*	-0.09	*-0.23*	1.00												
SO_4^{2-}	*0.23*	*0.40*	-0.10	-0.15	*-0.27*	-0.15	-0.20	-0.13	0.02	-0.14	0.04	-0.20	1.00											
Cd	*-0.28*	*0.22*	*-0.49*	*-0.28*	-0.20	*-0.43*	*-0.38*	*-0.47*	*-0.56*	*0.40*	0.04	-0.13	-0.21	1.00										
Cr	*-0.25*	0.10	-0.07	-0.11	-0.08	-0.06	0.01	-0.08	-0.12	0.22	0.13	0.01	-0.07	*0.81*	1.00									
Fe	*-0.29*	-0.16	0.09	-0.18	-0.16	0.09	0.10	0.18	0.05	-0.09	*0.39*	-0.16	-0.15	*0.23*	0.21	1.00								
Mn	*-0.28*	-0.05	0.20	0.01	0.13	0.15	*0.35*	*0.28*	0.10	0.02	*0.47*	0.01	-0.20	*0.25*	*0.35*	*0.58*	1.00							
Pb	-0.21	0.36	*-0.32*	*-0.24*	-0.20	*-0.27*	-0.21	*-0.32*	*-0.42*	*0.29*	0.04	-0.11	-0.15	*0.81*	*0.70*	0.08	0.15	1.00						
Si	*-0.53*	0.01	-0.09	-0.22	0.17	-0.01	-0.01	-0.02	*-0.26*	*0.34*	-0.19	*0.23*	*-0.56*	*0.55*	*0.33*	*0.26*	*0.36*	*0.40*	1.00					
Zn	-0.12	0.14	-0.11	-0.17	-0.08	-0.13	-0.07	-0.07	-0.11	0.10	-0.01	-0.19	-0.07	*0.32*	*0.28*	0.22	0.09	*0.35*	0.19	1.00				
Ni	-0.18	*0.30*	*-0.43*	*-0.24*	-0.18	*-0.33*	*-0.31*	*-0.38*	*-0.54*	*0.38*	-0.04	-0.18	-0.19	*0.76*	*0.53*	0.09	0.15	*0.78*	*0.51*	0.21	1.00			
DOC	*-0.30*	*-0.33*	*0.90*	0.17	*0.50*	*0.89*	*0.84*	*0.89*	*0.63*	-0.16	-0.12	*0.58*	*-0.22*	*-0.30*	0.04	0.12	*0.25*	-0.16	0.17	-0.07	*-0.28*	1.00		
NO_3^--N	-0.12	0.20	-0.01	-0.08	-0.10	-0.02	0.01	0.07	0.05	-0.11	-0.02	-0.12	0.10	-0.05	-0.03	-0.08	0.14	0.03	-0.05	0.04	0.00	-0.04	1.00	
HCO_3^-	-0.09	*-0.39*	*0.86*	*0.32*	*0.51*	*0.82*	*0.82*	*0.86*	*0.73*	*-0.27*	-0.05	*0.45*	-0.14	*-0.43*	-0.05	0.02	0.14	*-0.39*	-0.03	-0.10	*-0.30*	*0.78*	-0.04	1.00

Italic underline indicate significant at $p < 0.05$

6.2). The negative correlation exhibited by As and ORP indicate the occurrence of high levels of As under reducing groundwater environment; and it is further supported by the existences of positive correlation of As and NH_4^+-N and negative correlation between As and NO_3^--N. The higher concentration of As under reduced groundwater environment is likely due to reductive dissolution of Fe/Mn oxides and direct reduction of As(V) into As(III) (Du Laing et al., 2009). The natural origin and reductive process of As release in groundwater of study area is discussed in Chapagain et al. (2009). The significant correlations of NH_4^+-N with DOC (positive) and ORP (negative) indicate organic matter content and lower redox level (i.e. lower ORP value) of groundwater are likely to elevate NH_4^+-N concentration.

6.3.4 Spatial variation of water quality parameters

In case of spatial variation of groundwater quality, a progressive increase in concentration of major water quality variables is observed from northern towards central-southern part of the deep wells. The spatial variation of major water quality variables are shown in Figure 6.5. The elevated levels of DOC and NH_4^+-N seem to be related to the high organic matter content and the subsequent decomposition of underlying sediments in the central part of the valley.

6.3.5 Source/origin of water quality variables

The relationship of Na^+ and Cl^- concentrations is often used to identify groundwater origin and sources of the groundwater chemical constituents (Li et al., 2008). The ratio of Na^+ and Cl^- concentrations is expressed in Figure 6.6. It shows a good correlation between Na^+ and Cl^- concentrations in shallow groundwater and it has nearly followed 1:1 ratio in their occurrences. This relationship indicates a common origin of these ions in the shallow groundwater. This ratio is typically interpreted as a result of the dissolution of mineral, such as halite (NaCl) (refer to Li et al., 2008, Su et al., 2007). Absence of the mineral deposition and the locations of the shallow wells in the urban area suggest that they are originated from local contamination, i.e. the anthropogenic sources such as domestic wastewaters (Razack and Baitelem, 1988). Unlike the shallow groundwater, a high ratio of Na^+ and Cl^- (i.e. Na/Cl) is observed in deep groundwater. High concentration of Na^+ irrespective to Cl^- concentrations in deep groundwater probably resulted from soil-water interaction, and most likely due to weathering of feldspar in the deep aquifers. The strong positive correlations of trace elements (Cd, Cr, Fe, Mn, Pb, Zn, Ni) (Table 6.2) has indicated the natural origin of these elements into the deep groundwater (see, Chen et al., 2007).

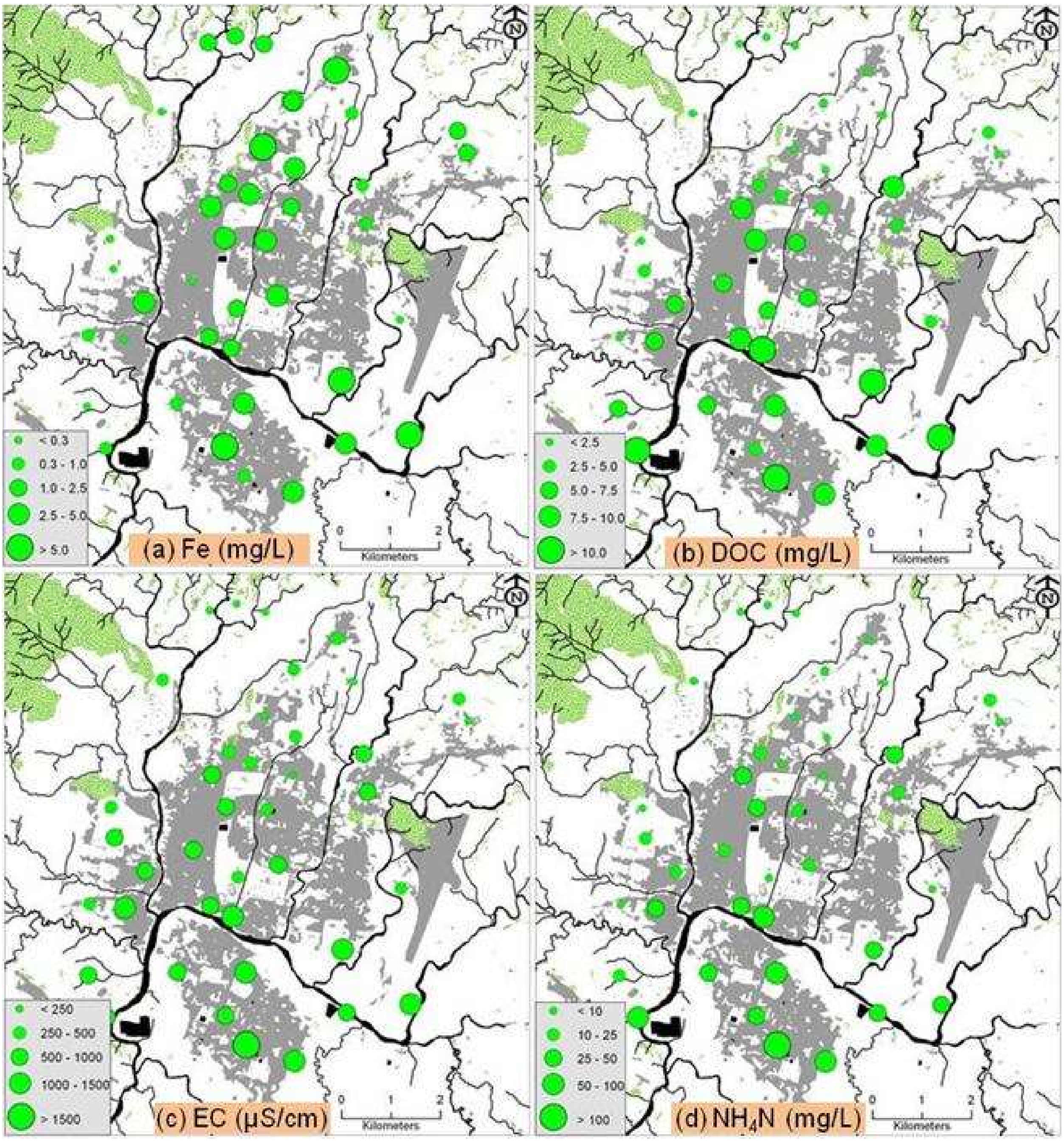

Figure 6.5 Spatial distribution of major water quality variables in deep wells

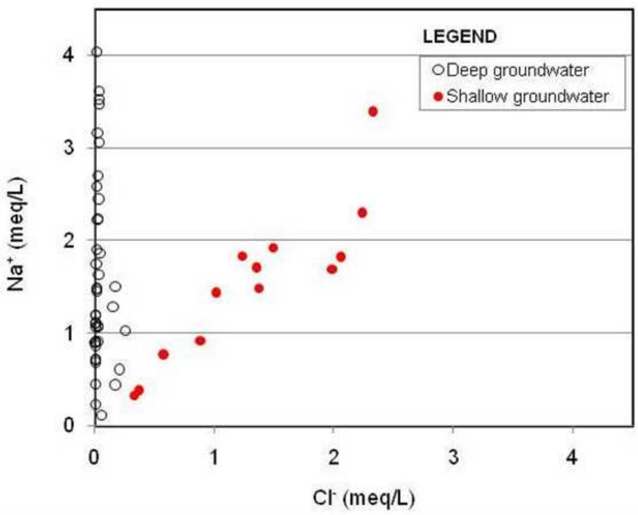

Figure 6.6 Relationship between Na^+ and Cl^- in groundwater

6.4 CONCLUSIONS

This study has examined water quality of groundwater in the Kathmandu Valley. The concentrations of NH_4^+-N, Pb, Fe, Cd at most of the sampling locations exceeds the WHO guideline levels for drinking water. Arsenic contamination is mainly observed in deep groundwater. Fifty-two percentage of deep groundwater samples exceeded the WHO standard for arsenic in drinking water (i.e. 10 μg/L). Arsenic concentration also varies with location, with relatively higher concentration in the central part of the groundwater basin. Arsenic release into the groundwater is mainly from natural sources under the reductive process. Whereas, enrichment of the sediments in the central part of the valley with the finer particles (i.e. clay) and higher level of reducing groundwater environment favors relatively higher arsenic concentration in the deep groundwater of central part than the northern part of the groundwater basin. However, further detail research is necessary to explain the other possibilities. The overall water quality of deep groundwater is primarily related to the natural hydrogeochemical environment; whereas, effects of human activities are prominent in influencing water quality of shallow groundwater.

6.5 ACKNOWLEDGEMENTS

We wish to express our sincere gratitude to the Global Center of Excellence (GCOE) program, University of Yamanashi, Japan for providing the financial support. We are thankful to Yuki Hiraga and all members of Kazama Lab. for their kind assistance.

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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 processes of contamination. The *treatment* group is developing an energy- and cost-effective technology for ammonia and iron removal from groundwater.

From 2009, ICRE-UY is channeling its research through Center of Research for Environment Energy and Water (CREEW), a local Non-Governmental Organization (NGO), as its overseas collaboration center. Besides these research activities, ICRE-UY has also collaborated with several NGOs and government organizations and conducted symposiums, meeting and training related to groundwater and hydrology. Some of them are: *International Symposium on "Environment, energy and water in Nepal: Recent research and direction for future" (31 Mar - 1 Apr, 2009); National Symposium on "Challenges and opportunities for sustainable management of groundwater resources of the the Kathmandu Valley, Nepal" (28 Dec, 2009; 23 Mar, 2010); Groundwater Expert Meeting on "Sustainable Management of Groundwater Resources of the Kathmandu Valley, Nepal" (5–6 July, 2010); Nepal National Water Week held (2009, 2010 and 2011); Virtual Academy Course on Hydrological Modeling (2008, 2009 and 2010).*

The results (of ICRE-UY's research in the Kathmandu Valley) are disseminated through several peer-reviewed papers, conference proceedings and presentations at national and international forums. Some of them are included as chapters 4, 5, 6 and 8 of this book too. The objective of this chapter is to discuss the characteristics of microbial pollution in ground and surface waters of the Kathmandu Valley, with focus on *E. coli* pollution of wells and rivers and its relation with other water quality parameters. The contents are based on Japanese version of a publication by the authors (Sakamoto et al., 2009).

7.2 SAMPLING AND ANALYTICAL METHODS

Water was sampled from wells, rivers and ponds from 21 August to 3 September in 2007. The wells were categorized into deep tubewells, shallow tubewells and shallow round wells (Sakamoto et al., 2009). The tubewells usually had several inlet screens of different depth. The round wells had diameters of 1-2 m and a free surface. *E. coli* and total coliform concentrations were analyzed using membrane filter culture method (USEPA Method No. 10029, 0.45 μm filter, 35-37, 48-hours of culture). Anion and cation concentrations were analyzed using ion chromatography. The methods are detailed in Sakamoto et al. (2009).

7.3 RESULTS AND DISCUSSION

7.3.1 Current situation of *E. coli* pollution

Analysis of *E. coli* concentration shows that only 29% of water from deep wells are drinkable and that the rivers and ponds are potential pollution sources (Table 7.1). Its frequency distribution indicates that 38% of deep well water had *E. coli* concentration lower than 1 cfu (Colony Forming Units)/100 ml and that about half of the shallow well water had *E. coli* of 1-5 cfu/100 ml. Warner et al. (2008) showed *E. coli* detection rate of 40% and concentration of 1 cfu/100 ml for deep wells. The difference of detection rate etc. may be caused by the difference of depth of observed wells.

Table 7.1 *E. coli* detecion and concentration

Type	*Total number of samples*	*Number of samples with E.coli*	*E.coli concentration (cfu/100ml)*
Deep Well	34	24	0.0 - 26.5
Shallow Well	11	10	0.0 - 35.5
Round Well	4	4	70 - 2000
River	8	8	4 - 364 x 10^4
Pond	2	2	10 - 156 x 10^4

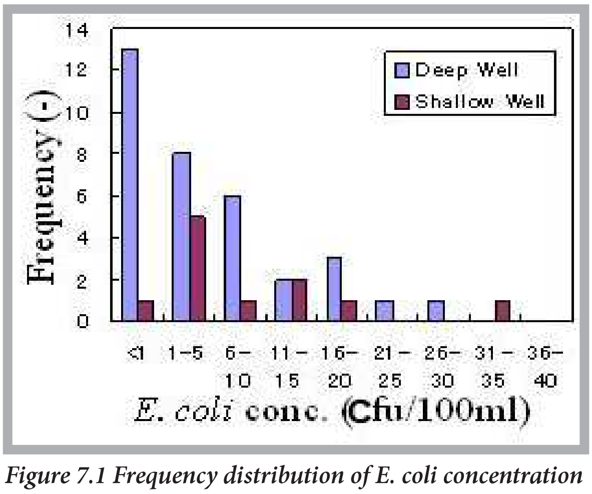

Figure 7.1 Frequency distribution of E. coli concentration

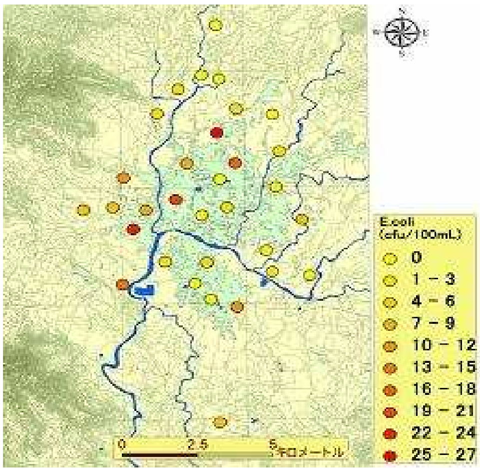

Figure 7.2 Spatial distribution of E. coli concentration of deep well

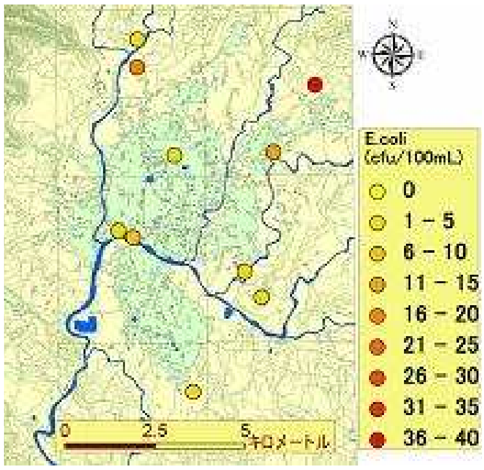

Figure 7.3 Spatial distribution of E. coli concentration of shallow well

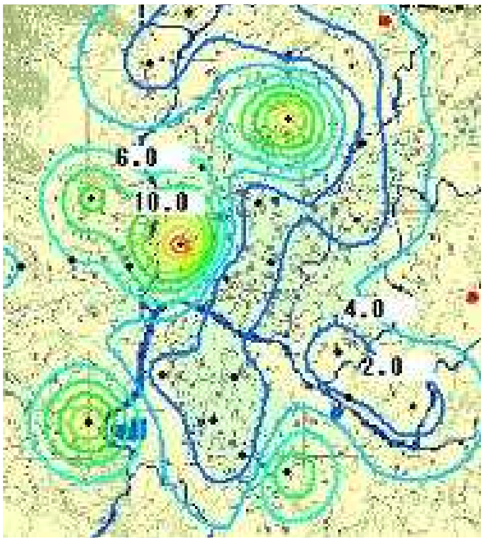

Figure 7.4 Interpolated E. coli distribution of deep well using Kriging (cfu/100 ml)

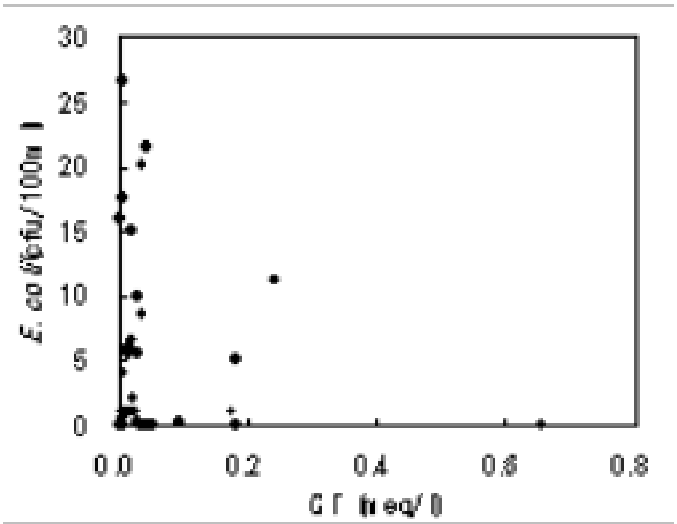

Figure 7.5 Relation between Cl⁻ and E. coli concentrations of deep well

Figure 7.2 shows the spatial distribution of *E. coli* concentration of deep well water and Figure 7.3 shows that of shallow well water. The polluted deep wells were mainly distributed in the central part (Figure 7.2) and the distribution was considerably random. There are comparatively more numbers of polluted shallow wells in the north side (Figure 7.3). When Figure 7.2 and Figure 7.3 are compared, the distribution of polluted deep well and shallow well are not coherent. The shallow wells in the northern part might be vulnerable because of comparatively high permeability (JICA, 1990). Figure 7.4 shows the *E. coli* concentration distribution interpolated by a Kriging method and shows local pollution. Figure 7.5 shows that the *E. coli* and Cl^- concentrations of deep wells had no significant relationship.

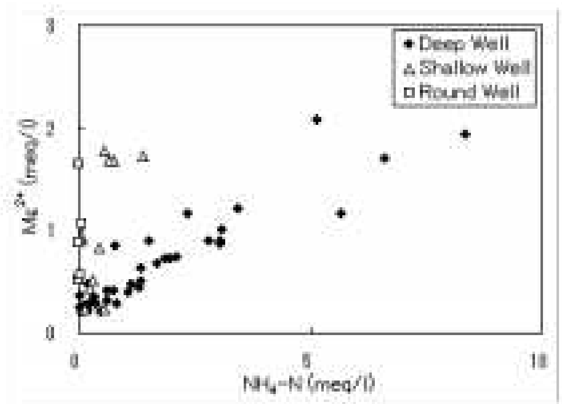

Figure 7.6 Relation between NH_4-N and Mg^{2+} concentration of well

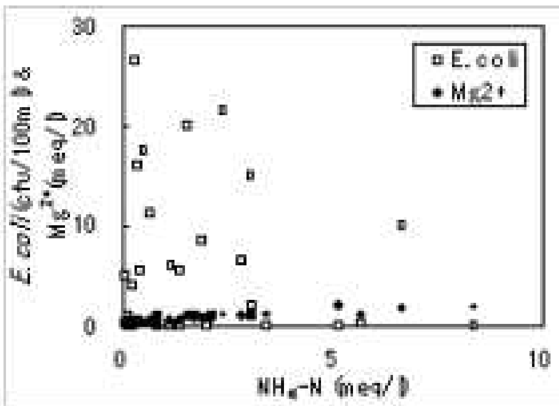

Figure 7.7 Relation among NH_4-N, E. coli, and Mg^{2+} concentration of deep well

Table 7.2 Ion concentration of wells and rivers

Type	Statistics	F^- (meq/l)	Cl^- (meq/l)	NO_2-N (meq/l)	NO_3-N (meq/l)	PO_4-P (meq/l)	SO_4^{2-} (meq/l)	Na^+ (meq/l)	NH_4-N (meq/l)	K^+ (meq/l)	Mg^{2+} (meq/l)	Ca^{2+} (meq/l)
Deep well	Ave.	0.016	0.061	0.006	0.004	0.076	0.017	1.496	1.726	0.071	0.666	1.606
	S.D.	0.020	0.114	0.039	0.013	0.084	0.086	0.879	1.940	0.047	0.475	1.058
	C.V.	1.26	1.87	6.10	3.58	1.10	5.16	0.59	1.12	0.66	0.71	0.66
Shallow well	Ave.	0.006	1.059	0.001	0.106	0.003	0.517	1.354	0.469	0.391	0.999	1.956
	S.D.	0.003	0.615	0.002	0.181	0.005	0.418	0.617	0.387	0.393	0.616	1.046
	C.V.	0.49	0.58	3.32	1.71	1.83	0.81	0.46	0.83	1.01	0.62	0.53
Round well	Ave.	0.007	0.802	0.000	0.511	0.002	0.350	1.371	0.020	0.592	0.933	1.846
	S.D.	0.004	0.595	0.001	0.580	0.003	0.125	0.886	0.029	0.813	0.459	0.438
	C.V.	0.57	0.74	2.24	1.14	1.10	0.36	0.65	1.41	1.37	0.49	0.24
River	Ave.	0.005	0.244	0.003	0.025	0.005	0.128	0.423	0.117	0.082	0.255	0.786
	S.D.	0.002	0.148	0.003	0.015	0.005	0.059	0.195	0.115	0.043	0.126	0.354
	C.V.	0.39	0.61	0.95	0.60	1.05	0.46	0.46	0.99	0.52	0.49	0.45

Ave. is average, S.D. is standard deviation, C.V. is coefficient of variation, meq/l is milli-equivalent per litre

7.3.2 Characteristics of water quality of total wells

Table 7.2 shows that N, P and F concentrations are higher for deep wells than for shallow wells. It is possible that an organic lacustrine sediment in the depths caused higher N and P concentrations. As for the shallow well, Cl^- concentration was higher than the deep well because of the influence of human activities. No significant characteristics of water quality of *E. coli* polluted deep well was found except a relation between NH_4-N and Mg^{2+}. The relationships shown in Figures 7.6 and 7.7 indicate that *E. coli* concentration decreases as NH_4-N concentration increases and NH_4-N concentration could be an index of non-pollution.

7.3.3 Characteristics of water quality of deep wells

The correlation coefficient matrix of the water quality of the deep well is shown in Table 7.3. 'x' and 'y' in Table 7.3 are location coordinates. Large correlation coefficients between total coliform and Cl^- and between NO_2-N and NO_3-N were caused by one well of very high concentration, and therefore those were not significant. Significant relations were among NH_4-N, Mg^{2+}, K^+ and Ca^{2+}. *E. coli* concentration had no significant correlation

Table 7.3 Correlation coefficient matrix of water quality of deep well

	x	y	F^-	Cl^-	NO_2-N	NO_3-N	PO_4-P	SO_4^{2-}	Na^+	NH_4-N	K^+	Mg^{2+}	Ca^{2+}	T.coli	*E.coli*
x	1.00														
y	0.00	1.00													
F^-	0.41	0.17	1.00												
Cl^-	-0.12	-0.33	-0.24	1.00											
NO_2-N	-0.02	0.07	-0.15	-0.14	1.00										
NO_3-N	0.09	0.14	-0.11	-0.06	0.89	1.00									
PO_4-P	-0.03	-0.29	-0.07	-0.26	-0.07	-0.19	1.00								
SO_4^{2-}	-0.19	0.19	-0.14	0.07	-0.08	0.06	-0.18	1.00							
Na^+	0.11	-0.20	0.26	-0.24	-0.02	-0.15	0.29	-0.31	1.00						
NH_4-N	0.13	-0.55	-0.28	-0.01	0.04	-0.09	0.49	-0.19	0.23	1.00					
K^+	0.08	-0.53	-0.27	-0.01	0.13	-0.03	0.49	-0.27	0.60	0.82	1.00				
Mg^{2+}	0.14	-0.51	-0.32	0.00	0.17	0.06	0.35	-0.15	0.31	0.93	0.83	1.00			
Ca^{2+}	-0.07	-0.40	-0.41	-0.02	0.13	0.06	0.33	0.13	0.37	0.69	0.69	0.80	1.00		
T.coli	-0.04	-0.22	-0.14	0.86	-0.05	-0.03	-0.16	-0.05	-0.20	0.02	0.03	0.02	-0.12	1.00	
E.coli	-0.35	-0.14	-0.03	-0.09	0.18	-0.10	0.18	-0.10	0.21	-0.02	0.12	0.01	0.13	-0.07	1.00

with other water quality indices including total coliform.Based on strong correlation between Na^+ and Cl^- of polluted rivers and shallow wells, we supposed that the same relation would be found in case of polluted deep wells. However, we could not reach a solid inference in this regard. For spatial distribution, there was a tendency of F^- concentration being high on the east side and NH_4-N concentration being high in the south as shown in Table 7.3 and Figures 7.8 and 7.9. High concentration region in Figure 7.8 was a part of lake-delta deposit. Because NH_4-N is thought to be an index that shows the potential

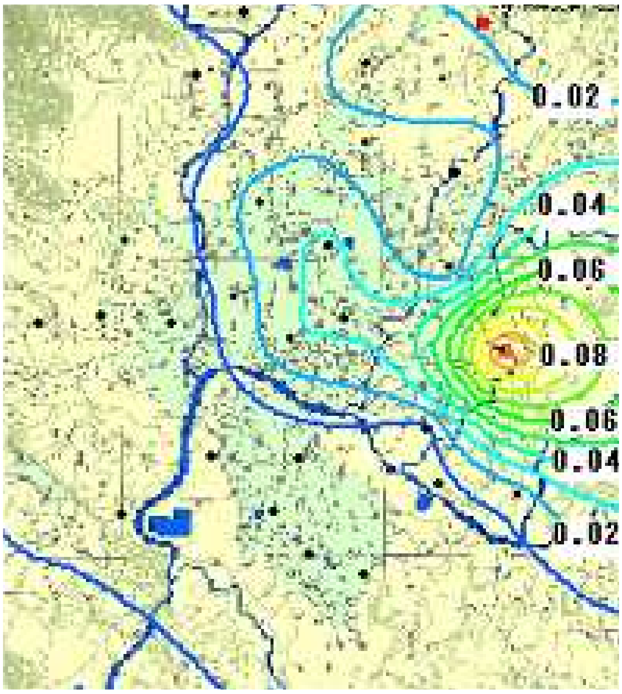

Figure 7.8 Interpolated F- distribution of deep well using Kriging (meq/l)

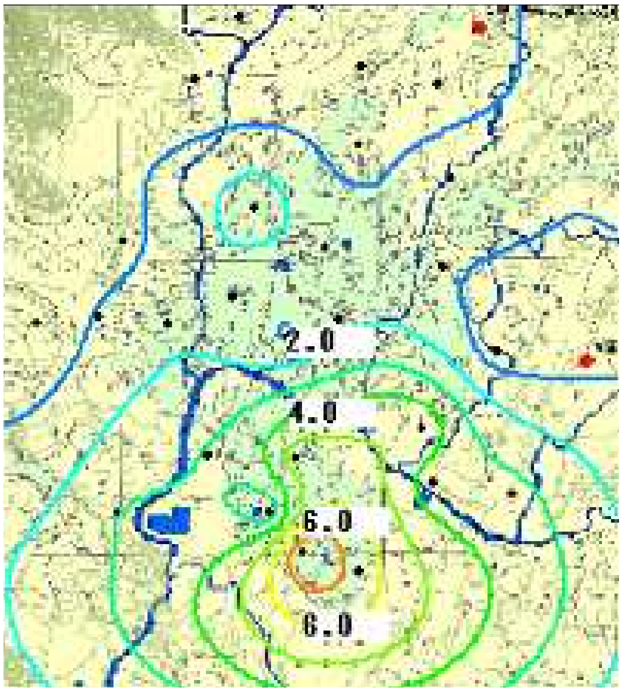

Figure 7.9 Interpolated NH_4-N distribution of deep well using Kriging (meq/l)

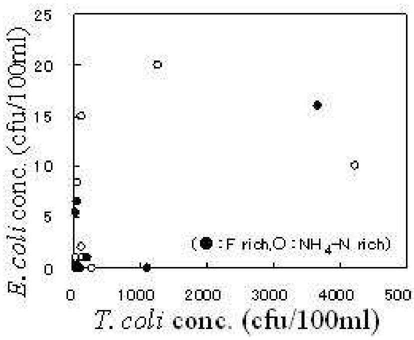

Figure 7.10 Relation between total coliform and E. coli concentration of deep well

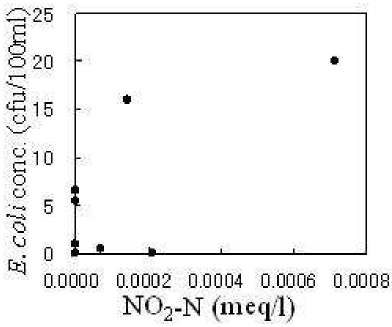

Figure 7.11 Relation between NO_2-N and E. coli concentration of deep F rich well

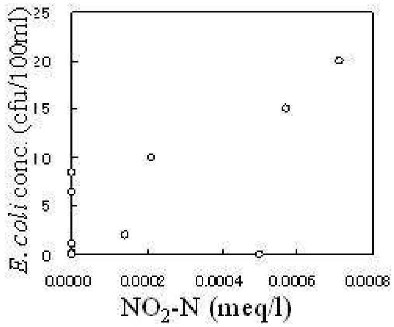

Figure 7.12 Relation between NO_2-N and E. coli concentration of NH_4-N rich well

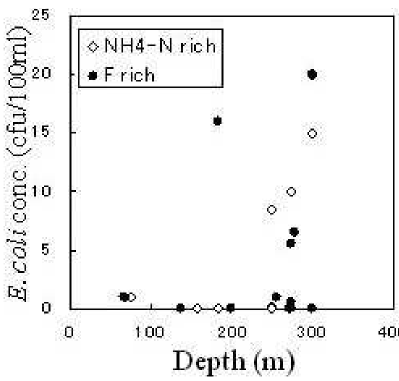

Figure 7.13 Relation between well depth and E. coli concentration of deep well

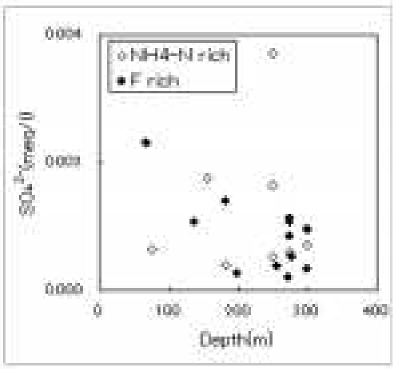

Figure 7.14 Relation between well depth and E. coli concentration of deep well

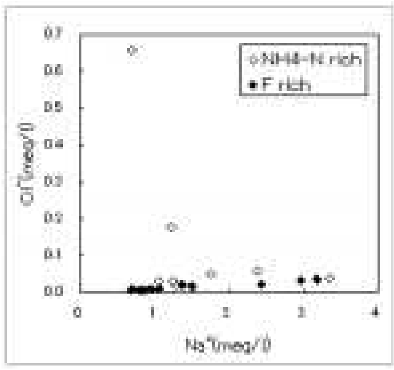

Figure 7.15 Relation between Na^+ and Cl^- concentration of deep well

of methane gas deposit, the origin of NH_4-N might be anaerobic stratum of organic matters.

7.3.4 Characteristics of F rich and NH_4-N rich wells

Deep wells included 14 F rich (0.01-0.12 meq/l) wells and 14 NH_4-N rich (1.5-8.4 meq/l) wells. For F rich wells, large correlation coefficients (0.71 and 0.76) were found between total coliform and *E. coli* concentrations and between *E. coli* and NO_2-N concentrations. For NH_4-N rich wells, large and significant correlation coefficient (0.72) was found between *E. coli* and NO_2-N concentrations as shown by Figures 7.10, 7.11 and 7.12. In Figures 7.11 and 7.12, the highest concentration well is the same well. The relation shown in Figures 7.11 and 7.12 might suggest increase of *E. coli* in reduction situation.

Figure 7.13 shows the relation between the depth and *E. coli* concentration of deep wells of known depth. There were wells of various depths and no relation between the depth and *E. coli* concentration was found. Only SO_4^{2-} concentration of F rich wells had relation with depth as shown in Figure 7.14. Figure 7.15 shows the relation between Na^+ and Cl^- concentrations. While F rich wells showed the positive correlation as shown in Figure 7.15, NH_4-N rich wells did not show such clear relation. This might be because of higher permeability of the region of F rich wells than NH_4-N rich wells. However, if two high Cl^- concentration wells can be neglected, NH_4-N rich wells had a similar relation to that of F rich wells

7.3.5 Relation between principal component score and *E. coli* concentration of deep wells

The characteristics of water quality of deep wells polluted by *E. coli* were not clear as for the other above mentioned parameters. Therefore, principal component analysis was applied to anion and cation concentrations for further examination. Tables 7.4 and 7.5 show the results (factor loading, eigenvalue and cumulative proportion) of principal component analysis of F rich wells and NH_4-N rich wells, respectively. The correlation coefficient between *E. coli* concentration and component score was calculated. The results showed that the score of the second principal component related to F concentration had the largest coefficient in case of F rich wells and the score of the third principal component related to PO_4-P concentration had the largest coefficient in case of NH_4-N rich wells. Figures 7.16 and 7.17 show the relation between the score and *E. coli* concentration of F rich wells and NH_4-N rich wells, respectively. These

Table 7.4 Results of PCA of deep F rich well

Parameter	Factor loading		
	PC1	PC2	PC3
F^-	0.27	0.83	0.20
Cl^-	0.91	0.12	0.32
NO_2-N	-0.45	-0.54	0.57
NO_3-N	0.41	-0.66	0.59
PO_4-P	0.97	-0.10	0.16
SO_4^{2-}	-0.43	0.47	0.61
Na^+	0.83	0.36	0.41
NH_4-N	0.77	-0.12	-0.42
K^+	0.96	-0.14	0.07
Mg^{2+}	0.87	-0.12	-0.34
Ca^{2+}	0.97	0.04	-0.03
Eigen value	6.31	1.83	1.69
Cumulative proportion	57.4%	74.0%	89.4%

Table 7.5 Results of PCA of deep NH4-N rich well

Parameter	Factor loading		
	PC1	PC2	PC3
F^-	0.39	0.63	0.39
Cl^-	-0.76	-0.35	-0.44
NO_2-N	0.41	-0.36	0.50
NO_3-N	0.89	-0.31	-0.32
PO_4-P	0.19	0.03	0.95
SO_4^{2-}	-0.38	0.84	-0.23
Na^+	0.23	0.89	-0.16
NH_4-N	0.86	-0.41	-0.08
K^+	0.91	0.13	-0.09
Mg^{2+}	0.89	-0.14	-0.38
Ca^{2+}	0.76	0.49	-0.18
Eigen value	4.86	2.70	1.88
Cumulative proportion	44.2%	68.8%	85.9%

results suggest the relation between *E. coli* and F^- concentrations and between *E. coli* and PO_4-P concentrations. However, there was one well with no *E. coli* and high score as shown in Figure 7.17.

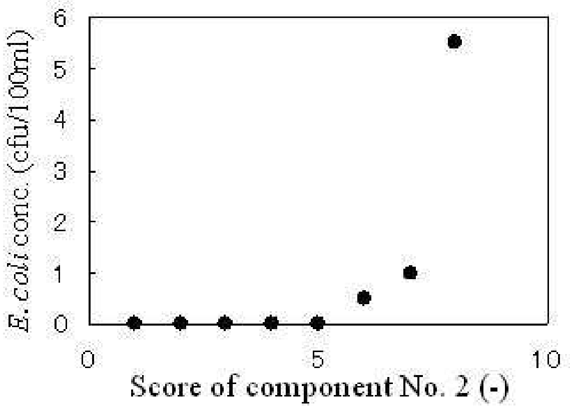

Figure 7.16 Relation between PCA score and E. coli concentration of deep F rich wells

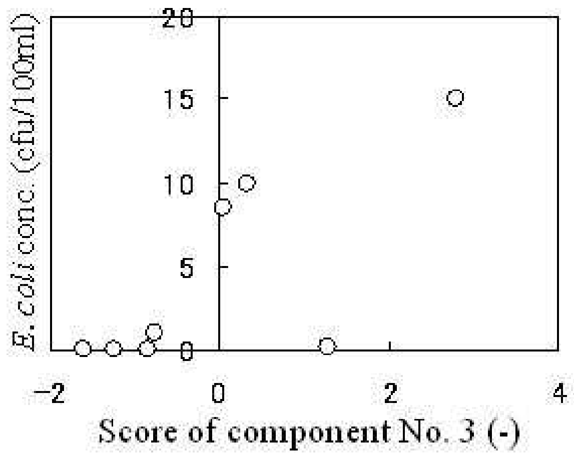

Figure 7.17 Relation between PCA score and E. coli concentration of deep NH_4 rich wells

7.4 CONCLUSIONS

Quality of ground and surface waters of the the Kathmandu basin was examined from the viewpoint of *E. coli* contamination with the following results:

1. There were only a few wells suitable for drinking because of *E. coli* detection in most of the wells and only 29% of deep wells had no *E. coli*.

2. Compared with shallow wells, deep wells had relatively high concentration of N, P and F. Deep wells had no tendency of increasing *E. coli* concentration with increasing Cl^- concentration. However, it showed an increasing trend of *E. coli* concentration with decrease in NH_4-N.

3. Deep wells included F rich wells and NH_4-N rich wells. *E. coli* concentration had no significant relation with ion concentration except for the weak relation with NO_2-N concentration. The observations did not support the view that deeper the well, lesser the concentration of *E. coli*.

4. The results of principal component analysis applied to ion concentration showed that *E. coli* concentration had a direct relation with the score of principal component related to F concentration in case of F rich wells and the score of principal component related to PO_4-P concentration in case of NH_4-N rich wells.

It has been understood that it is very difficult to relate quantitatively the *E. coli* concentration of the deep well water of the entire Katmandu basin to other water quality indices. Regular monitoring of the fluctuation and influences in the *E. coli* concentration within the well has been felt necessary in the future.

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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

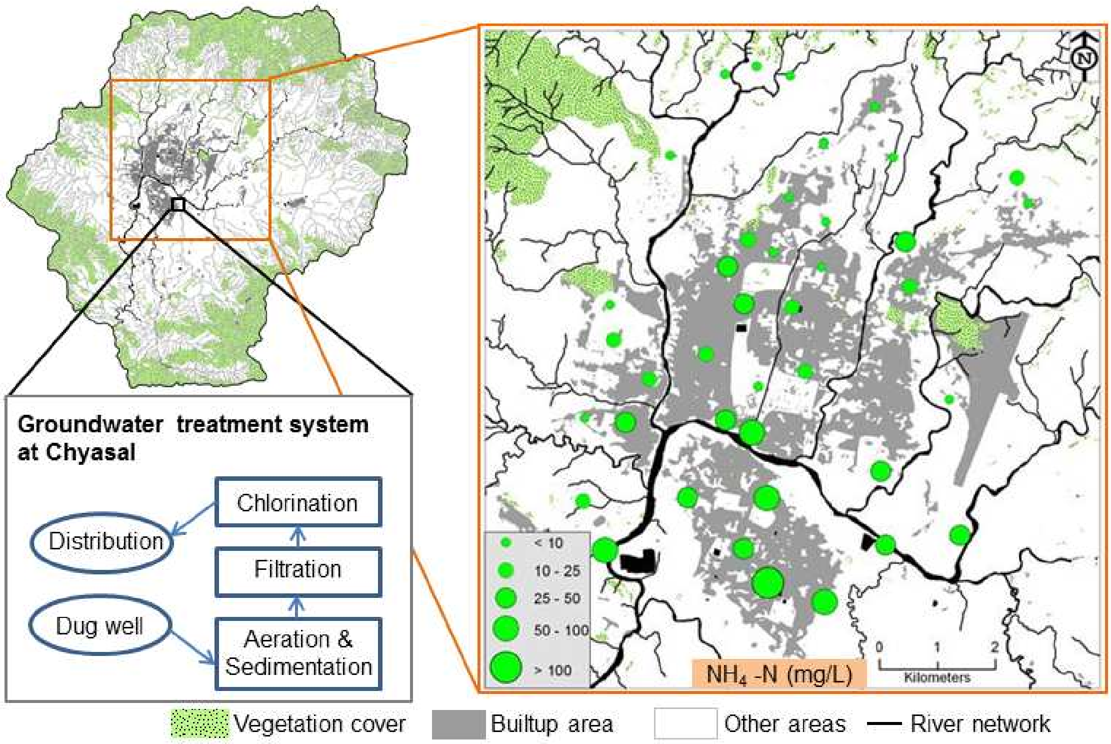

Figure 8.1 Location of study area along with NH_4-N distribution in the Kathmandu Valley (NH$_4$-N distribution from Chapagain, 2009)

to NO_3-N, high levels of which can cause methemoglobinemia or blue baby syndrome. Therefore, NH_4-N removal from groundwater resources to comply with the WHO standard is necessary.

In the endeavor to provide safe drinking water (i.e., NH_4-N concentration not exceeding 1.5 mg/L), many technologies have been developed for removing nitrogen from the contaminated groundwater. Based on applicability, the technologies can be categorized into two classes: (i) applicable to aquifer (*in-situ*) (Chaplin et al., 2009; Huagen et al., 2002), and (ii) applicable to pumped groundwater (*ex-situ*) (Ha et al., 2005; Khanitchaidecha et al., 2010). However, the latter is preferred over the earlier because of ease in operation and maintenance. Again, there are two types of NH_4-N removal systems applicable to the pumped groundwater, namely, physical-chemical and biological systems. Out of the two, the biological system is preferred over the physical-chemical system because of several disadvantages of the physical-chemical system (e.g., reverse osmosis, ion exchange, electro-dialysis) like ineffective removal at low NH_4-N concentration, high operation and maintenance costs and generation of waste brines (Sierra-Alvarez et al., 2007).

The concept of biological nitrification process is that NH_4-N is converted to NO_3-N via the intermediate nitrite-nitrogen (NO_2-N) under an aerobic process in which inorganic carbon (CO_2/HCO_3^-) is utilized as carbon source for microbial growth. The overall nitrification process including the microbial growth ($C_5H_7NO_2$) is shown in Equation 1 (Metcalf and Eddy, 2004). Several nitrification systems including suspended sludge and attached growth systems have been in use, such as continuously stirred tank reactor, airlift suspension reactor (Manipura et al., 2007) and swim bed reactor (Ha et al., 2005). Recently the attached growth system has been rapidly developed as an on-site technology (Stembal et al., 2005; de Vet et al., 2009; Khanh et al., 2010), in which, microorganisms attach on a carrier or media, such as polymer sponge and fiber (Chung et al., 2007; Ha et al., 2006; Khanh et al., 2010), and the system consisting of the attached microorganisms is continuously fed with NH_4-N contaminated water. Such provisions result in less microorganisms wash-out, high microorganisms contained in the system and high treatment capacity consequently (rather than the suspended sludge system). However, the above mentioned attached growth systems (Ha et al., 2005;

Chung et al., 2007; Ha et al., 2006; Khanh et al., 2010) need continuous air supply leading to increase in energy consumption and cost of the system.

$$NH_4^+ + 1.863O_2 + 0.098CO_2 \rightarrow 0.0196C_5H_7NO_2 + 0.98NO_3^- + 0.094H_2O + 1.98H^+ \quad \text{......(Equation 1)}$$

The objective of this research is to develop an "attached growth system" as a simple (in operation), energy-efficient (in particular, operate without air supply) and low cost system for removing NH_4-N from groundwater in the Kathmandu Valley. Though the system is developed considering groundwater characteristics in the Kathmandu Valley, it could be applicable to other areas as well.

8.2 MATERIALS AND METHODS

8.2.1 Description of the study area, and groundwater characteristics

This study considers a case of a small community groundwater treatment system located at Chyasal in the Kathmandu Valley (Figure 8.1). The community (Chyasal) is located around the center of Lalitpur Sub-Metropolitan City in the valley. In this area, a major part of drinking water is collected from traditional dugwells and stone spouts fed by a vast network of underground channels called "Raj Kulo". In 2007, a community-scale groundwater treatment system was established jointly by Urban Environment Management Society (UEMS) and United Nations Human Settlements Program (UN-HABITAT) with the objective of providing safe and adequate drinking water to some 320 households (with approximately 2,000 people) in the area. The system pumps groundwater from a 20-feet-deep dug well into a 5,000 L aeration and sedimentation tank and stores it overnight. The water is then pumped into three 1,000 L tanks, where it is filtrated using bio-sand technology. The filtrated water is collected in a 3,000 L tank for chlorination before being sent to the water bottling and distribution unit (see in Figure 8.1). The quality of raw groundwater and filtrated water via the existing treatment system is summarized in Table 8.1. The existing system can remove Fe from groundwater perfectly (no Fe remains); however, NH_4-N concentration in the filtered water remains ~10 mg/L, which is higher than the WHO standard for drinking. To improve the overall technical efficiency of the treatment system, a NH_4-N removal unit needs to be installed in the system. This study proposes an "attached growth system" as an energy-efficient and low cost technology suitable for NH_4-N removal from that system in particular and from groundwater in general.

8.2.2 Groundwater preparation

In this research, three types of groundwater containing various concentrations of Fe, IC and PO_4-P were prepared.

High Fe and nutrient (IC and PO_4-P) NH_4-N groundwater: The groundwater was collected from the dug well at Chyasal, and 0.48 $NaHCO_3$ and 0.02 $Na_2HPO_4.12H_2O$ (g/L) was added. The concentration of NH_4-N, Fe, IC and PO_4-P for this groundwater was approximately 15, 10, 70 and 2 mg/L respectively.

No Fe and high nutrient (IC and PO_4-P) NH_4-N groundwater: The Chyasal's groundwater was pre-treated by aeration and sedimentation and filtration (following the existing groundwater treatment system) to remove Fe, and 0.48 $NaHCO_3$ and 0.02 $Na_2HPO_4.12H_2O$ (g/L) was added. The NH_4-N concentration decreased to ~10 mg/L after the Fe pre-treatment processes and the concentrations of Fe, IC and PO_4-P for this groundwater were approximately 0, 70 and 2 mg/L respectively.

Pure NH_4-N groundwater: The pre-treated groundwater with no chemicals addition was used. The concentration of NH_4-N, Fe, IC and PO_4-P for this groundwater was approximately 10, 0, 30 and 0 mg/L respectively.

8.2.3 Design and operation of the attached growth system

The attached growth system consists of the two main parts; an acrylic column and a fiber carrier (NET Co. Ltd., Japan). The fiber carrier was made of polyester mono-filament as a frame and absorbent acrylic fiber as a bacteria holder. It was kept along the column for bacteria attachment and water pathway.

Table 8.1 Quality of raw groundwater and filtrated water (treated water by existing system) at Chyasal

Parameter	Raw groundwater (mg/L)		Filtrated water (mg/L) (in 2008)
	In 2007	In 2008	
NH_4-N	16.09	15.12	10.49
Fe	9.16	n.a.	0.00
Ca^{2+}	31.01	34.57	33.87
Mg^{2+}	10.82	10.43	11.19
K^+	21.59	20.14	21.67
Na^+	29.81	29.97	30.29
Cl^-	39.34	41.60	39.54
SO_4^{2-}	27.68	29.97	28.09
NO_2-N	0.00	0.09	1.00
NO_3-N	0.02	0.17	1.57
PO_4-P	0.01	0.00	0.01
Inorganic carbon	32.29	n.a.	26.96
Organic carbon	1.81	n.a.	1.92

(n.a. : Not available)

One of the three groundwater mentioned in section 8.2.2 (influent) was dropped to the top of the fiber carrier, then the influent penetrated through fiber carrier until the end of column. Due to good characteristic of the fiber carrier, the nitrifiers (bacteria responsible for nitrification) were attached easily and substrate (i.e., water, oxygen) was transferred properly. The size of acrylic column and fiber carrier for lab- and pilot-scale attached growth systems are described hereunder.

Lab-scale attached growth system: A 2.5 cm diameter and 100 cm length acrylic column containing 2.5×100 cm fiber carrier (with no bacteria attached initially) was used as the lab-scale system (Figure 8.2a). Flow rate of the influent at the top of the fiber carrier was maintained at 2.9 L/day. Effluent (groundwater after passing through the system) was collected from the bottom of the column for further analysis. A schematic diagram of the lab-scale system is shown in Figure 8.2a. Four systems were set-up for two experiments; to study the effect of Fe (lab-scale 1) and nutrient (lab-scale 2). The details are presented in Table 8.2.

Pilot-scale attached growth system: A 25 cm diameter and 150 cm length acrylic column containing 70×150 cm fiber carrier was used as the pilot-scale system (Figure 8.2b). Due to the large diameter of the column, the 70×150 cm fiber carrier was divided into 7×150, 25×150 and 38×150 cm to cover on three sizes of stainless steel cylinders (diameters: 2, 8 and 12 cm), and they were packed together in the acrylic column. The influent droplet was generated via 20 small droppers around the top of fiber carrier by overall flow rate of 216 L/day. The effluent was discharged through a small pipe from the column base (Figure 8.2b).

8.2.4 Analytical methods

The influent and effluent were sampled approximately one to two times in a week for NH_4-N, NO_2-N, NO_3-N and PO_4-P analysis. The concentration of NH_4-N, NO_2-N and PO_4-P were measured by Digital Pack Test Model WAK-NH_4-N(C), WAK-NO_2-N and WAK-PO_4-P(D) respectively (Kyoritsu Chemical-Check Lab, Corp.). The NO_3-N concentration was measured following the method described in the standard methods for the examination of water and wastewater (APHA, 1995). The NH_4-N removal efficiency was calculated using Equation 2

$$NH_4\text{-N removal efficiency}=\left(1-\frac{\text{Effluent } NH_4\text{-N}}{\text{Effluent } NH_4\text{-N}}\right)\text{x}100$$

...(Equation 2)

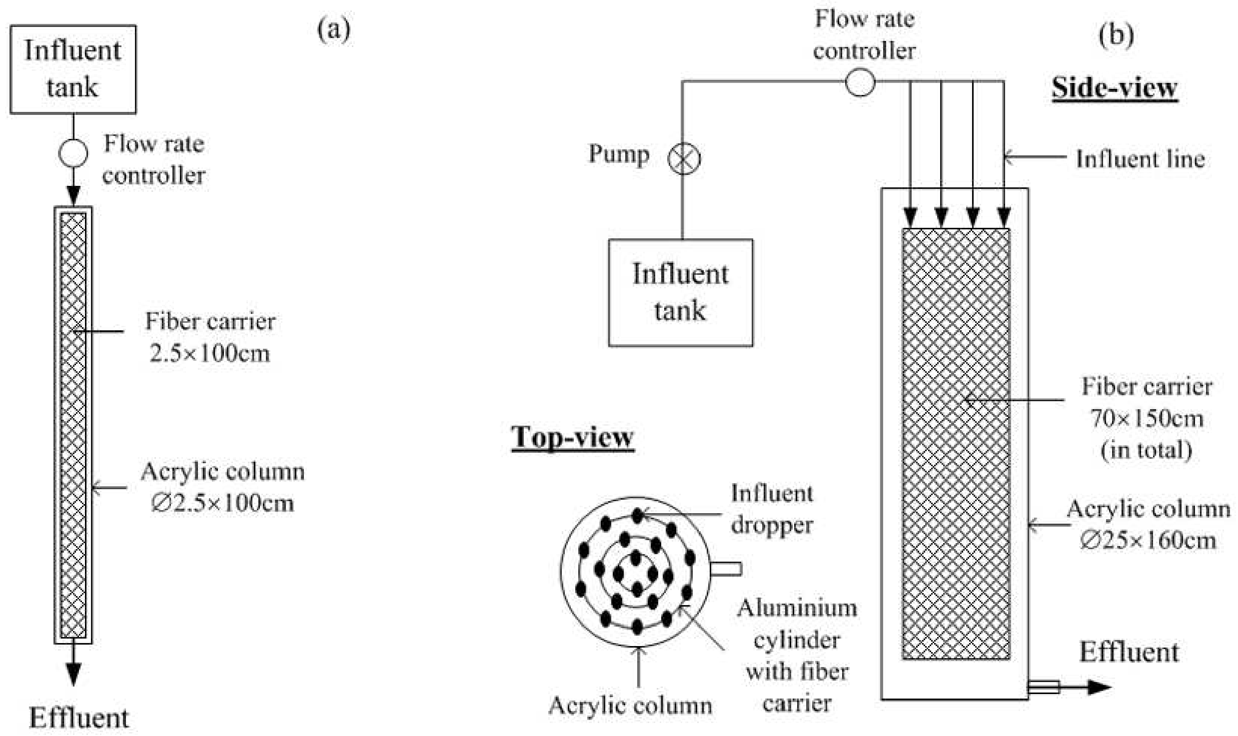

Figure 8.2 A schematic diagram of attached growth system in (a) lab-scale and (b) pilot-scale

8.3 RESULTS AND DISCUSSION

The results of NH_4-N removal by the attached growth system are discussed in the following sequence based on the experimental method; effect of Fe on NH_4-N removal (lab-scale 1), effect of nutrient on NH_4-N removal (lab-scale 2) and performance at pilot-scale.

8.3.1 Effect of Fe on NH_4-N removal (Lab-scale 1)

Two attached growth systems, both with no bacteria attached initially, were set up to study the effect of Fe on bacteria cultivation and NH_4-N removal efficiency. The first system (named as "Fe system") was fed with the high Fe and nutrient (IC and PO_4-P) NH_4-N groundwater and another system (named as "no Fe system") was fed with the no Fe and high nutrient (IC and PO_4-P) NH_4-N groundwater (Table 8.2). The NH_4-N concentration (of influent and effluent) and the removal efficiency of both the systems are presented in Figures 8.3a and 8.3b. In the "Fe system" (Figure 8.3a), no NH_4-N was removed during the first seven days, however, from the 8th day, the removal efficiency started to increase and reached to a steady state of 60-80% on the 14th day. On the other hand, in the case the "no Fe system", no NH_4-N removal was achieved until few days of operation, however, the removal efficiency increased dramatically to 95% on the 7th day (Figure 8.3b). These results reflect that Fe has significant impact on suppressing the growth of nitrifiers and inhibiting the nitrifiers' activity. This impact was due to conversion of the aqueous Fe (i.e., Fe^{2+} and Fe^{3+}) to the solid phase of ferric oxide (i.e., $Fe(OH)_3$ (Ha et al., 2005) and $Fe_2O_3.4.5H_2O$ (Cho, 2005)) because of exposure to oxygen (in air/water) that resulted precipitation of the ferric oxide on the fiber carrier, thus, reducing space for nitrifiers attachment. This explanation was supported by difference in colour of the fiber carrier between light brown in the "no Fe system" and reddish-brown in the "Fe system". In addition, a relatively lower NH_4-N removal in the "Fe system" is due to insufficient oxygen resulting from the use of the oxygen for the precipitation process of ferric oxide; in contrast, the "no Fe system" could keep high efficiency throughout the operation period (in Figure 8.3b). A sharp decrease in efficiency was observed on the 12th day due to no penetration of the influent droplet along the fiber carrier. After adjusting the influent dropper properly, the efficiency was increased to 95-100%.

The concentration of influent NH_4-N in the "no Fe system" was a bit lower than that

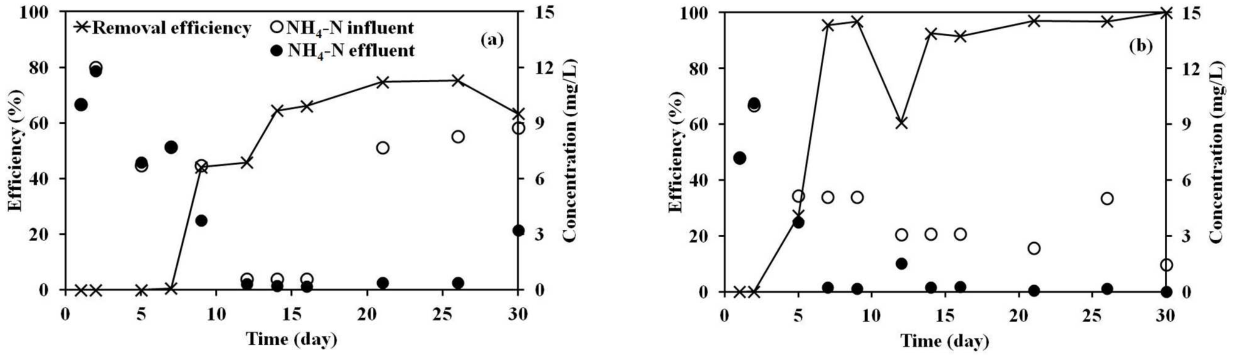

Figure 8.3 NH_4-N concentration (influent and effluent) and removal efficiency of (a) "Fe system" and (b) "no Fe system"

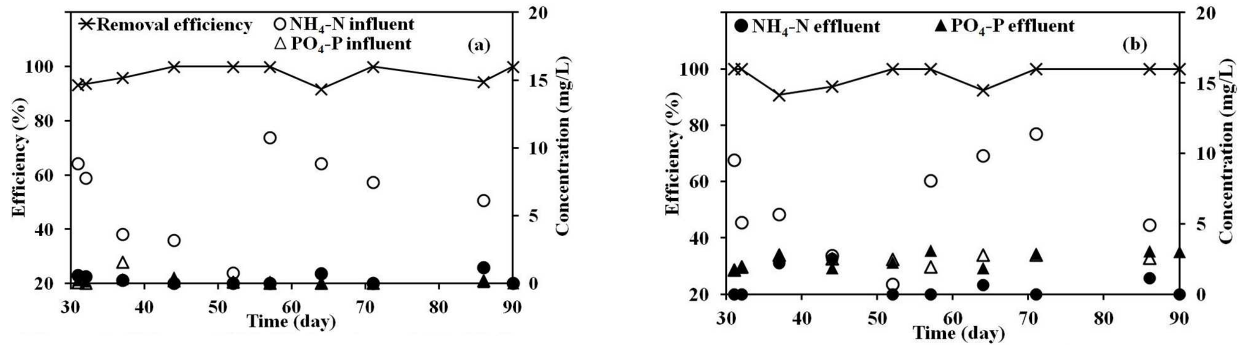

Figure 8.4 Influent and effluent NH_4-N and PO_4-P concentrations and efficiency of (a) "low nutrient system" and (b) "high nutrient system"

in the "Fe system", because some NH_4-N was converted to other nitrogen forms (i.e., NO_2-N, NO_3-N) during the Fe pre-treatment processes. Therefore, a high efficiency of the "no Fe system" could be either because of no Fe or low NH_4-N concentration. Although the efficiency of both the systems could not be compared, the results inform that a pre-treatment (to remove Fe) is needed to get high NH_4-N removal efficiency of the attached growth system, and the pre-treatment process may reduce the frequency of maintenance (times/month) for removing the ferric oxide. It can be concluded that performance of the attached growth system in treating NH_4-N contaminated groundwater is high when the groundwater is not contaminated with Fe.

8.3.2 Effect of nutrient on NH_4-N removal (Lab-scale 2)

Literature (e.g., Ha et al., 2005; Chang et al., 1999) suggest that excess IC (i.e., CO_2, HCO_3^-) and PO_4-P of 70 and 2 mg/L respectively are good for the efficient nitrogen removal using biological process. However, the groundwater in Chyasal area contains low concentrations of IC and PO_4-P (Table 8.1) compared to those suggested in the literature. Therefore, the effect of low nutrient, especially IC and PO_4-P, on NH_4-N removal using the attached growth system was studied.

Two "no Fe systems" fed with no Fe and high nutrient (IC and PO_4-P) NH_4-N groundwater were started approximately three weeks before starting the lab-scale 2. During those weeks, the nitrifiers were cultivated and enriched on the fiber carrier. After that, feeding to the first system was changed to pure NH_4-N groundwater (named as "low nutrient system") whereas another system continued feeding with the no Fe and high nutrient (IC and PO_4-P) NH_4-N groundwater (named as "high nutrient system"). The systems were operated for 60 days. During the 60 days of operation, no notable difference in NH_4-N removal efficiency between the high and the low nutrient systems was observed. Both the systems could be operated at high efficiencies of 95-100% (Figures 8.4a and 8.4b). The results reflect that nitrification could occur properly at a low nutrient concentration (i.e., 30 mg/L for IC and 0.01 mg/L for PO_4-P). Moreover, in the high nutrient system, the same PO_4-P concentration of ~2 mg/L was observed in influent and effluent (Figure 8.4b) indicating no

PO_4-P consumption for biological nitrification in this research. This phenomenon is in contrast to a previous study (Chang et al., 1999) which reported that bacterial activity enhances with increasing PO_4-P. This could possibly be due to varieties of bacteria cultivated at the site (8 phyla and 4 classes of bacteria - Alphaproteobacteria, Betaproteobacteria, Gammaproteobacteria, Deltaproteobacteria, Nitrospira, Actinobacteria, Bacteriodetes, Planctomycetes, Firmicutes, Chloroflexi and Gammatimonadetes - were found in the fiber carrier) rather than the specific bacteria (*Alcailgense eutrophus*) used in the previous study. Therefore, a mix-culture of bacteria attached to the fiber carrier may lead to synergy effect on NH_4-N removal efficiency even though the necessary nutrient (i.e., IC, PO_4-P) is limited. The achievement of NH_4-N removal in both the systems reflects no significant effect of the IC and PO_4-P concentration on nitrification and the 30 mg/L of IC contained in the groundwater was adequate to remove 10 mg/L NH_4-N. However, most nitrification systems are operated under excess IC condition because the IC (i.e., HCO_3^-) plays an important role as buffer to control the optimal pH in the system. In this lab-scale, the effluent pH was 7.5-8.0, which is in an acceptable range for drinking and no nitrification inhibition. From the results of lab-scale 2, it can be concluded that the pilot-scale attached growth system does not need addition of any chemicals.

8.3.3 Performance of pilot-scale attached growth system

The lab-scale analysis suggested no negative effect on the NH_4-N removal efficiency when the attached growth system was fed with no Fe and low nutrient groundwater. Since groundwater in the study area contains high Fe, for higher removal efficiency of the attached growth system, the groundwater needs pre-treatment processes (aeration, sedimentation and filtration) to remove Fe before starting the NH_4-N removal process. The pilot-scale attached growth system (described in section 8.2.3) was installed at Chyasal in November 2009. This section discusses the results of the first 180 days of preliminary operation: 1-30 days as the start-up period (nitrifiers cultivation) and 31-180 days as the operation period.

During the start-up, a number of bacteria attached to the fiber carrier, especially on its top, increased gradually; no bacteria attachment on the 1st day to a dense attachment on the 30th day. After a half of the fiber carrier was attached with bacteria, the operation period was started. During the operation, the concentration of NH_4-N, NO_2-N and NO_3-N in influent and effluent was analyzed regularly to determine performance of the attached growth system. The results are presented in Figure 8.5. The NH_4-N removal efficiency was in a range of 60-90%, however, a trend in the efficiency was continuously increasing over time (the dash line in Figure 8.5). The effluent NH_4-N and NO_2-N (intermediate form) was less than 3 and 1 mg/L respectively, while the NO_3-N was high (~12 mg/L). Possible reasons for the lower NH_4-N removal rate than ideal, i.e., 100% (Figure 8.6) could be either limited oxygen or IC (based on Equations 3-4) or limited bacteria attachment. The low NH_4-N remained and low

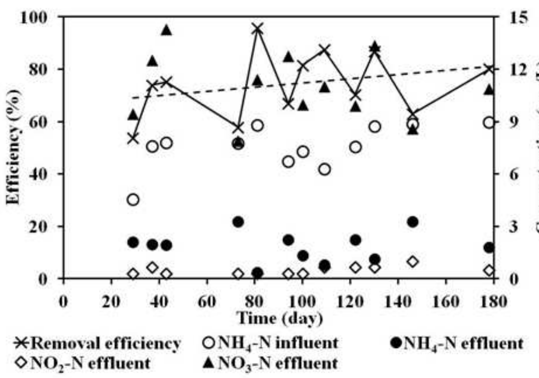

Figure 8.5 Influent NH_4-N and effluent NH_4-N, NO_2-N and NO_3-N concentrations and efficiency of the pilot-scale attached growth system

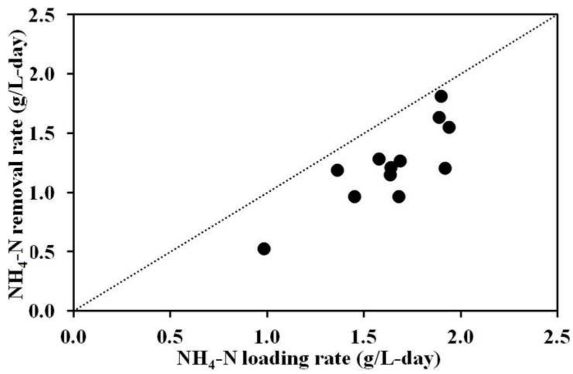

Figure 8.6 Relation between NH_4-N removal rate and NH_4-N loading rate of the pilot-scale attached growth system

Table 8.2 Summary of operating parameters for lab- and pilot-scale experiments

Experiment number	Duration (days)	Fiber carrier size (cm×cm)	Groundwater source
Lab-scale 1			
Column 1 (Fe system)	*30*	*2.5×100*	*High Fe and nutrient (IC and PO_4-P) NH_4-N groundwater*
Column 2 (no Fe system)	*30*	*2.5×100*	*No Fe and high nutrient (IC and PO_4-P) NH_4-N groundwater*
Lab-scale 2			
Column 3 (low nutrient system)	*60*	*2.5×100*	*Pure NH_4-N groundwater.*
Column 4 (high nutrient system)	*60*	*2.5×100*	*No Fe and high nutrient (IC and PO_4-P) NH_4-N groundwater*
Pilot-scale	*180*	*70.0×150*	*Pure NH_4-N groundwater*

Table 8.3 Comparison of the performance of attached growth system (this research) with other systems reported in literature

System	NH_4-N removal efficincy (%)	Influent NH_4-N (mg/L)	Effluent quality (mg/L)		Groundwater source	Operation	Aeration	Reference
			NH_4-N	NO_3-N				
Biofilter	*96.2*	*2.6*	*0.1*	*2.2*	*Raw*	*Pilot*	*Yes*	*Stembal et al. (2005)*
Trickling sand filter	*38.6*	*4.4*	*2.7*	*n.a.*	*Raw*	*Pilot*	*Yes*	*de Vet et al. (2009)*
Swim bed reactor	*95-100*	*30*	*0-2*	*28-30*	*Synthetic*	*Lab*	*Yes*	*Ha et al. (2006)*
Attached growth reactor	*95-99*	*20*	*0-1*	*n.a.*	*Raw*	*Lab/Pilot*	*Yes*	*Khanh et al.(2010)*
Attached growth reactor	*70-100*	*10*	*0-3*	*9-15*	*Raw*	*Lab/Pilot*	*No*	*This research*

NO_2-N accumulated discard the hypothesis of limited oxygen and IC for nitrification. Therefore, the possible reason for that could be less bacteria attachment on the fiber carrier because of the short operation period of the system.

$$NH_3 + CO_2 + 1.5O_2 \rightarrow NO_2^- + H_2O + H^+ \quad \text{... (Equation 3)}$$
$$NO_2^- + CO_2 + 0.5O_2 \rightarrow NO_3^- \quad \text{... (Equation 4)}$$

A comparison of the performance of the attached growth system developed in this research with other systems reported in literature shows that the removal efficiency and the quality of treated water (effluent) are acceptable (Table 8.3). In addition, there are significant advantages of the system developed in this research; (i) no air supply, (ii) no chemicals addition and (iii) simple in design and operation. These advantages mean that the attached growth system is a cost- and energy-efficient and easy to operate and maintain at the site. As load shedding is increasingly becoming a common phenomenon in the study area, this kind of energy-efficient treatment system is one of the most appropriate systems to be a part of the groundwater (containing high NH_4-N) treatment system.

Although the attached growth system could reduce NH_4-N concentration to 0.5-3.0 mg/L (in the range of the WHO standard of 1.5 mg/L), the concentration of NO_3-N in the effluent is high (i.e., 9-15 mg/L). To reduce the NO_3-N concentration to lower than the WHO standard (i.e., 11 mg/L), a post-treatment process called as

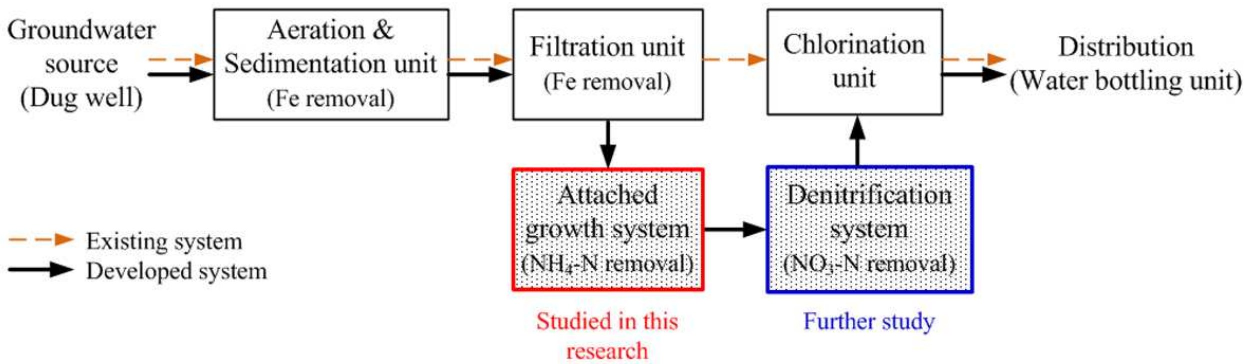

Figure 8.7 Proposed improvement in the existing groundwater treatment system in the study area

denitrification system (NO_3-N→N_2) is required to be installed as shown in Figure 8.7. Although another denitrification system is needed to complete NH_4-N removal, the simplicity and energy-efficiency of the attached growth system induce it as an attractive technology for the study area. The design and operation of cost- and energy- efficient denitrification system will be studied further. In addition to the performance of attached growth system, treatment capacity of the current system is 216 L/day which is very low compared to the water demand in that area (i.e., 800-1,200 L/day in dry season and 2,200-2,500 L/day in wet season). This is an ongoing research and the next step will focus on gradually improving the capacity of the system from 216 L/day to 1,500 L/day.

8.4 CONCLUSIONS

This study designed and tested "attached growth system" to treat NH_4-N from groundwater in the Kathmandu Valley. In the proposed system, oxygen required for nitrification is transferred from air/water so that no air supply is needed for operation. An existing groundwater treatment system at Chyasal area in the valley was taken as a case study site. The performance of the system based on analysis at lab- and pilot-scales shows that: (i) a high Fe (of 10 mg/L) has a negative impact on NH_4-N removal efficiency (decrease the efficiency by 30%), while the low inorganic carbon (of 30 mg/L) and phosphorus (of 0.01 mg/L) in raw groundwater has no effect on the efficiency; and (ii) the attached growth system, if setup after the pre-treatment processes for Fe removal (i.e., aeration and sedimentation and filtration), the removal efficiency (with no Fe and no additional chemicals) would be 60-90% under a flow rate of 216 L/day. However, the study should be continued further in the following aspects: (i) installing and analyzing performance of a denitrification system to remove remaining NO_3-N for complete nitrogen (i.e., NH_4-N, NO_3-N) removal; (ii) analyzing the performance with gradual increase in flow rates (up to 1,500 mg/L) for exploring the prospects for increasing treatment capacity; and (iii) analyzing other quality parameters (e.g., *E. coli*) of the treated groundwater.

8.5 ACKNOWLEDGEMENTS

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SECTION IV

GROUNDWATER USE

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 unreasonably high (ADB, 2003). A survey (CBS, 2005) found that 86% of households are compelled to use secondary sources of water such as shallow wells or private vendor/tanker supplies in order to meet their basic needs.

To cope with the intermittent water supply, households are forced to rely on alternative sources. Most of the households rely on multiple water sources, which is a common feature among the developing countries. A recent report (CBS, 2005) found that piped-water-supply and tubewell/borehole/jet-pump-well are the major sources of water in the household premises of Kathmandu. The survey conducted by Yoden and Chettry (2010) also found that households in the area are likely to rely on alternative sources when they feel the scarcity of water supplied from the piped-water supply system. On the whole, only 15% of the households manage with only the KUKL water and around 41% use only the alternative sources in the wet season.

Among a variety of water sources, groundwater is the most widely used because of its availability, easy accessibility, and low cost. Especially, households with a private well heavily rely on it because it is extremely convenient to collect groundwater from it. The purposes of groundwater are widely ranged, i.e. drinking, cooking, bathing, laundry, cleaning, kitchen garden, etc. However, the existing studies (CBS, 2005; Yoden and Chettry, 2010) suggested that the public prefer the piped-water supply over alternative sources, in particular for drinking and cooking purposes. This indicates that the public perceive potential health risks in the current groundwater status and have difficulties in managing domestic water use given the limited piped-water supply.

Given the current status of water supply services as well as groundwater, it is clear that use of both piped-water and groundwater should be considered together in formulating future policies for water supply and water resources management. For that purpose, this chapter provides evidences as to piped-water and groundwater use of households in Kathmandu. Sections 9.2 and 9.3 briefly describe the methodology of data collection and profile of samples, Section 9.4 provides a comprehensive picture of domestic water use, and finally, Section 9.5 discusses and summarizes how groundwater (and piped-water) use should be put in view of the future policies.

9.2 DATA COLLECTION

9.2.1 Surveyed areas and seasons

The data used in this chapter was collected from household surveys, which were carried out in several selected areas in Kathmandu, Nepal, from 2005 to 2007. The surveyed areas were Min Bhawan (a part of Ward 34), Anam Nagar (a part of Ward 32) and Chabahil (a part of Ward 7). The data was collected in the dry, wet and winter seasons, separately, in order to observe differences in availability of supplied water and public's potential demand.

9.2.2 Sampling design and implementation

The required sample size at 95% significance level was found to be 300. The sample size was considered as 300 or 10% of total households, whichever is greater. The sample size ensures a representative sample of the study population and sufficient statistical variation in explanatory variables. In the case of the study, as the study intends to collect panel-data, part of the samples was expected to be lost during the survey period (Deaton, 1997). Therefore, the initial number of samples was determined to be 33% more than the required sample size. The study employed random sampling method to select units of observations. To ensure to have an unbiased set of samples, a sampling frame was prepared so as to include all existing houses in the surveyed areas.

9.2.3 Data collection method

The data collection method was interview using a set of structured questionnaires. The same sampled households were visited in the three different seasons to prepare a set of panel-data. The interviews were conducted in all households in a sampled house-building to collect information of both house-owners and house-tenants. One interview took around 45 minutes.

9.2.4 Questionnaire development

Questionnaires were carefully developed based on field observations, discussions with experts and feedback obtained through series of pre-tests. The set of questionnaires comprised of four parts: (i) information on the house-building; (ii) the household's general water use including use of alternative sources; (iii) the household's water supply use; and (iii) the household's socio-economic profile.

9.2.5 Data collection

Data collection activities were carried out, through recruiting enumerator candidates, training the enumerators, conducting pre-tests, implementing the data collection and exercising quality control of the collected data. Then, data-cleaning and data-entry were administered. Because of the careful survey design and the closely-monitored data collection activities, the collected data is considered as the most elaborate data set of domestic water use.

9.3 SOCIO-ECONOMIC PROFILES OF SAMPLES

Table 9.1 shows sampling area, seasons and statistics of sampled households. Out of the sampled households, a good number of them were interviewed. Some of the sampled households refused to answer the interview. The refusal rates are significantly low compared to other social surveys in developing countries (Deaton, 1997).

There are 3 households residing in a house-building on an average. House-buildings of the samples can be divided into three types according to the composition. They are house-buildings occupied by: (i) a single owner household; (ii) a single house-owner and more than a house-tenant; (iii) more than a house-tenant. The percentages of the three types are 26.5%, 66.9% and 6.6%, respectively. It is to note that, as households residing in the same house-buildings share a single piped-connection and groundwater, households living in different house-building types are under different conditions for domestic water use.

As mentioned above, several households reside in a house-building – one house-owner and several house-tenants in most cases. House-tenants usually rent a space from their owner, who lives in the same building. In the samples, 32% are owners while 68% are house-tenants. The ownership of a household may influence their domestic water use in several ways. Under the current connection policy, only single piped-connection is provided to a house-building. Thereby households in a house-building share a single tap. Considering the fact that almost all water-related facilities are provided and maintained by an owner, the tenants' access to the facilities greatly depends on the owner's arrangement of these facilities. Table 9.2 provides a summary of the main socioeconomic profiles. There is no significant

Table 9.1 Interview results

Area	Season	Visited house-buildings	Interviewed households	Not-interviewed households	
				Refused	Not available
Min Bhawan	*Dry*	*145*	*420*	*8*	*28*
	Wet	*143*	*430*	*6*	*40*
	Winter	*131*	*379*	*2*	*34*
Anam Nagar	*Dry*	*99*	*250*	*9*	*21*
	Wet	*94*	*255*	*12*	*21*
	Winter	*75*	*194*	*6*	*15*
Chabahil	*Dry*	*90*	*228*	*2*	*21*
	Wet	*84*	*219*	*0*	*20*
	Winter	*73*	*173*	*1*	*21*

Table 9.2 Profiles of the interviewed households

	Unit	All	Owner	Tenant
Sex of household head	*1 if female*	*0.13*	*0.12*	*0.14*
No. of years residing in the current place	*Year*	*4.97*	*9.90*	*2.70*
No. of rooms	*No.*	*2.37*	*3.83*	*1.67*
No. of family members	*No.*	*4.04*	*5.04*	*3.56*
Educational attainment of household head				
No formal education	*1 if yes*	*0.08*	*0.14*	*0.06*
Pre-primary or primary	*1 if yes*	*0.01*	*0.01*	*0.02*
Lower or higher secondary	*1 if yes*	*0.21*	*0.20*	*0.22*
College	*1 if yes*	*0.68*	*0.65*	*0.70*
Monthly income (wet season)				
Less than NRs. 5,000	*1 if yes*	*0.08*	*0.02*	*0.11*
NRs. 5,000 – 10,000	*1 if yes*	*0.35*	*0.23*	*0.41*
NRs. 10,000 – 15,000	*1 if yes*	*0.20*	*0.22*	*0.19*
NRs. 15,000 – 20,000	*1 if yes*	*0.13*	*0.18*	*0.10*
More than NRs. 20,000	*1 if yes*	*0.13*	*0.20*	*0.11*
N.A./Unwilling to disclose	*1 if yes*	*0.21*	*0.15*	*0.09*

difference observed between owners and tenants except for a number of years residing in the current place, a number of rooms and monthly income. Monthly income of owners are higher than that of tenants overall. However, it is not appropriate to simply conclude that the tenants are poorer than the owners overall. The fact should be considered that the family size of the owners is likely to be larger than that of the tenants.

Figure 9.1 shows poverty incidence curves

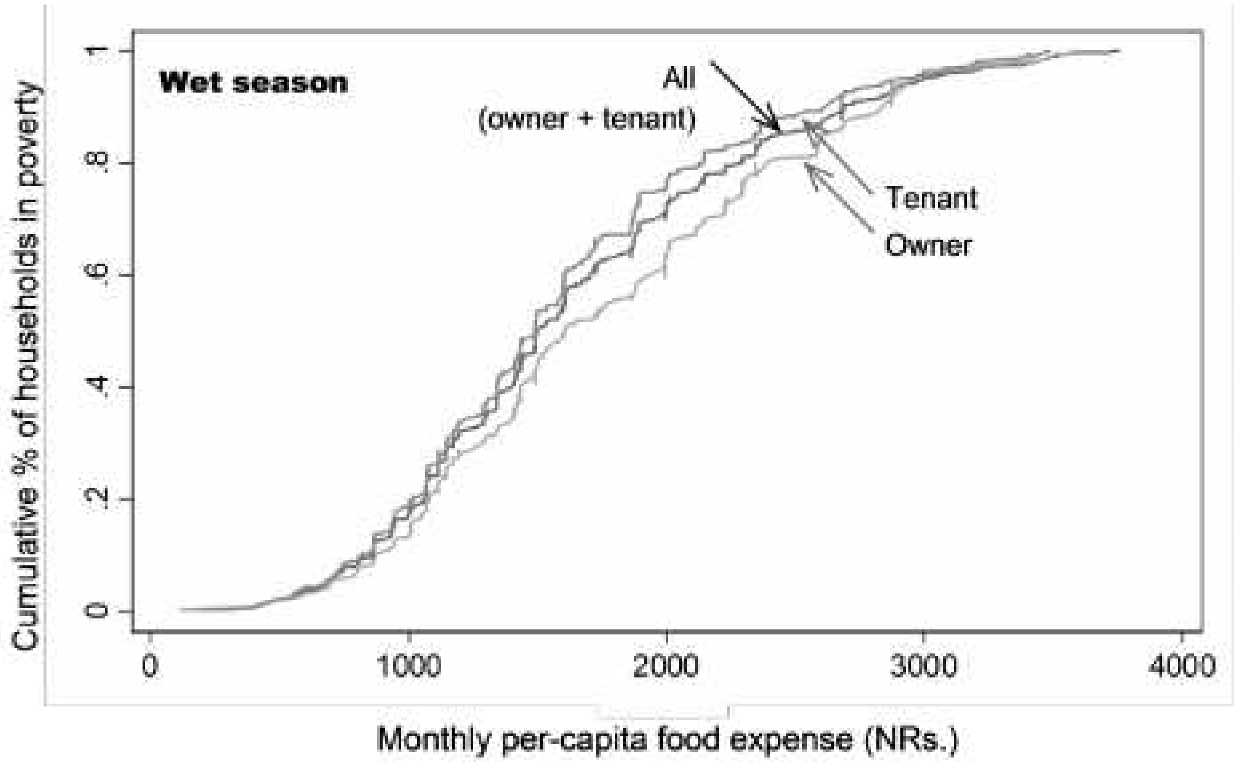

Figure 9.1 Cumulative frequency distribution: per capita food expense (wet season)

(cumulative distributions of monthly food expense per person) by ownership for the wet season. The gap between the two groups is the largest in the middle part, which is around NRs. 2,000. On the other hand, in the low and high ends of expenditure levels, the difference between the two groups is slight. Particularly, the part below the food-poverty line defined in NLSS (CBS, 2004), which is NRs. 593, there is little difference between them.

9.4 A COMPREHENSIVE PICTURE OF DOMESTIC WATER USE

9.4.1 Access to water sources

In Kathmandu, there are various options of water sources for the public. Among them, water sources in the private compound, if any, are the most convenient in terms of access, cost, and usability. Such sources are piped-water and groundwater from a well. As provided in Table 9.3, on an average, 91% and 67% of the households have access to piped-water connection and private well in their compound, respectively. For almost all the cases where there is a private water source in the compound, both owner and tenants share the source.

As presented in Table 9.4, most of the households with access to piped-water supply in the premise rely on it throughout the year. The households with private piped-water but not using it are those who receive no drop of water from the connection. Groundwater from a private well is the second major water source used. In the dry season, when the piped-water supply service deteriorates, more households rely on private wells. Other major alternative water sources are water fetched from neighbours' house, water delivered by vendor, stone spouts and bottled jar water (Table 9.4).

Table 9.3 Access to water sources in the compound

	All (%)	Owner (%)	Tenant (%)
Observations	*896*	*291*	*605*
Piped-water supply services	*90.6*	*90.0*	*90.9*
Well in the compound	*66.8*	*64.3*	*67.9*

Table 9.4 Uses of various water sources

	Dry season (%)	Wet season (%)	Winter season (%)
Private piped-water supply	*87.0*	*89.0*	*89.7*
Private well	*54.9*	*48.1*	*49.7*
Neighbor's piped-water supply	*5.9*	*2.8*	*4.4*
Neighbor's well	*14.5*	*1.8*	*5.6*
Corporation's tanker supply	*4.0*	*1.7*	*0.8*
Vendor/private tanker	*10.7*	*1.0*	*3.6*
Stone spout, spring	*13.8*	*5.4*	*7.2*
Public tap	*2.0*	*0.8*	*0.4*
Public well	*0.1*	*0.7*	*0.7*
River/lake/pond	*0.0*	*0.0*	*0.0*
Rainwater	*1.8*	*6.5*	*0.0*
Bottled water	*1.3*	*0.4*	*0.1*
Bottled jar water	*11.8*	*5.5*	*5.5*
Other water sources	*4.0*	*0.5*	*1.2*

In the dry season, a number of households using neighbours' sources, vended water, stone spouts and jar water is significantly large, compared to the wet and winter seasons. On the other hand, piped-water and private wells are the major sources relied on by households in the other two seasons. While private well is used as the main source, other sources are chosen as supplemental water sources.

Owners and tenants comparison in terms of water source choice: For the two major water sources, i.e. piped-water and groundwater, there seems to be little difference in choice among the owners and the tenants. However, there is a certain gap in the choice when it comes to other sources. More owners rely on tanker supply, vended water and rainwater than tenants. Among these sources, the first two require a user to own large-size storages because the supply is usually in bulk. Rainwater also requires households to own large-size storages and to have enough space to place them for collecting and storing. These constraints may discourage tenants from utilizing these sources. On the other hand, tenants are likely to rely on stone spout (public source) and neighbours' sources, which are free from such constraints.

9.4.2 An analysis of piped-water use

Piped-water supply services: As presented above, nearly 90% of the houses are connected to the piped-water supply system. On an average, the interviewed households receive 3.1, 3.8 and 3.3 times of piped-water supply services per week in the dry, wet and winter seasons, respectively. The average service hours per week are 6.0, 13.2 and 5.5 in the dry, wet and winter seasons, respectively. In the dry and winter seasons, more than 90% of the connections receive the piped-water service for less than 10 hours per week. In the wet season, more than 60% of the connections receive the piped-water service for less than 10 hours per week.

Volume of piped-water consumed: Figure 9.2 presents the cumulative frequency distribution of the volume of piped-water consumed, by season and ownership. Table 9.5 provides the representing values of the piped-water volume consumed. Regarding the differences among seasons, both owners and tenants consume piped-water most in the wet season. Overall, the majority of owners consume less than 50 litres/capita/day (lpcd) throughout the year, which is regarded as the basic requirement according to the international standard

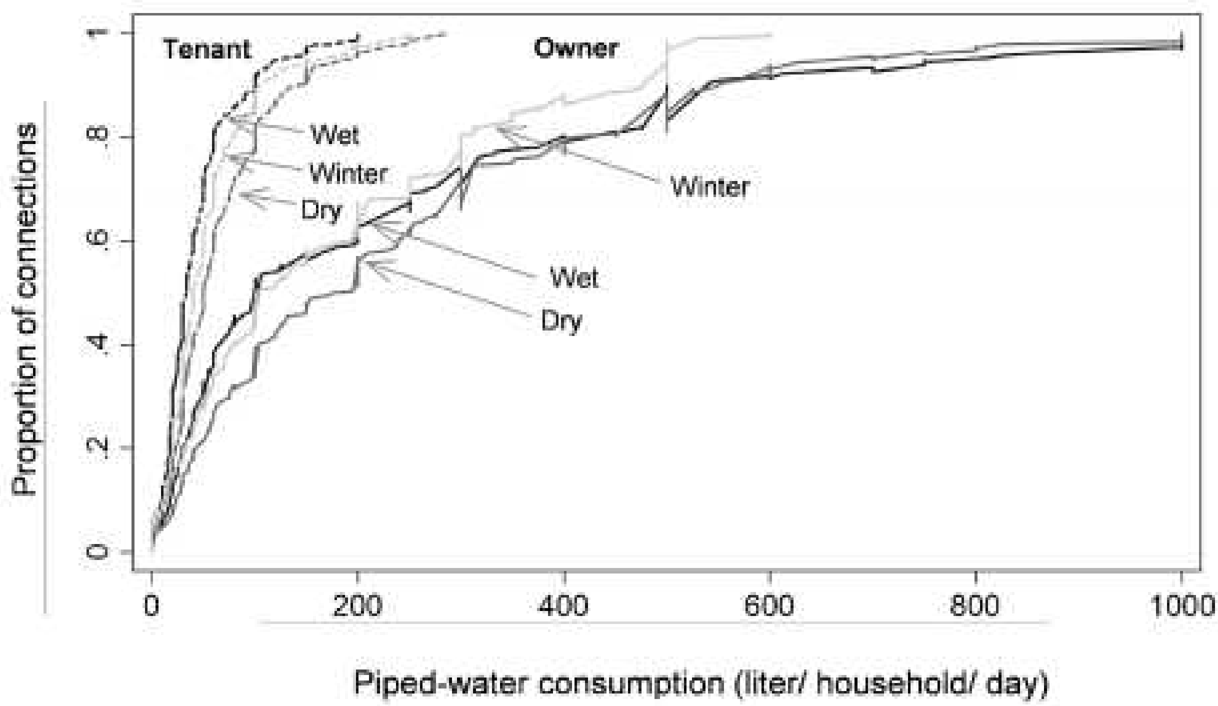

Figure 9.2 Cumulative frequency distribution: per-household piped-water consumption

Table 9.5 Consumption of piped-water

	Obs. (N)	Piped-water consumption (litre/day)				
		25%tile	50%tile	75%tile	Mean	S.D.
Per household						
House-owner						
Dry season	*237*	*40*	*100*	*321*	*254*	*369*
Wet season	*257*	*60*	*200*	*400*	*291*	*371*
Winter season	*229*	*45*	*125*	*300*	*208*	*215*
House-tenant						
Dry season	*517*	*20*	*34*	*60*	*62*	*102*
Wet season	*565*	*30*	*53*	*100*	*83*	*100*
Winter season	*452*	*25*	*43*	*75*	*69*	*91*
Per capita						
House-owner						
Dry season	*236*	*8*	*24*	*79*	*54*	*77*
Wet season	*256*	*13*	*39*	*88*	*61*	*72*
Winter season	*228*	*9*	*29*	*70*	*46*	*49*
House-tenant						
Dry season	*517*	*6*	*11*	*20*	*18*	*25*
Wet season	*565*	*9*	*17*	*33*	*26*	*30*
Winter season	*452*	*7*	*15*	*23*	*20*	*24*

Table 9.6 Perception of sufficiency of piped-water

	Dry season		Wet season		Winter season	
	Owner (%)	Tenant (%)	Owner (%)	Tenant (%)	Owner (%)	Tenant (%)
Insufficient for drinking and cooking purposes	*39.3*	*36.0*	*9.1*	*10.1*	*27.5*	*17.1*
Insufficient for bathing and laundry purposes	*74.1*	*79.5*	*36.0*	*44.7*	*60.8*	*58.9*

(WHO/UNICEF, 2008). A majority of tenants consume less than 20 lpcd, which is regarded as the minimum requirement according to the international standard (WHO/UNICEF, 2008). The difference among the three seasons is relatively small. However, this does not necessarily mean that their water demand is small. The small consumption is mainly due to the scarcity of water at consumers' end as well as the constraints in terms of in-house water use.

Perception of sufficiency: Public perceptions on sufficiency (in terms of volume) of the supplied piped-water for basic purposes are tabulated in Table 9.6. The results show that the percentages of households satisfied with the available amount of piped-water are almost at the same level for owner as well as tenant groups, despite that the amount of water consumption of both the groups is strikingly different.

Satisfaction with quality of piped-water: Table 9.7 provides the results on satisfaction level about quality of piped-water. Despite the significant variation in perception of sufficiency throughout the year, the satisfaction level of water quality is rather constant. As presented in Table 9.7, a majority of the public find quality of piped-water satisfactory. However, 65-67% of the households believe that the supplied piped-water contains health risk throughout the year. Consequently, around 95% of the consumers apply at least one treatment for drinking purpose. They believe that there is little risk in the water after treatment. Regarding the water for cooking purpose, more than 90% and 95% of the households do not apply any treatment in the dry and wet season, respectively.

9.4.3 Combined use of multiple water sources

As described above, alternative sources are indispensable for the public to manage their domestic water use, while households prefer piped-water to alternative water sources (CBS, 2005; Yoden and Basnyat, 2008). Households rely on alternative sources because piped-water supply system is not functioning properly in terms of quantity and quality of supplied water, pressure, reliability and regularity. It is well known that such substitution between several water sources is more likely to occur when piped-water services are not fully reliable and when the quality of non-piped water is perceived as satisfactory (Pattanayak et al., 2006; Nauges and van den Berg, 2009).

Hence, for a full picture of domestic water use, it is needed to look at use of both piped-water and non-piped water sources, which would be a stimulus to policy discussions of water resources management as well as water supply development. This section starts with the overview of combined use of multiple water sources, focusing on groundwater as a major alternative source. Then, it reports how consumption of piped-water and groundwater are related in terms of water volume consumed and water sources choices, by presenting results of a previous study.

Use of multiple water sources: Table 9.8 describes how the interviewed households combine the use of the piped-water and alternative sources. In the table, water sources are divided into three categories according to the accessibility: piped-water; water from a private well in the premise; and other alternative sources. As seen in Table 9.8, only 18% and less than 50% of the households manage only with the piped-water in the dry and wet season, respectively. This confirms results presented above, households with a private well tend to rely on it throughout the year. The comparison between owners and

Table 9.7 Satisfaction with quality of piped-water

Satisfaction with quality	Dry season		Wet season		Winter season	
	Owner (%)	Tenant (%)	Owner (%)	Tenant (%)	Owner (%)	Tenant (%)
Satisfied	*54.0*	*61.4*	*66.1*	*67.3*	*70.8*	*73.7*
Not satisfied	*40.9*	*35.1*	*29.3*	*29.7*	*25.3*	*23.6*
Don't know	*5.1*	*3.5*	*4.6*	*3.0*	*3.9*	*2.7*

Table 9.8 Combined use of multiple water sources

Combination way	Dry season		Wet season		Winter season	
	Owner (%)	Tenant (%)	Owner (%)	Tenant (%)	Owner (%)	Tenant (%)
Private piped-water only	*18.6*	*18.0*	*44.7*	*45.2*	*33.2*	*35.9*
Private piped-water and well	*26.5*	*31.1*	*25.6*	*29.7*	*35.2*	*36.5*
Private piped-water & other sources	*24.1*	*23.6*	*10.3*	*6.9*	*12.3*	*11.6*
Private piped-water, well and other sources	*15.8*	*13.6*	*8.0*	*5.8*	*7.5*	*6.1*
Private well and other sources	*15.1*	*13.6*	*11.4*	*12.2*	*11.1*	*9.9*
Total	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*

tenants suggests that tenants are more likely to rely on well in the compound but less likely to rely on other alternative sources than owners.

Total volume of water use from multiple sources: Figure 9.3 illustrates the total amount of water consumed from multiple sources in use (median). There are mainly three points to be noted from the view point of alternative water source usage.

Firstly, the result indicates that the amount of water that households find is more or less sufficient. Look at the two groups of owners: households using only piped-water (the first group from the left); and households using piped-water and the other alternative sources (the third group). Most of the households in the latter group are those without a private well in the compound. The two groups consume around the same amount of water. This suggests that households, which find the supplied water insufficient tend to supplement it with alternative sources, and they supplement until the total amount of water from the two sources is close to that of households using only piped-water.

Secondly, Figure 9.3 indicates easier accessibility and/or usability of a private well compared with other alternative sources. Owners with a private well (the second group from the left) consume slightly more than the third group. Both the groups rely on two water sources, i.e. piped-water and another alternative source. However, the total consumption of the second group is larger than that of the third group. It indicates that households find superior accessibility and/or usability of the private well to that of the other alternative sources. The larger total amount of the second group also implies that households with a well are more likely to rely on alternative sources than households without a well under the poorer supply service.

Thirdly, the water consumption of tenants is at a significantly lower level throughout the year for all the groups. The consumption of the first group (median value), who use only piped-water, is smaller than 20 lpcd, which is below the universally defined minimum requirement (WHO/UNICEF, 2008). Even the most-water-consuming households consume less than 40 lpcd. However, it should be noted that this does not necessarily suggest their smaller water demand than that of the owners.

Preferences in use of different sources: In the previous subsection, it was found that many households rely on alternative water sources to supplement the limited amount of piped-water. The next question is, whether there is any pattern or preference in combining use of several sources? And if so, what are the patterns or preferences? Here are answers to the question.

The most popular source for drinking and cooking purpose is the piped-water, which is used by more than 80% of the households throughout the year. A certain number of households use stone spouts (7%), jar water (11%), groundwater from a well (5%) and water from neighbours (7%) for drinking purpose in the dry season. However, these sources are rarely used for the two purposes in the other seasons. When it comes to the hygienic purposes, i.e. bathing and laundry, the situations change significantly. More households rely on alternative sources. Private well is the most popular, which is probably because of its easier accessibility, followed by tanker supply and stone spout. Bathing and laundry usually require larger amount of water but less quality.

In summary, it could be concluded that the public are likely to allocate the piped-water for drinking and cooking purposes first, and use the water for other purposes if some amount of water remains. The alternative sources are chosen according to their demand as well as the cost to obtain. People tend to use "safe" (as they perceive) water for drinking and cooking purposes, even though it is expensive in some cases. For the hygienic activities, they tend to choose water with lower cost in terms of price to purchase and/or labor to obtain.

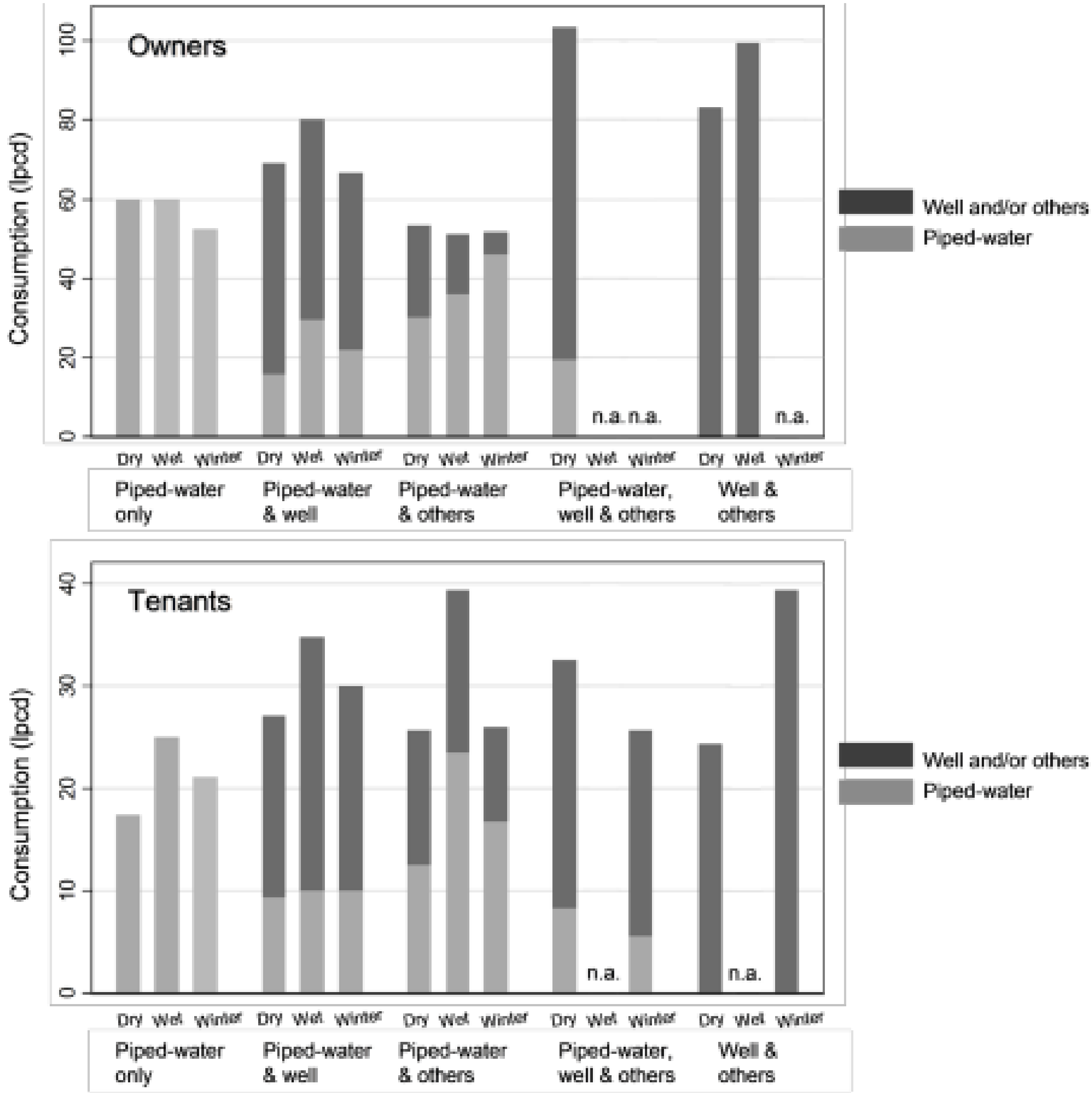

Figure 9.3 Total consumption of water from all sources in use by combination ways

9.4.4 Factors determining volume of water consumed

This subsection briefly presents determinants of piped-water and groundwater volume consumed, based on a previous study (Yoden, 2010) conducted by the author. The analysis exploited only data set of owners from the wet season so as to ensure sufficient variation of supply hours. The amount of piped-water supplied in the dry and winter seasons is not fully sufficient so that a number of the sampled households receiving a substantial amount of water was very small. Therefore use of the other seasons' data is considered to restrict the analysis of cases where there is relatively sufficient piped water available (Yoden, 2010). The determinants of the owner's piped-water consumption and groundwater consumption were estimated by employing multiple linear regression analyses.

Determinants of piped-water consumed: Determinants of piped-water consumed are briefly summarized. As commonly known, the supply hours (the availability of piped-water from the connection) is a primary determinant of the piped-water volume consumed and this applies to the case in Kathmandu. However, the degree of increased volume by the long supply hours differs according to supply level. While the duration of supply hours has a significant effect on the consumed volume under poorer supply, it has little impact on the volume under better supply. The quality of supplied water and regularity of the service are also important aspects in increasing domestic piped-water consumption.

Besides the supply service level, the capacity to cope with the deficient service is crucial in domestic piped-water consumed. As long as the supply is intermittent, it is crucial for consumers to have good in-house water-related facilities for coping with the intermittency. The results revealed that, especially under the better supply, the size of storage is significantly important to collect an adequate amount of supplied water. The education level of household is also an important factor for domestic piped-water consumption. Better educated households tend to prefer the piped-water and consume more water because of their higher social/economic status as well as their high health awareness. At the same time, because of their likely wealthier living conditions, they are likely to have good in-house water-related facilities and be able to cope with the deficient service well.

Determinants of groundwater consumed: The consumption of groundwater is well explained by the educational attainment of a household head, the piped-water supply hours and the use of jet pumps for groundwater extraction. Unlike in the case of piped-water consumption, households headed by lower educated member (less than secondary school or no formal education) consume groundwater more than higher educated households. It is interesting to note that, for households with a private well, the improvement of the piped-water supply service contribute little in increasing their piped-water consumption, but it leads them to minimize the use of groundwater, which would lead to smaller health risks. The groundwater consumption is also influenced by the use of jet pumps. Households using a jet pump consume more water than the others.

9.4.5 Determinants of choice of water sources

In this subsection, determinants of choice of the available water sources are presented, based on a previous study (Yoden, 2010) conducted by the author. The analysis exploited data set of the wet season for the same reason mentioned in the previous subsection. The determinants of the water sources choice were estimated, by employing ordered probit/logit models, based on the examination suggesting that the public prefer piped-water to alternative sources.

For drinking and cooking purposes: As the descriptive statistics in the previous section presents, there are quite a few households relying on alternative sources for drinking and cooking purposes. The results suggest that good piped-supply is a primary condition to prevent households relying on alternative sources for these purposes. Households receiving longer supply, and perceiving the quality of piped-water as good, tend to rely more on piped-water for these purposes.

For bathing and laundry purposes: The piped-water supply is again one of the influential factors to the water sources choice for bathing and laundry purposes. Households receiving longer supply and perceiving the quality of the supplied water good are more likely to use alternative sources. In addition, households having a private well in the compound tend to rely on groundwater. In case of owners, lower educated households are more likely to rely on alternative sources. Absence of ground tanks also leads them to rely on alternative sources. In case of tenants, the other influential factors are: a number of households in a building; the use of ground tank; and the regularity of the supply service.

In summary, the results indicate that the determinants of the choice of water sources differ according to the domestic water purpose. For purposes, which require higher quality, i.e. drinking and cooking, it could be concluded that households prefer using piped-water over other sources. The supply services level primarily determines the sources used. On the other hand, for purposes that require a larger amount of water and not necessarily of high quality, i.e. bathing and laundry purposes, determinants are more related to households' features, such as educational level, the use of ground tank and the presence of a private well in the compound. Particularly, it is important to note that households with a private well and being less educated are more likely to rely on alternative sources.

9.5 DISCUSSION AND SUMMARY

In summarizing the chapter, several implications for future policy are discussed from the viewpoint of piped-water and groundwater use for domestic purposes. First, future policy should take into account the fact that a majority of the households already widely rely on alternative sources due to the limited availability of piped-water. Among various alternative sources available in the valley, groundwater is the major alternative source. The amount of groundwater drawn for domestic purposes might be relatively smaller compared with other sectors. The problem, however, is more related to public health issues. As a lot of households rely on groundwater even for drinking and cooking purposes, risk assessment of groundwater quality in the valley should be put in place.

Second, the analysis results indicate that increasing the piped-water availability is not a single solution for improving domestic water use as well as public health. The results indicate the variety of choices in water supply development projects. Given the current situation, it would be unrealistic to expect that, in Kathmandu, the total production of piped-water increases significantly in the near-to-mid term. However, there are other things the government sector can do to improve the public's water use. The results suggest that the improvements in the quality of the supplied water and the regularity of the service can also have positive impacts on the volume of consumed water, which is crucial for minimizing health risks. The improvements in those aspects would benefit, especially, the vulnerable households more than others, such as tenant households, households, which don't have water-related facilities (e.g. large-size storage, pump), those who have low health awareness, etc. As many of lower educated households often cannot afford effective in-house water-related facilities, they hardly cope with the intermittent supply in an efficient manner. For them, the regularity and the predictability of the supply schedule are crucial for fully utilizing the supply service. In addition, it should be noted that lower educated households tend to rely on unsafe water sources, in particular when the alternative source is significantly convenient in terms of monetary values as well as labour efforts. The results clearly suggest that the improvements will prevent them from relying on unsafe water, leading to more hygienic domestic water use. If such improvement projects are implemented tied up with health awareness programs, it will be more effective for public health improvement. These implications are consistent with frequently emphasized knowledge that health awareness promotion should be implemented in conjunction with a water supply improvement project, to realize the people's proper water-related behaviours.

As repeatedly emphasized, the availability of safe water, in terms of access and volume, is not the single determinant of adequate domestic water use. The way the water is provided, the capacity of people coping with and utilizing the service, and the health awareness enabling proper water use, offer potential benefits of safe water when all are in set. Thus, future policy should look beyond safe water provision, and take domestic water use into account – how the public use water and what constraints they face. When this is achieved, the design for service improvements can incorporate necessary measures so that it will enable the public to maximize potential benefits from the services and to attain adequate domestic water use.

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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

Table 10.1 Projected population for the Kathmandu Valley and KUKL service area (KVWSWSI, 2010)

Year	2001 (census)	2010	2015	2020	2025
Kathmandu Valley	*1,579,737*	*2,712,000*	*3,486,000*	*4,481,000*	*5,761,000*
KUKL service area	*1,285,737*	*2,135,000*	*2,713,000*	*3,242,000*	*3,963,000*

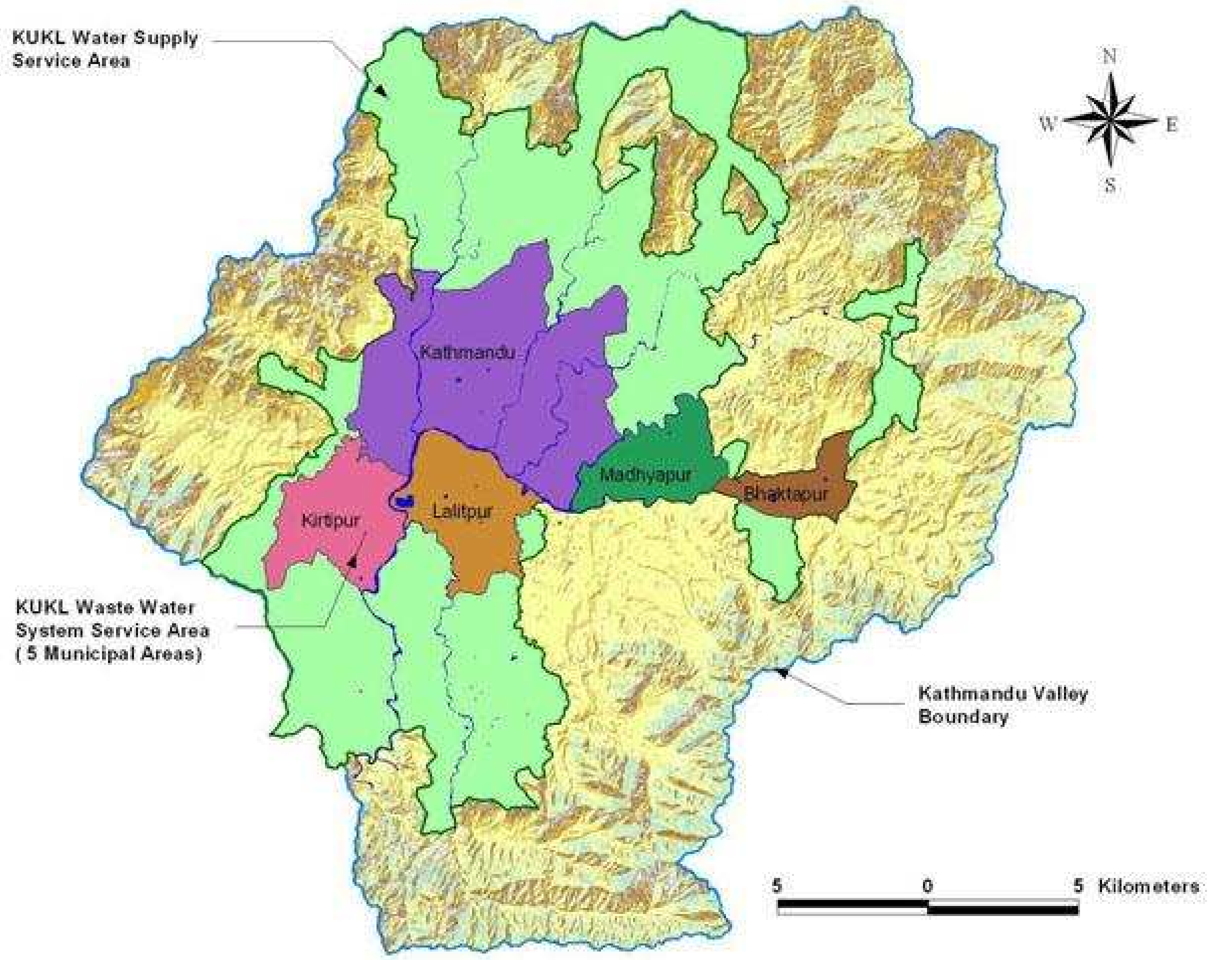

Figure 10.1 Kathmandu Valley and KUKL service area (KUKL, 2011)

outcome of alleviating the chronic shortage of potable water. MWSP is implemented under two sub-projects. Sub-project-1 delivers bulk potable water to the head of the Kathmandu Valley (i.e., Melamchi Diversion Scheme). Its major civil components are the 26 km tunnel and the new water treatment plant (WTP) at Sundarijal. The MWSP sub-project-2 has major civil components of water distribution system and wastewater system improvements in the valley. The MWSP has aimed for 24 hours water supply of 135 lpcd and structured water infrastructure rehabilitation and development programs under sub-project-2 to reduce unaccounted for water (UfW) to 20% from 40%; first 10% in transmission and treatment process and another 10% in distribution system. The activities under subproject-2 are listed below:

- Rehabilitation and development of surface water and groundwater sources
- Rehabilitation and development of WTPs
- Bulk distribution system
- Water supply service reservoirs repair and new construction
- Distribution network improvement (DNI)
- Land acquisition for the programs

As per an agreement made with the Asian Development Bank (ADB) for the MWSP, the Government of Nepal restructured the existing state owned regulator and operator, Nepal Water Supply Corporation (NWSC) and established three separate entities; Kathmandu

Valley Water Supply Management Board (KVWSMB) as owner and policy maker, *Kathmandu Upatyaka Khanepani Limited* (KUKL) as operator and manager of services, and Water Supply Tariff Fixation Commission (WSTFC) as economic regulator of the services. The KUKL service area includes 5 Municipalities and 48 VDCs (Figure 10.1). Water supplies for remaining 51 VDCs are managed by Department of Water Supply and Sewerage (DWSS).

It is generally expected that the current situation of water supply and water environment, including groundwater environment, would be improved after the completion of the MWSP. In this context, this chapter discusses situations of groundwater use in the Kathmandu Valley under pre- and post-Melamchi scenarios.

10.2 ANALYSIS APPROACH

Parameters considered in the analysis are water demand, production, supply, groundwater contribution in total supply, and supply hour/day. The year 2011 is considered as current condition and the years 2016, 2019 and 2025 are considered as post-Melamchi condition because it is expected that the first phase of Melamchi water will be added in 2016 and other additions of 170 MLD will be in 2019 and in 2025.

Water demand is usually derived from the population within service area (considering floating population also), population growth, domestic water consumption level assumptions, and a provision for non-domestic water consumption. The floating or temporary population is assumed to be 30% of the total population. However, demand is also a function of water price, affordability and accessibility of water supply, but accurate estimates of the impact of these factors require extensive analysis of historical data. They are not considered in this study. Both permanent and temporary populations are considered to estimate water demand. The supply in lpcd is evaluated considering supply quantity for total effective population (both permanent and temporary), but only 40% of consumption rate is considered for temporary population. The demand in lpcd is taken 135 lpcd as estimated by MWSP.

The analyses are made on monthly as well as annual basis. Analysis for current condition is basically based on groundwater production and supply data/information from KUKL well-fields. For the post-Melamchi scenario, projections are based on current trends.

10.3 PRE-MELAMCHI WATER DEMAND AND GROUNDWATER USE

10.3.1 Water demand

The present permanent population of the KUKL water supply service area is estimated at over 2.1 million (Table 10.1). Adding 30% accounted for temporary population (KVWSWSI, 2010), the total population to be considered for gross demand, will be 2.73 million. Considering household sanitation system in the service area, it is reasonable to take per capita demand in the range of 85 to 95 lpcd. The KVWSWSI (2010) has considered 93 lpcd. However, MWSP has considered consumption rate of 135 lpcd for total population including temporary population. The total water demand at the rate of 135 lpcd at service level or point of use would be 315 MLD, which is similar to KUKL's estimated demand of 320 MLD (KUKL, 2011). Estimated unaccounted for water (UfW) considered for the system is 35-40% (KUKL, 2011). Considering UfW as 40%, net water supply would be decreased by 40% compared to the production.

10.3.2 Groundwater use

Groundwater abstraction in 2000 was estimated at 59.06 MLD, out of which 49.4% was by KUKL (at that time the supply system belonged to NWSC) alone (Metcalf and Eddy, 2000). As KUKL is a major user, this study discusses groundwater use in the valley based on KUKL production and supply of groundwater resources.

Deep tubewells are the main means of extracting groundwater for use in the water supply system. Out of 78 existing deep tubewells only 57 are currently in operation mainly from 7 well fields, namely, Manohara, Gokarna, Dhobikhola, Bansbari, Mahadevkhola,

Table 10.2 Current average monthly demand, supply and deficiency (KUKL, 2011)

Month	Demand	Production	Supply	Deficiency
Jan	*315*	*114 (13.5)*	*91*	*224*
Feb	*315*	*99(33)*	*79*	*236*
Mar	*315*	*89(33)*	*71*	*244*
Apr	*315*	*95(33)*	*76*	*239*
May	*315*	*96(33)*	*77*	*238*
Jun	*315*	*114(13.5)*	*91*	*224*
Jul	*315*	*141(13.5)*	*113*	*202*
Aug	*315*	*145(13.5)*	*116*	*199*
Sep	*315*	*149(13.5)*	*119*	*196*
Oct	*315*	*142(13.5)*	*114*	*201*
Nov	*315*	*132(13.5)*	*106*	*209*
Dec	*315*	*116(13.5)*	*93*	*222*
Inside ( ) is groundwater contribution; all the units are in Million-litres-a-day (MLD)				

Bhaktapur, and Pharping (KUKL, 2011). Most of the tubewell's electro-mechanical parts are in a poor condition with most flow meters missing or broken. Tubewells used to be operated only in the dry season in order to supplement reducing surface water sources, but, due to demand exceeding supply, most of them are now also used in the wet season. Total dry season (4 months: February to May) rated production is 33 MLD with a reduced wet season (remaining 8 months) production of 13.5 MLD (Table 10.2). Additional groundwater has been extracted through 15 dugwells as supplement of deep groundwater abstractions. An inventory of deep tubewells currently in operating condition under KUKL is listed in Appendix 10.1. Average time of daily groundwater pumping is 16.5 hours. Discharge drawing from these tubewells is less compared to its pump capacity and power consumption. It shows many pump sets have to be replaced to run on its maximum capacity.

The portion of groundwater contribution in the total production is 35% (on an average) during dry season (4 months from Feb to May) and 11% during wet season (remaining 8 months). The pumping rate of the private wells in the valley is smaller compared to KUKL's tubewell abstraction. Deeper groundwater is being over-extracted and extraction is unsustainable. It is estimated that there are over 10,000 dug wells, which are used to supplement the KUKL water supply. More reliable water supplies will reduce the need for groundwater pumping, thus allowing more sustainable use of this valuable water resource.

10.3.3 Groundwater depletion trends

The trend of groundwater extraction volume from private wells and gas wells remains almost constant during the last several years. But the production from KUKL wells is increasing greatly. JICA (1990) had used historical well hydrographs to assess the seasonal fluctuation of groundwater level and recharge into main aquifer in the study of groundwater management of the Kathmandu Valley. Tank Model (Sugawara et al., 1974) was used for simulation to develop the relationship between rainfall and groundwater level. The annual fluctuations (maximum groundwater level - minimum groundwater level) of long-term average at two sites were estimated. In the study, they estimated mean annual fluctuation on a well at Sundarijal (WHO7A) by taking average over the period 1940-1986 as 1,500 mm and on a well at Maharajgunj (B12) over 1947-1975 as 457 mm. Both wells are located in the northern part of the basin.

The Kathmandu Valley groundwater basin can be isolated from other groundwater bodies outside the valley. Recharge from outside the valley is assumed to be negligible. The groundwater levels have been in nearly steady condition in the early stages of the 1980's, because no large well was operated at that time in the basin. JICA (1990) has developed a relationship by trial-and-error method in order to make the calculated groundwater level of the main aquifer to coincide with the observed value. Extraction of groundwater by pumping has been found to increase since 1984 so it is justifiable to assume that groundwater level was in a steady state condition on and before 1983.

Groundwater assessment model developed by Shrestha (2001), has found groundwater level decreasing sharply from 1985 onwards and balanced water available was abruptly changed from 1986 onwards. The model had assumed initial groundwater storage as 1,000 mm to calculate relative drawdown of the groundwater. The model predicted the maximum soil moisture content as 225 mm; which was in the range of 200 to 250 mm estimated by Binnie and Partners (1973) for the Kathmandu Valley. The study used mean annual actual evapotranspiration calculated by Shrestha (1990) as 829 mm while the mean annual potential evapotranspiration was 1,074 mm. An annual actual evapotranspiration was found almost constant for the valley. Some recharge areas, which are on the northern part of the valley, is urbanizing rapidly. On the other hand, extraction of groundwater is also increasing to fulfill the demand of water. These are the main reasons for rapid depletion of groundwater levels.

The drawdown was calculated with reference to the year 1975. The initial condition of groundwater level is taken as of the year 1972. The drawdown depth observed in the valley basin was much close with observed drawdown for all observed years. The model has found three distinct trends of drawdown such as decreasing trend from 1977 to 1981, increasing trend from 1981 to 1985 and sharp increasing trend after 1986. Main reasons behind sharp increasing trend of drawdown were listed as three- to four-fold increasing in new house construction and over extraction of groundwater to cope with the shooting water demand due to rapid and unplanned urban growth. The total basin equivalent drawdown was found to be increased by 2.75 m in 1984 and 7.5 m in 1989 when compared to that in 1978. The model predicted drawdown only due to groundwater extraction, which was found to be increased by 2 m in the year 1984 and 6 m in the year 1989 compared with the drawdown during 1978. Shrestha (2001) concluded that drawdown of 0.75 m in the year 1984 and 1.5 m in the year 1989 could be attributed to the hydrological change due to land-use modifications.

10.4 POST-MELAMCHI WATER DEMAND AND GROUNDWATER USE

In the post-Melamchi scenarios, the permanent population is forecasted to rise from present 2.1 million in 2011 to 2.8 million in 2015, 3.3 million in 2020 and 4.0 million in 2025 (Table 10.3, 10.4). Out of the total population forecast, 77%, 87% and 96% of that will be served, as a result of the MWSP and future investments, in 2015, 2020 and 2025 respectively (KVWSWSI, 2010). Predicting the exact number of temporary population in the valley is a challenging task, as there is no reliable data. KVWSWSI (2010) undertook a sample survey to ascertain the temporary population. The sample surveys were focused on three categories of the temporary population such as street vendors; students, service holders and labors seeking job in the valley; and house servants/ keepers. The survey indicated that temporary population amounted to approximately 30% of the permanent population. The proportion of temporary population varies between municipal and VDC wards. It has to be taken into account in population projections and service demands.

Based on information published on work progress by MWSP, it will be reasonable to believe that the Melamchi water will be started to serve in its first phase (stage I) to the valley by 2016. The second and third phases, each of 170 MLD, are expected to be added in 2019 and in 2025 respectively. According to the

Table 10.3 Pre- and post-Melamchi scenario on demand, production, supply, groundwater contribution and supply hour per day for 2011 and 2016

Year			**2011**				**2016**					
Permanent population			**2.1 million**				**2.8 million**					
Temporary population			**0.63 million**				**0.84 million**					
Month	*Demand MLD*	*Production MLD*	*GrWr %*	*Sup. MLD*	*Sup. lpcd*	*Sup. hr/day*	*Demand MLD*	*Production MLD*	*GrWr %*	*Sup. MLD*	*Sup. lpcd*	*Sup. hr/day*
Jan	*318*	*114.01*	*12*	*91.21*	*38.8*	*6.89*	*423*	*284.01*	*5*	*255.61*	*81.5*	*14.49*
Feb	*318*	*98.309*	*34*	*78.65*	*33.4*	*5.94*	*423*	*268.31*	*12*	*241.48*	*77.0*	*13.69*
Mar	*318*	*88.529*	*37*	*70.82*	*30.1*	*5.35*	*423*	*258.53*	*13*	*232.68*	*74.2*	*13.19*
Apr	*318*	*93.819*	*35*	*75.06*	*31.9*	*5.67*	*423*	*263.82*	*13*	*237.44*	*75.7*	*13.46*
May	*318*	*95.149*	*35*	*76.12*	*32.4*	*5.75*	*423*	*265.15*	*12*	*238.63*	*76.1*	*13.53*
Jun	*318*	*113.93*	*12*	*91.14*	*38.7*	*6.89*	*423*	*283.93*	*5*	*255.54*	*81.5*	*14.49*
Jul	*318*	*140.93*	*10*	*112.74*	*47.9*	*8.52*	*423*	*310.93*	*4*	*279.84*	*89.2*	*15.86*
Aug	*318*	*144.48*	*10*	*115.58*	*49.1*	*8.74*	*423*	*314.48*	*4*	*283.03*	*90.2*	*16.04*
Sep	*318*	*149.1*	*9*	*119.28*	*50.7*	*9.02*	*423*	*319.10*	*4*	*287.19*	*91.6*	*16.28*
Oct	*318*	*141.73*	*10*	*113.38*	*48.2*	*8.57*	*423*	*311.73*	*4*	*280.56*	*89.5*	*15.90*
Nov	*318*	*131.6*	*10*	*105.28*	*44.8*	*7.96*	*423*	*301.60*	*5*	*271.44*	*86.6*	*15.39*
Dec	*318*	*115.9*	*12*	*92.72*	*39.4*	*7.01*	*423*	*285.90*	*5*	*257.31*	*82.1*	*14.59*
Av	*318*	*119.0*	*19*	*95.2*	*40.4*	*7.2*	*423*	*289.0*	*7*	*260.1*	*82.9*	*14.7*

'GrWr' is groundwater contribution in total supply; 'sup.' is supply; 'hr/day' is hours per day ; 'MLD' is million-litres-a-day

Table 10.4 Pre- and post-Melamchi scenario on demand, production, supply, groundwater contribution and supply hour/day for 2019 and 2025

Year			**2019**				**2025**					
Permanent population			**3.3 million**				**4 million**					
Temporary population			**1 million**				**1.2 million**					
Month	*Demand MLD*	*Production MLD*	*GrWr %*	*Sup. MLD*	*Sup. lpcd*	*Sup. hr/day*	*Demand MLD*	*Production MLD*	*GrWr %*	*Sup. MLD*	*Sup. lpcd*	*Sup. hr/day*
Jan	*500*	*454.01*	*3*	*408.61*	*110.*	*19.63*	*605*	*624.01*	*2*	*561.61*	*125*	*22.29*
Feb	*500*	*438.31*	*8*	*394.48*	*107*	*18.95*	*605*	*608.31*	*5*	*547.48*	*122.*	*21.73*
Mar	*500*	*428.53*	*8*	*385.68*	*104*	*18.53*	*605*	*598.53*	*6*	*538.68*	*120*	*21.38*
Apr	*500*	*433.82*	*8*	*390.44*	*105*	*18.76*	*605*	*603.82*	*5*	*543.44*	*121*	*21.56*
May	*500*	*435.15*	*8*	*391.63*	*106*	*18.82*	*605*	*605.15*	*5*	*544.63*	*126*	*21.61*
Jun	*500*	*453.93*	*3*	*408.54*	*110*	*19.63*	*605*	*623.93*	*2*	*561.54*	*125*	*22.28*
Jul	*500*	*480.93*	*3*	*432.84*	*117*	*20.80*	*605*	*650.93*	*2*	*585.84*	*130*	*23.25*
Aug	*500*	*484.48*	*3*	*436.03*	*118*	*20.95*	*605*	*654.48*	*2*	*589.03*	*131*	*23.37*
Sep	*500*	*489.10*	*3*	*440.19*	*119*	*21.15*	*605*	*659.10*	*2*	*593.19*	*132*	*23.54*
Oct	*500*	*481.73*	*3*	*433.56*	*117*	*20.83*	*605*	*651.73*	*2*	*586.56*	*130*	*23.28*
Nov	*500*	*471.60*	*3*	*424.44*	*115*	*20.39*	*605*	*641.60*	*2*	*577.44*	*128*	*22.91*
Dec	*500*	*455.90*	*3*	*410.31*	*111*	*19.71*	*605*	*625.90*	*2*	*563.31*	*125*	*22.35*
Av	*500*	*459.0*	*4*	*413.1*	*112*	*19.9*	*605*	*629.0*	*3*	*566.1*	*126.0*	*22.5*

'GrWr' is groundwater contribution in total supply; 'sup.' is supply; 'hr/day' is hours per day ; 'MLD' is million-litres-a-day

prediction, the permanent population of the service area will be 2.8 million in 2016 (Table 10.3). Water demand after the first phase of MWSP completion, i.e. on 2016, is calculated as 423 MLD serving permanent population of 2.8 million and temporary population of 0.84 million (30% of permanent population) with 24 hour water supply of 135 lpcd. Average water production including additional 170 MLD would be 289 MLD. Groundwater would contribute only 7% in the total supply. The supply is calculated considering 10% transmission and treatment process loss and average supply as 260.1 MLD. The supply in lpcd is evaluated considering supply quantity for total effective population (both permanent and temporary), but only 40% of consumption rate is considered for temporary population. It shows an average of 82.9 lpcd serving the total population with 24 hour water supply. If the supply is managed with project demand of 135 lpcd, the average supply duration per day will be of 14.7 hours only.

Water demand, supply and groundwater contribution in total supply for current and post-Melamchi cases are shown in Figure 10.2. From the figure, it is clear that the MWSP will increase average water supply from 40 lpcd in 2011 to 126 lpcd in 2025. If supply system is managed with project demand of 135 lpcd, the

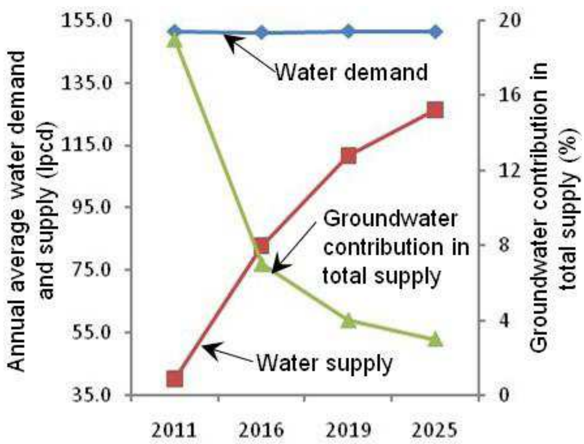

Figure 10.2 Increasing average supply and decreasing groundwater contribution in total supply with MWSP

average supply duration per day will also increase from 7 hour a day in 2011 to 23 hour a day in 2025. With increased water supply from surface sources, average groundwater contribution in total supply will decrease from 19% in 2011 to 3% in 2025. In addition to abstraction of groundwater for KUKL supply system, adequate and improved water supply by KUKL is expected to help reduce haphazard use of groundwater by general public, industries, public and private institutions, among others. It could ultimately help replenish the depleted groundwater levels.

10.5 SUMMARY AND CONCLUSIONS

KUKL is a major user of groundwater resources. This study analyzes water demand, supply and groundwater abstraction (by KUKL) in the Kathmandu Valley for pre- and post-Melamchi cases. Considering water supply scenario of 2011, average water supplied at the point of use will be 57 MLD taking 40% UfW (KUKL, 2011) and consumption rate of the supply is 24.3 lpcd. Average (of 12 months) groundwater contribution in total supply in 2011 is 19%. The supply duration/day is calculated as 4 hours if the demand is considered to be as 135 lpcd. But the supply duration is much less than calculated at present condition of KUKL water supply. Major possible reasons, which cause such differences from the actual conditions might be listed as: (1) inaccurate forecasting of served population; (2) absence of effective Management Information System (MIS) of water supply system; and (3) inaccurate estimating UfWs (transmission, treatment and distribution). Most of the huge deficit between water demand and supply is being met by extracting groundwater resources in one or other ways.

To address water scarcity in the Kathmandu Valley and reduce stress on groundwater resources for a long-term, a project, called as Melamchi Water Supply Project (MWSP), is underway. The MWSP is expected to bring water from Melamchi River in Indrawati basin to the Kathmandu Valley. After completion of the project in three stages, groundwater contribution in total KUKL supply is expected to be reduced to 7%, 4%, and 3% in 2016, 2019 and 2025, respectively. In addition, adequate and improved water supply by KUKL is expected to help reduce haphazard use of groundwater by other users too.

The MWSP alone, however, will not be sufficient for providing adequate water supply to cover the entire forecasted population to be served. In addition, due to limitation of KUKL's distribution networks and their capacity, it could be expected that groundwater use would probably be continued, if not increased. Therefore, some options for regaining depleted groundwater levels should be planned and implemented. Identification and protection of recharge areas, local as well as large scale, may help increase amount of groundwater recharge. Rapid drawdown of groundwater level could also be regained by controlling excessive extraction of deep as well as shallow groundwater providing alternate sources of water such as introducing rainwater harvesting techniques from micro (private) to macro (institutional) level, and water demand management.

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APPENDIX 10.1 Inventory of deep tubewells currently in operation within KUKL service area (Operation Division, KUKL)

Location	Type of pump installed	Head in m	Discharge in litre per minute	Power consumption	Average daily operation, hr
MANOHARA WELL FIELD					
MH - 2	*Submersible Pump*	*150*	*350*	*-*	*-*
MH - 7	*Submersible Pump*	*100*	*350*	*-*	*-*
MH - 3	*Submersible Pump*	*100*	*600*	*30 H.P.*	*18*
MH - 4	*Submersible Pump*	*100*	*1000*	*35 H.P.*	*18*
MH - 5	*Submersible Pump*	*100*	*1200*	*45 H.P.*	*20*
MH - 6	*Submersible Pump*	*110*	*600*	*30 H.P.*	*20*
GOKARNA WELL FIELD					
GK - 1	*Submersible Pump*	*90*	*1000*	*30 H.P.*	*15*
GK - 2	*Submersible Pump*	*100*	*800*	*30 H.P.*	*18*
GK - 3	*Submersible Pump*	*90*	*800*	*25 H.P.*	*20*
DHOBIKHOLA WELL FIELD					
DK - 3	*Submersible Pump*	*80*	*1000*	*40 H.P.*	*15*
DK - 4	*Submersible Pump*	*80*	*700*	*25 H.P.*	*18*
DK - 5	*Submersible Pump*	*70*	*500*	*20 H.P.*	*18*
BANESWOR AREA					
Koteswor Airport Well	*Submersible Pump*	*80*	*900*	*25 H.P.*	*15*
Sinamangal Well and Pump	*Submersible Pump*	*100*	*1200*		*15*
BANSBARI WELL FIELD					
BB - 0	*Submersible Pump*	*110*	*1300*	*50 H.P.*	*20*
BB - 1	*Submersible Pump*	*158*	*600*	*22.5 H.P.*	*20*
BB - 2	*Submersible Pump*	*90*	*900*	*40 H.P.*	*20*
BB - 3	*Submersible Pump*	*110*	*700*	*40 H.P.*	*20*
BB - 4	*Submersible Pump*	*90*	*700*	*25 H.P.*	*20*
BB - 5	*Submersible Pump*	*100*	*1000*	*41 H.P.*	*20*
BB - 6	*Submersible Pump*	*90*	*600*	*20 H.P.*	*20*
BB - 7	*Submersible Pump*	*110*	*1200*	*40 H.P.*	*20*
BB - 9	*Submersible Pump*	*60*	*300*	*12.5 H.P.*	*20*
Maharajgung Reservoir Site	*Submersible Pump*	*80*	*800*	*30 H.P.*	*22*
Bansbari Reservoir Site	*Submersible Pump*	*110*	*1300*	*50 H.P.*	*22*
Goangabu Samudayak	*Submersible Pump*	*105*	*1400*	*40 H.P.*	*20*
Goangabu Pig Farming	*Submersible Pump*	*110*	*1300*	*50 H.P.*	*18*
Baniyatar Height	*Submersible Pump*	*105*	*600*	*30 H.P.*	*20*
Baniyatar Well no.- 2	*Submersible Pump*	*90*	*800*	*25 H.P.*	*20*
Sangle Khola New Tubewell	*Submersible Pump*	*110*	*1000*	*40 H.P.*	*20*

MAHADEV KHOLA WELL FIELD					
MK - 1	*Submersible Pump*	*105*	*700*	*25 H.P.*	*18*
MK - 2	*Submersible Pump*	*105*	*350*	*20 H.P.*	*18*
Mk - 3	*Submersible Pump*	*105*	*1250*	*41 H.P.*	*20*
MK - 4	*Submersible Pump*	*110*	*1400*	*45 Kw*	*20*
MK - 5	*Submersible Pump*	*105*	*350*	*20 H.P.*	*20*
TRIPURESWOR AREA					
Kalimati KL - 1	*Submersible Pump*	*85*	*250*	*7.5 H.P.*	*-*
Kalanki KL - 2	*Submersible Pump*	*75*	*250*	*5 H.P.*	*18*
Kuleswor KL - 3	*Submersible Pump*	*70*	*400*	*15 H.P.*	*18*
Lagan Well KL – 4	*Submersible Pump*	*75*	*800*	*30 H.P.*	*18*
Tahachal Campus	*Submersible Pump*	*70*	*300*	*12.5 H.P.*	*18*
Tripureswor Office Site	*Submersible Pump*	*75*	*300*	*12 H.P.*	*18*
CHHETRAPATI AREA					
Sitapaila Well (Chhetrapati)	*Submersible Pump*	*85*	*160*	*3 H.P.*	*20*
Ratnapark Well	*Submersible Pump*	*85*	*600*	*15 Kw*	*18*
Kanya Mandir School Site	*Submersible Pump*	*95*	*1050*	*35 H.P.*	*18*
BHAKTAPUR WELL FIELD					
Bode Treatment Plant Well	*Submersible Pump*	*70*	*1100*	*26 Kw*	*22*
Bode Well BH - 2	*Submersible Pump*	*70*	*700*	*25 H.P.*	*22*
Bode Well BH - 3	*Submersible Pump*	*70*	*900*	*25 H.P.*	*22*
Bode Well BH - 4	*Submersible Pump*	*70*	*1000*	*35 H.P.*	*22*
Bode Dugwell Site	*Submersible Pump*	*70*	*800*	*20 H.P.*	*22*
Indra Kamal Well	*Submersible Pump*	*70*	*900*	*35 H.P.*	*20*
Lokanthali Well	*Submersible Pump*	*70*	*800*	*25 H.P.*	*18*
PHARPING WELL FIELD					
PH - 1	*Submersible Pump*	*70*	*1000*	*15 Kw*	*22*
PH - 2	*Submersible Pump*	*100*	*700*	*20 Kw*	*22*
Balkumari Well	*Submersible Pump*	*90*	*1000*	*25 H.P.*	*15*
Jwagal UN Park Well	*Submersible Pump*	*80*	*600*	*25 H.P.*	*15*

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

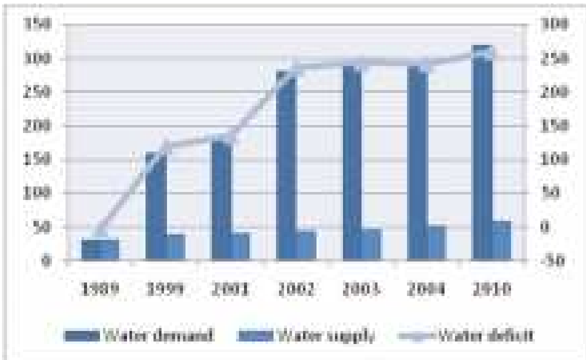
This chapter is based on the results and findings of the M.Sc. research carried out by the students of Interdisciplinary Water Resources Management.

Table 11.1 Historical overview of the institutional reforms of water distribution system in the valley (NGO Forum, 2008b)

Year	Water distribution institution	Objective
1929	*Pani Goshwara Established*	*Distribution of municipal water supply to individual houses*
1974	*Water Supply and Sewerage Board*	*Management of all the water system*
1987	*Water Supply and Sanitation Cooperation*	*Management of drinking water supply and sanitation*
1989	*Nepal Water Supply Corporation*	*Management of urban water in 14 urban centers (5 within the Kathmandu Valley and 9 outside the valley)*
2006	*Kathmandu Valley Water Supply Management Board*	*Preparation of the policy for the use of groundwater and recommend to the government for approval; regulation of the groundwater extraction and issue license*
2008	*Kathmandu Upatyaka Khanepani Limited*	*Supply good quality drinking water supply to the residents of the Kathmandu valley*

(from KUKL), with water demand of 320 MLD and production of 86 MLD in the dry season and 148 MLD in the wet season. This wide gap (shown in Figure 11.1) is being met either by shallow groundwater (mainly in the form of dug-wells and tubewells) or water from deeper aquifers - either drilled in their (individuals, industries, institutions, or hotels) own backyard or collected by some agencies and then supplied by tankers.

In the context of increasing water scarcity, groundwater markets are rapidly evolving in the valley. However, this is yet to be properly analyzed and documented. The objective of this paper is to shed light on the evolution of groundwater markets in the Kathmandu Valley by analyzing actors, status of the markets and regulations.



All the figures are in MLD

Figure 11.1 Water demand, supply and deficit in the the Kathmandu Valley (prepared with data from Gyawali (1988), NWSC (2004), KUKL (2009; 2010))

11.2 EVOLUTION OF WATER MARKETS

Table 11.2 Evolution of water markets in the Kathmandu Valley

Modes of water supply as identified by ADB	In 2009/11[2]	In 2000/02
(i) customers having to collect water from the provider's source	*Water vendors buy the water from the water tanker suppliers in bulk (in 5,000-7,000 litres) and sell it in small amount (determined by the size of the vessel that consumers bring with them to buy water) varying from 1 to 100 litres.*	*There is no record of such market activities in 2000/02*
(ii) transporting water to customers' homes	*Water tanker trucks are very prominent mode of operation. They have grown rapidly in numbers. Water tanker buys or collects water from the source point and delivers it directly to consumers' home in bulk quantity. Besides, the tanker operators also sell water in small quantities of 100 to 300 litres to large number of consumers' at a locality.*	*The water tanker operation was already in existence in Kathmandu in 1987/88. It was in significant amount in 2000/02. Even the water tanker operators have formed their association in 2000[1]. This mode of supply has been very recent innovation in Kathmandu. So, there were no such activities in the 2000/02*

	Besides tanker operation, water vendor uses small tractors to carry water in 1,000 litres plastic tanks and sell it to the consumers. A water vendor has even built a metallic cylindrical body as tanker truck to carry water. This mode is effective in the urban core where the streets are narrower for tanker trucks to pass.	
(iii) piping water to customers' homes	*Piping water to customers' homes is rare in Kathmandu but is in existence. In areas as Tamshipakha, Purano Naikap VDC, Kapan Jordhara, water vendors or water well owners sell water by supplying through pipes and charge it on an hourly basis.*	*There were no such activities in 2000/02*
(iv) treating and selling water in bottles or barrels.	*Selling packaged drinking water bottles of 1 litre and jars of 20 litres has an important role in meeting the drinking water needs of people of Kathmandu. It has grown with time. Water vendors (or distributors) even deliver the water jar at homes.*	*Such mode was already in existence in the mid 1980s till now*

[1]Gyawali (1988) and Moench (2001); 2 Field study (2009/11)

Thompson's cultural theory (2003) portrays that water is considered as a private commodity and it is taken as an opportunity to derive market benefits by pricing value of water as per one of the perspectives, i.e. market individualistic. Water scarcity has therefore led different agencies at individual, community and industrial levels to pump groundwater as the most suitable alternative to meet the water demand and derive the economic benefits through piped water.

In Kathmandu, evolution of water market mechanisms started during 1987-1988, which expanded in the following years. The period after 1990 witnessed rapid growth in the market solution to water services in the valley, which was the beginning of immigration to the urban centers. These market solutions involve different volume of water transactions and serve different cliental groups catering their differential needs. These include the simplest form of selling bucket of water to the consumer to more complex services such as processing and distributing water in sealed bottles.

Water market has been evolving rapidly in the Kathmandu Valley in the past decade (Table 11.2). With the involvement of differential actors, these markets are functioning at different scales ranging from individual, community, commercial level and up to the industrial level. Increasing gap between water supply and demand (Figure 11.1), the limitedness of the water supply agency (KUKL) and other traditional sources to meet water needs in quality and quantity and exploration of the immense economic opportunities that has remained latent until the last decade in the context of rapid urbanization are reasons behind the emergence of the water-market. These water markets are heavily based on groundwater extraction except a few which are based on surface water as their source. Along with the evolution of market mechanisms in water services, community institutions have also started to evolve in many parts of the valley in developing community based water supply systems.

11.3 OPERATION LEVELS OF THE WATER MARKETS

The conventional system of meeting water requirement of the people in the valley has been intervened by market mechanisms. Water market that has evolved is very dynamic with high flexibility of addressing specific water demand at a given location and at a given time, with the only constraint being ability to pay for the water by the people. Water market has ability to address water need in quantity from very low water demand (as much as of 1 litre) to very high water demand (as much as 12,000 litres/day). Therefore, water market has grown very rapidly in the valley at different operational levels which are discussed below.

11.3.1 Individual level

Water market functioning at an individual level largely relies on tanker water supply; however, trends have begun wherein individual people owning shallow or deep well sell water at a nominal price. The main crux of this operation is that groundwater is being extracted to address the water scarcity. This form of market has commenced just recently and is triggered by water scarcity. However, it has multiplied across several wards of tne Kathmandu Metropolis, which is now growing rapidly due to economic opportunity provided by the market. The water market operation at the individual level are mainly concentrated in the city cores of the valley like Nardevi, Tamsipakha Dhalko, Khusibu, Dhobichaur, Bhurungkhel, Yetkha, Dhokatole, Ason, Kankeshwori, Hyumat, Chalkhu, Tripureshwor, Ombahal and Ganabahal as identified by Shrestha (2011) while few are also found at other wards of the metropolis. In the core wards and western wards of metropolis only, there are 62 water vendors (Shrestha, 2011). The key water source of the inhabitants of these areas is municipal water supply through KUKL. However, the supply is intermittent and therefore inadequate to meet the water needs of the people. Traditional houses in the city cores lack underground storage tanks for huge amount of water delivered by the water tankers. In this context of water scarcity, water vendors have emerged in the city. Water vendors buy water in huge quantities from water tanker suppliers, store it in reservoir tanks (generally 2,000 to 5,000 litres plastic tanks) and sell to local inhabitants in jars or water bottles or metal barrels (*gagris)* charging a nominal amount i.e. NRs. 8/20 litres on an average.

The market turns out to be more visible and prominent during the dry season as the municipal water supply becomes almost negligible. Although unregistered and unrecognized, this sort of water market has flexibility in addressing water needs of the people under water scarce condition and reduce their hardships and drudgery.

11.3.2 Community level

As stated earlier, the water market also appears significantly at the community level, which is largely concentrated in the core areas of Lalitpur Sub-Metropolitan City. The city is famous for the traditional water conveyance systems which were established in such a way that people were served water, both in quality and quantity, all round the year; however, they are falling in serious despair in recent times. These collective actions are essentially based on reviving the traditional water systems and building institutional mechanisms for the maintenance and upkeeping of the system and distributing water among the beneficiaries. Community investments are also observed in the development of new systems.

At present, community people are in the process of either reviving the traditional sources or are extracting groundwater from shallow or deep wells and distributing it to the locals in a systematic way. This has now given rise to groundwater market at different parts of the Kathmandu Valley with more than 21 such community water supply systems functioning at Patan (field visit, 2010) along with a few others in the inner cores of Kathmandu metropolis as well.

In areas of Patan such as Kwelachhi, Bhinyolachhi, Chyasal, Bhelachhi, Dhapagal, Tangal, Chabal, Ibahal, Agnishala, Purnachandi and Bhubahal, community people pump groundwater from dugwells with or without installation of filtration system. The filtration systems generally found are Iron Removal Plant (IRP), bio-sand filter and pressure filter. Community people then store water in underground tanks or plastic reservoir tanks of 5,000 litres to 10,000 litres capacity. In several such systems, chlorination is done. They sell water to the local inhabitants in small amounts ranging from 2 to 20 litres. Unlike these systems, people of Ikhachhen community have initiated the conservation of the *Alko hiti* (stone spout) in such a way that they utilize water from stone spouts and distribute in a systematic way through pipelines. Group of households are provided with water distribution points and the households connect private pipe to those points to fetch water. Alongside with this system, in Subahal community, there is deep-well groundwater extraction and its trade. Apart from these markets, there is another form of community level market, where water is sold to community people via tanker from the outskirts of the Kathmandu Valley, which is similar to that of individual level market. The community people or groups of people buy tanker water and reserve it in a reservoir. Then, reserved water is distributed to the consumers at a nominal cost. Such water transaction is seen in Haugal, Lukhusi and Bhelachhi community of Patan.

For the operation and maintenance, a users' committee is formed, which collects money from the consumers and manages the entire system. The users committee charge NRs. 1 to 2 for unfiltered water and 3 to 5 for 20 litres of filtered water. However, in *Alko hiti*, consumers pay water tariff on monthly basis. As a partial solution to water supply, such markets are expanding in Patan area and consumers are satisfied with the service provided by the markets. These community systems offer alternatives to developing decentralized water systems that would lessen the burden on the formal water utilities.

11.3.3 Commercial level

Water markets in the commercial level are operated by water tankers. Their mechanisms, volume of market and price-related issues are discussed hereunder[1].

Locations and mechanisms of water extraction: Water market that has evolved, in the context of private water-tanker suppliers, is heavily based on the groundwater. Private water tanker suppliers (operators) have played a major role in fulfilling the water demand of Kathmandu via market mechanisms. Basic nature of this water market is that water is transferred from the rural-urban areas adjacent to the core of urban region to the urban area. The water sources in the water extraction location are mostly groundwater extracted either from shallow or deep aquifers and only few places have surface water sources (Figure 11.2). Prominent and popular areas are Chobar (nearby old cement factory and lake called Taudaha), Matatirtha VDC (Village Development Committee), Jorpati VDC and Balaju (nearby Ganga Cinema Hall). Besides, other locations include Manamaiju VDC, Sitapaila, Thulo Bharyang, Gongabu Buspark, Kapan (nearby Bishnumati River), Mulpani VDC (Thali), Gothatar (Kadha Ghari) and Baikhu. There are water extractors in Ramkot, Thankot and Hattigauda areas. In addition, there are other unidentified locations scattered in small pockets within the valley from where private tankers acquire water. Water extractors except at Chobar extract groundwater (though one extractor at Chobar uses deep boring system).

In Matatirtha, there are spring sources and dug-wells. At other locations, water extraction is done using shallow or deep borings. Water extractions from certain places as Godavari *kunda*, Dhapasi, Ichangu Narayan VDCs have been prohibited owing to resistance from the local people.

At the surface water sources, water extractors use simple intake structures made of stones. For dug-wells, they pump water directly from the wells. The depth of the dug-wells ranges from 6 to 16 metres. In addition, for boring mechanisms, they bore 4 or 6 inches pipes and pump water. In the places like Jorpati and Mananaiju VDCs, there are shallow borings with depth ranging from 9 to 45 metres. At locations as Balaju, Sano Bharyang, Gongabu Buspark water is extracted using deep boring installations with depth more than 200 metres. Water extractors use simple water treatment facilities at different locations. The water-treatment includes aeration, sedimentation and filtration (generally pressurized sand filters). Some extractors use bleaching powders and *fitkiri* for chlorination.

[1] *These results are based on the M.Sc. Thesis on 'State and Services of Private Water Tanker Operation in Kathmandu" by Dibesh Shrestha, Interdisciplinary Water Resources Management, Nepal Engineering College-Centre for Post-graduate Studies (nec-CPS).*

In some locations, as Baikhu or dugwells in Matatirtha, the water is pumped directly into the tanker trucks for delivery.

Water extraction at different locations and groundwater extraction by private water tankers: Figure 11.2 shows the volume of water extraction by private water tankers at different locations of the valley. It was observed that total volume of water extractions in the mentioned locations (in Figure 11.2) was 12.58 MLD in peak season and 6.36 MLD in off-peak season. The water extraction in off-peak season drops to half of the volume of water extraction in peak-season. Besides, with few exceptions (e.g., in Chobar), all of the extracted water comes from groundwater and spring sources. In those locations, it was observed that more than 90% of water is extracted from groundwater. Extending this value to the Kathmandu Valley, it is estimated that 23 MLD of water is extracted in peak season and 13.8 MLD in off-peak season, with annual extraction of 6.35 MCM of groundwater. This volume of groundwater extraction by the tanker operators is significantly large when compared with the total annual groundwater withdrawal and the safe yield of groundwater in the valley; 14.6 million m^3/year by Binnie and Partners (1988), 15 MLD by JICA (1990), 4.61 million m^3/year by Gautam and Rao (1991). Additionally, Stanley International (1994) has estimated sustainable groundwater withdrawal as 26.3 MLD. On the contrary, the rate of groundwater extraction in the valley has been estimated to be about 58.6 MLD (Metcalf and Eddy, 2000 cited in ICIMOD, 2007). This extraction adds up to the existing groundwater overdraft from other different entities and has the potential to reinforce the impacts of groundwater overdraft.

Volume of water supplied by private water tankers: The summer season (February to June) in the area with rise in temperature and low amount of rainfall, is marked by a high demand of water supply from the water tanker trucks. This is the peak season for the tanker-based water market. In the remaining months, from June to January (monsoon and winter), there is comparatively low water demand and this is the off-season. Different sizes of the water-tanker trucks were observed to be operating in the valley: 5,000,

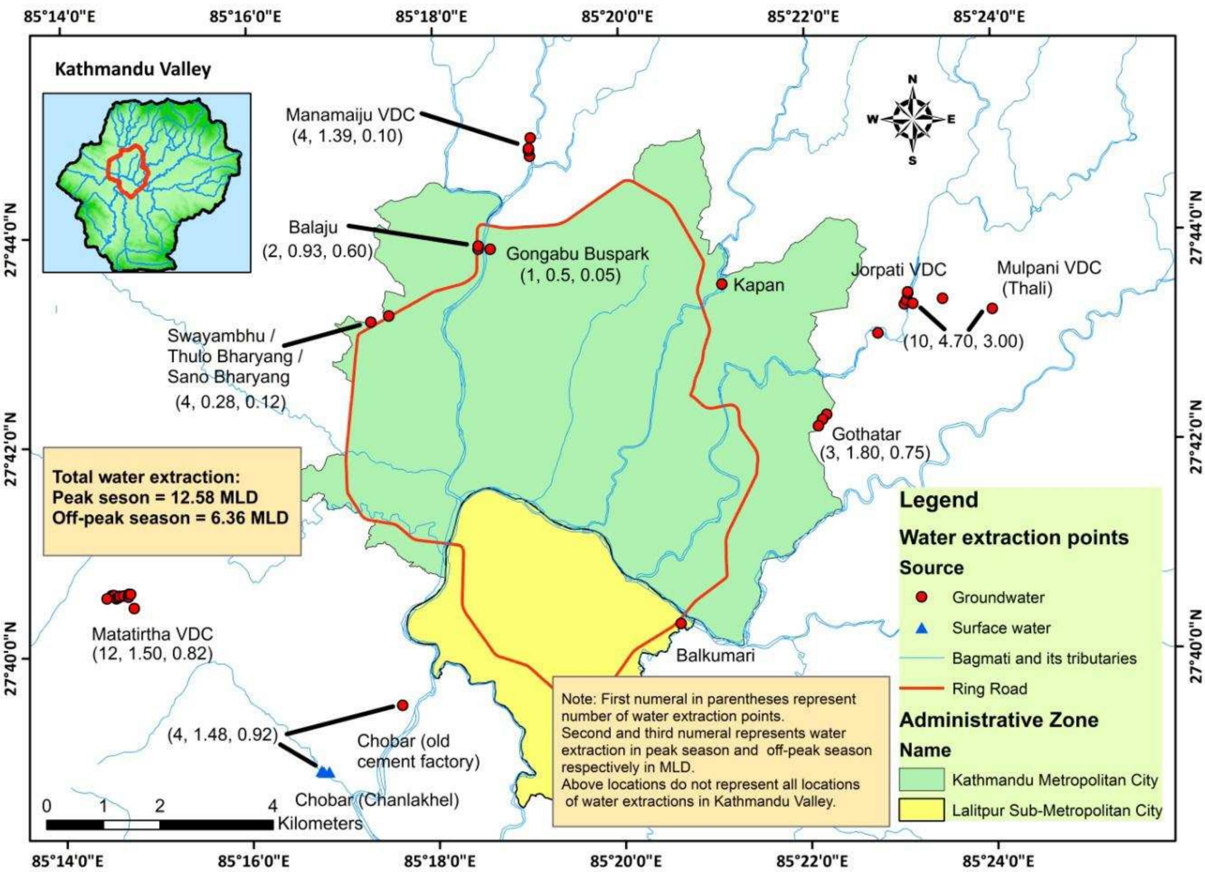


Figure 11.2 Volume of water extractions at different locations in the Kathmandu Valley (data from field study, 2010)

6,000 and 7,000 litres (small tanker trucks) and 10,000 and 12,000 litres (large tanker trucks). The proportion of a number of trips by small tankers to that of large tankers in peak season was observed about 63%:37% and that in off-season is about 56%:44%. Using this proportion, the average carrying capacities of a tanker truck in peak and off-peak season were estimated to be 8,220 and 8,610 litres, respectively. From field study, it was observed that the average trips made by a tanker per day in peak and off-peak season were 4.15 and 2.38, respectively. Functionaries of the tankers' association estimates about 700 to 800 tankers operate in the valley. Using 750 numbers of tankers for estimation, it was estimated that the total water supply by water tanker trucks in peak (dry) season was 25.58 MLD and 15.36 MLD in off-peak season, which is 7.06 MCM of water annually. It is clear that the private water tanker suppliers contribute to fulfill 8% and 4.8% of the total water demand of 320 MLD in peak (dry) season and off-peak seasons respectively.

Price paid by the consumers to water tanker supplies: Price is another important factor of the operation of the water market. Price charged to the consumers by the suppliers are dependent on the size of the tanker trucks (quantity), cost they incur, distance between the source and destination and the consumers' attributes (regular or periodic, large water consumer or small, personal relation with supplier). The range of price paid by the consumers for small tankers, i.e. 5,000 to 9,000 litres, varied from NRs. 900 to 1,800, with mean values of NRs. 1,254. Likewise, for the tankers of 6,000 and 7,000 litres capacity, the mean price was NRs. 1,300 (NRs. 203 per m^3) and the median value of NRs. 1300. Similarly, for large tankers of 12,000 litres capacity, the price ranged from NRs. 1,300 to 2,500, with the mean value of NRs. 1,811 (NRs. 151 per m^3) and median value NRs. 1,800.

11.3.4 A comparison among different operational levels

Different operational levels of water market have distinct features that differentiate or make similarities among them. These characteristics are discussed in Table 11.3.

11.3.5 Other forms of water markets

Other forms of the water markets include the one in which water vendors sell water directly to households in 500 or 1,000 litres plastic tanks. They transport water in vehicles like small tractors and unload water through pump in consumers' storage unit. In such a case, price charged to the consumer is about NRs. 600 for 1,000 litres. Such a market is common in Bhaktapur district, core areas of Lalitpur and areas as Dallu, Swayambhu, Tamsipakha in Kathmandu. Likewise, in Kalimati private tanker water suppliers also sell water directly to consumers but in small amounts as 100 or 20 or 10 litres. They charge approximately NRs. 40 for filling a 100 litres plastic vessel.

Table 11.3 Comparison of different operational levels of water markets

Aspects	Individual level (profit-based operation)	Community level (service-based operation)	Commercial level (profit-based operation)
Zone of operation	*Not specific zone but such market exists where water supply from other sources is minimal*	*These also operate in the zone of water scarcity, however, they are confined to boundary of the community*	*Zone of water extraction is defined but that of water distribution is not. The latter is scattered and operates under water demand*
Target groups	*Households in populated areas*	*Community households.*	*Consumers can be any social entity from small household to large extensive water consuming institutes as hospitals or hotels.*
Storage unit by consumers	*Consumers buy water in small vessels as buckets, gagris or water jars. (1, 20, 100 or even 1,000 litres)*	*Consumers buy water in small vessels as buckets, gagris or water jars. (1 litres to 100 litres)*	*Consumers store water in underground reservoirs (capacity: >5,000 litres)*

Price of water to the consumers	*Varies from NRs. 400 to 600 per 1,000 litres*	*Varies from NRs. 50 to 1,000 per 1,000 litres for unfiltered water; and from NRs. 150-250 per 1,000 litres for filtered water*	*Varies from NRs. 151 to 203 per 1,000 litres*
Investment level by water vendors/ entrepreneurs	*Low*	*Medium*	*High*
Investment level by consumers	*Low*	*Low*	*High*
Technological level	*Simple technology of water storage and pumping*	*Units of water extraction and filtration*	*Extensive water-extraction installations as deep boring, filtration units, and tanker units for transportation*

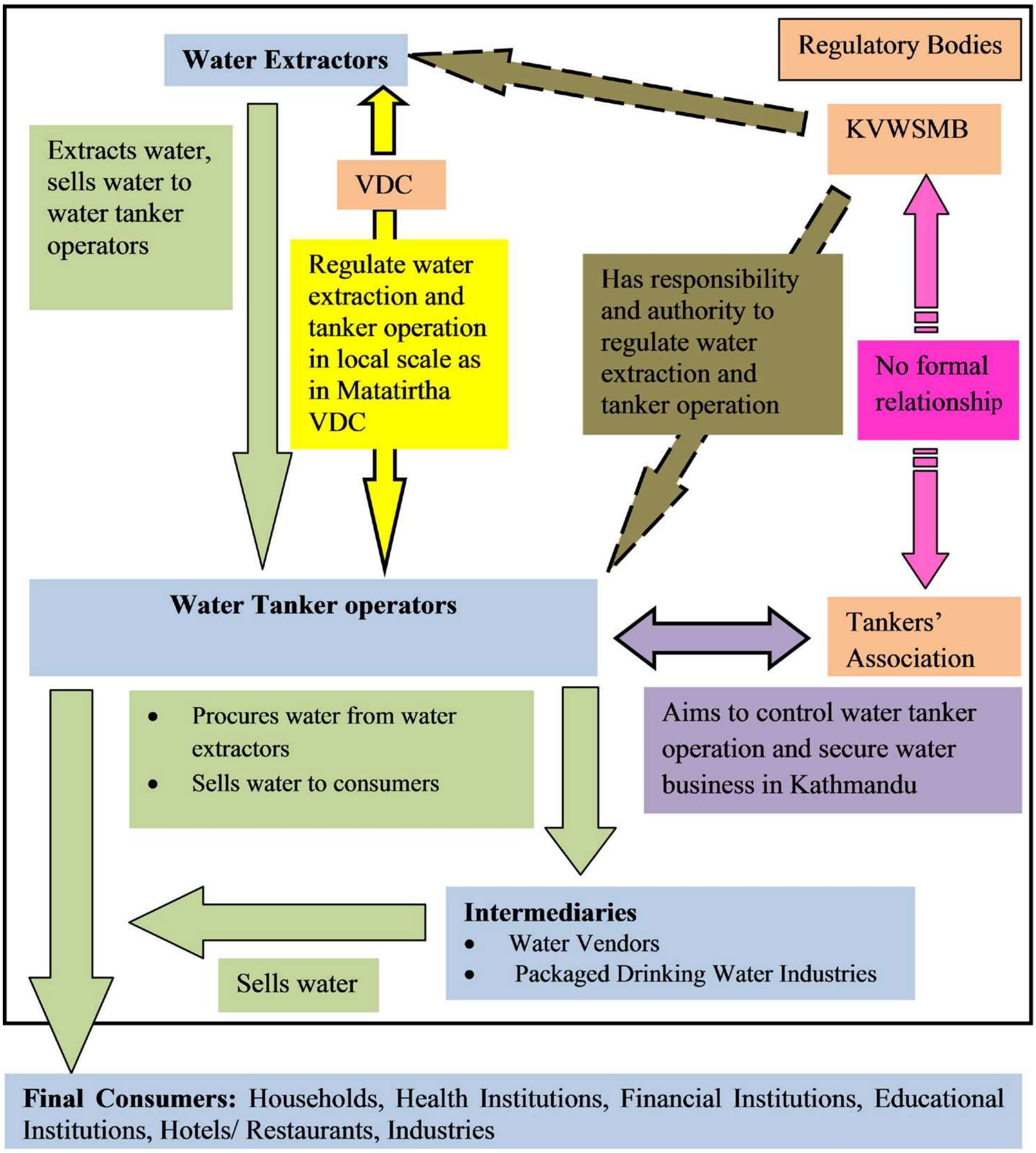


Figure 11.3 Actors involved in individual and commercial water markets

11.4 WATER SUPPLY CHAIN IN WATER-MARKETS AND ACTORS INVOLVED

Every operational level of water market forms a chain of water supply from water sources to the consumers. This supply chain involves many actors that have direct or indirect stake in water market operation, which differ according to the operation scale of water market, basically, into distinct parts: supply chain for the commercial operational level and supply chain for the community level. The former one also incorporates water market with the individual operational level. These two different types of supply chains are discussed in following sections.

11.4.1 Supply chain for commercial level (including individual level)

Commercial level of water market is in the form of private water tanker operation. This supply chain, as illustrated in Figure 11.3, essentially involves different actors with different roles. The first link of water supply chain is well owners that either make investment by themselves for extraction of water or lease out the source for extraction. Water extractors invest on developing physical plants for water extraction. Water extraction may be from the surface or groundwater sources. Major investments are in developing wells and water filtration and treatment systems. They sell water to the water tanker operators. Water tanker operators are the transporters of water and tanker trucks are transporting units. They buy water from the well extractors and sell it to the consumers. They provide door to door vending service. Consumers are the water buyers to fulfill their water needs. There are two types of consumers; intermediaries who buy water to sell and direct consumers who buy water for meeting their water need (other than selling). Water vendors and packaged drinking water industries are intermediaries. Households, hospitals, educational institutes, industries are direct/final consumers. Water vendors, which are the intermediaries, buy water from the tankers and then sell it to the final consumers. In doing so, it forms its own chain that becomes a part of the overall supply chain of water tanker operation. In this case, when water vendors extract water from their own wells, then its supply chain exist as independent chain and not as part of supply chain of water tanker operation. The above chain is only applicable for the industrial and individual levels.

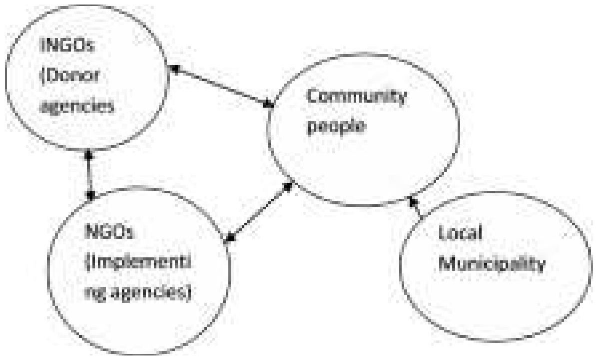


Figure 11.4 Actors involved in community water supply system

11.4.2 Supply chain for community level

Involvement of the actors in the community level water supply system (Figure 11.4) is different from that involved in the commercial level. Here, either the community or the donor agencies gather all the necessary financial requirements of the system. In some cases, municipality can also provide some financial support for the implementation of the system as seen in Chyasal water supply system at Patan. The implementing agencies identify the potential location for the water extraction in consultation with the local community people. Besides these direct actors, there are regulatory actors involved directly or indirectly in water tanker operation. Valley Drinking Water Entrepreneurs' Association is a professional body of water tanker operators that promotes and secures water tanker business in Kathmandu. Kathmandu Valley Water Supply Management Board (KVWSMB) is the responsible body for regulating the different aspects related to water market as water extraction, water selling licensing, water pricing and water quality assurance. Besides, VDCs, as in Matatirtha VDC, are also involved in regulation at local scale. Other indirect bodies include Department of Cottage and Small Industries where water tanker companies get registered as a 'company', and Department of Transportation Management to which water tanker operators pay transportation taxes and charges.

11.5 REGULATION OF WATER MARKETS

11.5.1 Current state of water market regulation

Water market mechanisms are growing and playing a significant role in meeting the water needs of the valley. However, the whole market mechanisms are unregulated. They exist as independent private water providers with no co-ordination with the concerned authority, and as such there are no interactions among themselves; in brief, they are fragmented. Despite this overall scenario of the water markets, water tanker operators of Kathmandu and Lalitpur districts have formed an association in order to bring water tanker operation into self-regulation. The association was established in 2000 with objectives of promoting and securing the water tanker operation and business resulting from it and raising the united voice in support of or against any external interventions. Currently, it is known as Valley Drinking Water Tanker Entrepreneurs' Association (VDWEA) *(Upatyaka Khanepani Tanker Byabasai Sangh)*. As of May 2011, it has 216 registered entrepreneurs with 370 water tanker trucks. The association has sub-committees in major water extraction locations which aim to regulate and promote the tanker operation in their respective locations. Along with this self-controlling body of water tanker operators, there is regulation of water tanker operation by local authority. This type of regulation can be observed in case of Matatirtha VDC, where there have been agreements between the local people, water entrepreneurs and VDC to regulate different aspects of water business. Major features of this agreement are that there is prohibition in deep boring water extraction and VDC levy taxes on use of water sources and water tanker trucks. At the local operation level of water market, the water entrepreneurs work independently with competition among themselves. There is no professional group of these entrepreneurs unlike the group of water tanker operations. At the community level, communities themselves are owners and regulators.

If the holistic dynamics of water market mechanism is to be observed, then there is no recognition of water market mechanisms by the authority or government as water service providers. Despite the profit-oriented nature, they have been providing water services to the people. As such, they are water service providers like KUKL. However, these water service providers are recognized in or as other sectors, for instance, water tanker operators are registered in the Department of Cottage and Small Industries as companies and that they are better recognized as transportation units and pay taxes to the Department of Transportation Management. Besides, local operational level of market exists as a common business. In this case, both the concerned authorities and the common people have disregarded the role of such local water business in easing out the water supply to people of the urban core.

11.5.2 Different aspects of water markets for regulation

As already discussed, water entrepreneurs are providing water services to the people. This incorporates two basic elements: business element (commercial aspect) and service element. According to the Water Resources Act (1992), license is necessary to use water for commercial purposes. Hence, at the first, permission to use water for commercial purpose should be taken by entrepreneurs of all operation levels. Besides, it was observed that the markets are basically dependent on the groundwater resources and currently, water extractors are extracting water from shallow and deep aquifers only at the cost of obtaining water without any kind of regulation. Hence, an important area of regulation can be on extraction of groundwater. Besides, the water supplied by the water entrepreneurs must comply with the national standard for drinking water. As there are no information on quality of water supplied by the entrepreneurs, it is necessary to monitor the quality of water supplied by the water markets to ensure right of the people for safe drinking water. Along with the water quality, price charged by the water entrepreneur to the consumers is also a very important aspect that needs to be regulated. Price should be according to water usage, quality and quantity of water to be supplied.

11.5.3 Regulatory bodies of water markets

Though the water markets are not regulated at present, there are regulating mechanisms and bodies that have the potential to regulate the different aspects of the water markets. In case of the water supply within the Kathmandu Valley, the authority of regulating water supply is handed to KVWSMB under the KVWMSB Act (2006). Hence, it is a primary duty of the board to regulate various aspects of the water market mechanisms. KVWSMB has also initiated licensing procedure to extract groundwater. However, it has not given recognition to water tanker operation or small water vending as water service provider. Besides, Groundwater Resources Development Board (GWRDB) and KVWSMB are responsible bodies for incorporating regulatory instruments for extraction of groundwater into the groundwater policy. In addition, Department of Food Technology and Quality Control (DFTQC) holds the authority to monitor water quality of packaged drinking water. Its jurisdiction can also be extended to monitor water quality provided by different levels of the water market mechanism. At the local scale, Local Self-Governance Act (1999) provides the local authorities to regulate water sources as it has been done in Matatirtha VDC. Therefore, there are regulatory bodies and mechanisms to regulate the water markets; only the need is to realize the responsibility, express commitment and implement that to improve the overall water supply situation in the valley.

11.6 CONCLUDING REMARKS

Water markets through water tankers, though insignificant, were already into existence since the 1980s. The significant contribution of water tanker in fulfilling the water need of the valley was visible after the utility was incapable to meet the increasing needs of the valley. In the context of growing water scarcity, water markets are evolving and rapidly growing. Because of that, the traditional sources that were once ignored because of convenience and pride of having potable water supply at the doorsteps of the denizens of the Kathmandu Valley, were revived after the concerned government agency fell short to meet the increasing demand in the valley. Conservation and management of the sources is currently being done by the communities through formation of users' committees.

Water entrepreneurs are providing water services to the people with that two basic elements: one is the business (commercial aspect) and the other is the service. Regulatory mechanisms and regulatory bodies also do exist. However, the regulatory body - KVWSMB - has not formally recognized the water tanker and water vending as water service providers. Even though KVWSMB has not imposed any regulations on the water markets, some forms of self-regulations do exist, for example, self-regulation of water tankers services by Valley Drinking Water Entrepreneurs Association (established in 2000), regulations of operation and management at the community level water markets by forming water users' association, and arrangements by VDC for collecting certain charges for the water to regulate different aspects of water business. Nevertheless, these markets are amplifying groundwater extraction as there is no institutional practice either to regulate or at least systematize the market. Groundwater is being extracted haphazardly wherever the water supply is inadequate. Although, community level groundwater markets are based on shallow groundwater extraction, different mechanisms for groundwater recharge need to be promoted and practiced so as to maintain the sustainability of the groundwater resource. For that, overall information on groundwater resources (e.g., updated well inventory, daily groundwater extraction amount, etc.), which are currently limited, should be maintained. As the existing water markets are serving as water service providers, they should be brought under regulation with necessary actions and commitments to improve the overall water supply of the valley.

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SECTION V
INSTITUTIONS AND POLICIES

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 developments and initiatives taken by different government and private organizations.

12.2 FORMAL INSTITUTIONAL MECHANISMS

Several ministries and agencies are mandated for the groundwater development and management in Nepal. They have been assigned with sectoral functions related to water resources under various Acts. Besides ministries, planning and coordinating functions have also been given to a number of institutions at various levels. These institutions are involved in planning, ensuring co-ordination among the government and related stakeholders, policy formulation, their implementation and operation, maintenance and management of water resources. Some of the governmental agencies of Nepal and their year of establishment and groundwater related functions are described in Table 12.1.

12.2.1 Institutions at policy level

The governmental institutions that are responsible for development and management of groundwater resources at the policy levels include Ministry of Physical Planning and Works (MoPPW), Ministry of Environment (MoE), Ministry of Irrigation (MoIr), Ministry of Energy (MoEn), Ministry of Industry (MoI), and Ministry of Science and Technology

Table 12.1 Summary of pre-existing institutional arrangements related to groundwater development and management in Nepal

Government agency	Year of establishment	Groundwater related functions
1. **Ministry of Irrigation (MoIr)** *(formerly Ministry of Water Resources)* a. *Groundwater Resources Development Board (GRDB)* b. *Department of Irrigation*	*1976*	• *Responsible for the development and management of surface and groundwater resources* • *Oversees policy related to groundwater* • *Implementing body of groundwater resources development* • *Development of groundwater for irrigation*
2. **Ministry of Physical Planning & Works (MoPPW)**	*2000*	• *Providing adequate, locally sustainable water supply and sanitation facilities for improvement of personal, household and community hygiene behavior for Nepalese people emphasizing on lower income group* • *Drinking water supply (surface and groundwater), operation and management in areas outside the coverage of KUKL* • *Monitor the quality of service provided by the operator* • *Prepare policies for the use of groundwater and recommend to the government for approval* • *Regulate the groundwater extraction and issue license* • *Undertaking and managing the water supply and sanitation system including wastewater services of the valley under a license and lease agreement with the KVWSMB for 30 years* • *Providing quantitative, qualitative and reliable service to the consumers of the Valley*
a. *Department of Water Supply and Sewerage (DWSS)*	*1972*	
b. *Kathmandu Valley Water Supply Management Board (KVWSMB)*	*2006*	
c. *Kathmandu Upatyaka Khanepani Limited (KUKL)*	*2007*	
3. **Ministry of Industry (MoI)**	**2008**	• *Conducting geological surveys and maintaining databases*
a. *Department of Mines and Geology (DMG)*	*1977*	
4. **Ministry of Environment (MoE)**	*1995*	• *Groundwater quality protection*
a. *Department of Hydrology and Meteorology (DHM)*	*1988*	• *Collecting, storing, managing and releasing climate data*

5. **Ministry of Energy** a. *Water and Energy Commission Secretariat (WECS)*	*2009* *1975*	• *Formulation policies and strategies for the water resources and energy sector* • *Rendering opinion, advice and recommendations on bilateral and multilateral issues relating to water resources and energy* • *Providing assistance to the concerned ministries in formulating policies included in the perspective/ periodic plan relating to the water resources and energy sector*
6. **District Water Resource Committee** a. *Water User's Associations* b. *Farmers Managed Irrigation System*	*1998*	• *Issuing licenses for the use of water resources (including groundwater)*

(MoST). Though these institutions work separately under their individual thematic areas, many of their activities are seen to be overlapping. For example, the MoPPW is responsible for increasing access to water supply and better sanitation facilities, whereas MoE has the responsibility of environmental conservation, pollution prevention and control and conservation of national heritage. Similarly, MoI has the role of utilization and management of overall water resources including groundwater resources and MoST coordinates all the bodies performing different activities related to science and technology. Therefore, in one way or the other, groundwater falls under their jurisdiction either for its use, development, conservation or management. Similarly, MoI and some other ministries listed above are performing preliminary studies and research on groundwater sector and many of them conclude with bilateral and multilateral dialogues and agreements to develop and manage the resources. Similarly, many of them are provided assistance from international donor agencies in order to have proper coordination among them and avoid duplication of work. However, due to overlapping responsibilities, available financial resources for conservation of groundwater resources are probably underutilized. Some overlapping areas at the policy level include;

- Formulating and implementing short-term and long-term programs at the national level and coordinate among the programs, to meet people's demand for potable water.
- Assessing the adverse impacts on the environment from implementation of water resources projects and recommending suitable mitigation measures.
- Identification of new technology through the development and promotion of research activities in the field.

12.2.2 Institutions at implementation level

Many departments and boards formulated and working under the ministries implement the policies, acts and regulations for the development and management of water resources. Some of the implementing institutions and their major objectives related to groundwater management are:

- **Department of Hydrology and Meteorology:** to collect hydrological and meteorological information and monitor the water quality.
- **Department of Mines and Geology:** to conduct engineering and environmental geological mapping and hazard assessment including infrastructure development, mitigation and protection of the environment.
- **Department of Irrigation:** to plan, develop, maintain, and manage small and large scale surface and groundwater irrigation schemes to increase agricultural productivity.

- **Department of Water Supply and Sewerage:** to assure improved health status by providing adequate quality and sufficient volume of drinking water from available sources including groundwater.
- **Groundwater Resources Development Board:** to enhance groundwater study and investigation and also manage the resources qualitatively as well as quantitatively.
- **Kathmandu Valley Water Supply Management Board:** to manage groundwater extraction and license issues.
- **Kathmandu Upatyaka Khanepani Limited:** to undertake and manage water supply, sanitation and wastewater services under license and lease agreement.
- **Rural Water Supply and Sanitation Fund Board:** to promote sustainable and cost effective rural water supply and sanitation services.

However, there is lack of coordination among these institutions too, which results in the overlapping roles and responsibilities often leading to confusion in the regulation of the available water resources.

12.2.3 Institutions at co-ordination level

Some institutions that co-ordinate with the formulating and implementing agencies like ministries and departments include National Development Council, National Planning Commission, Water and Energy Commission Secretariat, and National Water Resources Development Council. Coordinating activities performed by these institutions are listed below:

- **National Development Council:** to provide directives to the National Planning Commission on issues of national importance based on various studies and research.
- **National Planning Commission:** to monitor and evaluate the development plans, policies and programs by allocating, exploring and implementing those policies, especially to develop physical infrastructure for irrigation, drinking water and sanitation.
- **National Water Resources Development Council:** to decide on national water resources policy with a view to maximizing benefits and monitoring and evaluation of the development projects related to water resources.
- **Water and Energy Commission Secretariat:** to undertake water resources policy and planning and development of irrigation, hydropower and drinking water projects.

The roles and responsibilities of policy making and implementation of the institutions enlisted above collide with each other. Moreover, no single organization is seen obligatory to bear the sole responsibility of the overall development and management of the groundwater resources.

12.2.4 Institutions at regulatory level

At the regulatory level, institutions and committees like Water Users Association, National Federation of Irrigation Water Users Association Nepal, District Water Resources Committee, Water Sources Dispute Resolution Committee and Water Resources Utilization Investigation Committee are responsible for regulating the policies, plans and acts formulated and implemented at the local level. Their major objectives are as follows:

- **District Water Resources Committee:** to grant license for utilization, and solve disputes related to water and energy utilization, conservation, management and development.
- **National Federation of Irrigation Water Users Association Nepal:** to identify and extend sustainable irrigation system through effective participation of water users associations in the management and maintenance of all sorts of irrigation channels and trends.
- **Water Resources Utilization Investigation Committee:** to resolve conflicts regarding the utilization of

water resources on large and middle-scale projects.

- **Water Sources Dispute Resolution Committee:** to resolve disputes related to water supply and system operated by the individuals.
- **Water Users Association:** to allocate water based on demands and achieve distribution and production of resources in an equitable basis among users in the river basin with the sense of ownership and incentives of creating institution for resources mobilization, record keeping, sanctioning, water fee collection and account auditing.

As with the institutions on the upper levels, the responsibilities of institutions at the regulatory level also overlap with their working modules. All such committees are focused on dispute resolution and management whereas the precise objective of development of the resources and the regulations required for extraction and utilization is still lagging behind.

12.3 INFORMAL VOLUNTARY INSTITUTIONS

Several informal institutions are also working voluntarily in research and advocating equitable and sustainable utilization, development, management and conservation of groundwater resources. This section briefly describes some of such organizations involved in groundwater sector in Nepal.

- **Center for Research for Environment Energy and Water (CREEW)** was formed with the aim of simplifying the complexities of problems, issues and consequences of the environment, energy, and water through organizing research. CREEW's thematic research areas include climate change issues, groundwater, hydrology and water resource, public health and sanitation, renewable energy, and solid waste and wastewater. The organization is responsible for promoting newer technologies and activities that help sustain the environment.
- **Environment and Public Health Organization (ENPHO)** is a service-oriented national Non-Government Organization. Established in 1990, it envisages contribution in sustainable community development by combining research and actions through the integrated programs in the environment and public health areas. In case of groundwater its main objective is to study groundwater quality, develop and promote appropriate technologies and capacitate people to provide safe groundwater to vulnerable community.
- **Farmers Managed Irrigation System Promotion Trust (FMIST)** is a legally registered non-profit, non-partisan, nongovernmental professional organization that enhances FMISs and assists in their organizational and management innovations, disseminates knowledge and information on FMIS through seminars, dialogue, workshops and research contributions and develops human resources through applied research, education and training in FMIS.
- **Helvetas/Nepal** has been working in the drinking water and sanitation sector in Nepal for more than 20 years. It has supported Self Reliant Drinking Water Support Programme (SRWSP), developed on the basis of its experiences in the Western Development Region (WDR) of Nepal. It mobilizes communities, focusing on women's participation, including women communities and to build capacity of partners and provides high quality drinking water systems. Its *modus operandi* involves defining wards and Village Development Committees (VDCs) as planning units and facilitating the formation of Water Resource Management Sub-committees (WRMSCs) at the ward and community levels. The WRMSCs represent themselves in a larger Water Resource Management Committee (WRMC) together with VDC members.
- **Jalsrot Vikas Sanstha Nepal (JVS)** is a non-profit, non-government, non-

political and professional organization established in the year 1999 under Association Registration Act 2034. It is also a host institution for Nepal Water Partnership (NWP). Its main objectives are to help formulate policies on Integrated Water Resources Management, help sustainable conservation, utilization and management of water resources, analyze the prevailing differences among donor agencies and recipient countries and suggest remedial measures, help develop methods for optimal utilization of water resources, etc.

- **Japan International Cooperation Agency (JICA)** is a prominent donor agency working in the sector of groundwater in Nepal. It has sponsored Groundwater Resources Development Board (GWRDB) for the exploration of groundwater resources in Terai plain between 1993 and 1995. With ENPHO, it has conducted research on Arsenic vulnerability in groundwater of the Valley. In 1990, it has executed a groundwater management project in the Kathmandu Valley under Nepal Water Supply Cooperation (NWSC). In this project, JICA contributed to generate several baseline data on the seasonal fluctuation of groundwater level and recharge into main aquifer, deduced storage coefficient, estimated discharge for wells of NWSC and much more.
- **NGO Forum for Urban Water & Sanitation (NGOFUWS)** is a forum working for civil society to ensure equity of access, long term performance, and enhanced environment in the urban areas. The organization is actively involved in preservation and promotion of indigenous knowledge and culture of water resources management and sanitation practices. It also conducts research on different aspects of stone spouts preservation and conservation activities.
- **Nepal Water for Health (NEWAH)**, since its establishment in 1992, has been working actively to serve poor and rural and sub-urban communities to secure basic services of water and sanitation from the East to the Far West. It provides domestic water supply to the rural people, poor and marginalized communities. Over 200 groundwater projects have been implemented since 2002 till date in all the 20 districts of Terai. It includes installation of shallow, deep and hand dug wells, implementation of Water Safety Plan in Groundwater Iron Removal Plant, Arsenic identification and mitigation and installation of groundwater recharge pit.
- **Nepal Water Conservation Foundation** (now registered as Institute for Social and Environment Transition-Nepal). ISET-Nepal collaborate closely on the development and implementation of joint projects. NWCF had conducted interdisciplinary research on interrelated issues that affect the use and management of water with specific focus on the Himalaya-Ganga region. It had focused on generation and dissemination of knowledge on water management through research, publications and engagement in public dialogues. It has also sought to address emerging challenges and ever changing educational needs of water management. NWCF works with local communities as well as with organizations at local, national, regional and international levels.
- **The Small Earth Nepal (SEN)** is the secretariat for the Nepal National Water Week since 2010, while it is coordinating the events since 2008. It has successfully completed the first and second national symposiums on groundwater resources of the Kathmandu Valley in collaboration with CREEW. During the Water Week 2011, along with WECS and the Central Department of Environmental Science, Tribhuvan University (CDES/TU), it has conducted the two-week long e-discussion on "Water for Cities: Responding to the Urban Challenges" and accomplished the nationwide photography competition focused on groundwater. SEN is working on water sector with various activities (research, education, awareness and advocacy) since its establishment in 2001.

- Cooperation of **UNICEF** with GoN started from 1970 and has been able to secure a very important place among the donor agencies. The activities of UNICEF mainly included community water supply and sanitation (CWSS) for gravity flow water supplies in the hills, Terai Rural Water Supply and Sanitation with shallow tubewells in the Terai areas along with construction of household and institutional latrines.
- **USAID/Nepal** is a donor agency which has already helped 64,000 households to adopt micro-irrigation systems (treadle pumps, drip systems, sprinkler systems, and low-cost water storage) and provided technical assistance to more than 3600 farmer groups (55% women members) in 2008-2009. In 2006, USAID funded a hygiene improvement project, "Bringing Consumers to the Table: Perception and practice of Household Water Treatment Methods in Nepal."
- **WaterAid Nepal** is an international charity organization working in Nepal since 1987 on water, sanitation and hygiene with a network of seven partner organizations in the country. Its working areas constitute both rural and urban areas including slums and squatter settlements in the Kathmandu Valley and towns in the narrow strip of flat, fertile land along the Indian border of Terai. Access to safe water, sanitation and improved hygiene and latrine installation both in rural and urban areas and to influence government policy to serve the interests of vulnerable people are the main objectives of the organization.
- **The World Bank** has funded Irrigation and Water Resource Management Project, which began in 2008 with US$ 48 million and now has been extended through 2013 with an additional US$ 14 million. The project objectives are to help the government of Nepal improve agricultural productivity, improve management of selected irrigation schemes, and improve institutional capacity for integrated water resources management. As of 2009, the project had helped the Government to form water user associations in 73 project areas and had started construction of 18 irrigation schemes, with farmers contributing labor.
- **Water User Association (WUA)** is a group of individuals intending to make use of a water resource for their collective benefit. WUAs must be registered under the Water Resources Act 1992. This provides the government with a mechanism to regulate the collective use of the water resource. Such WUAs have the flexibility as a multi-functional entity to be utilized for other non-water related activities as well.

12.4 ACTS, REGULATIONS AND POLICIES

Although a number of acts, regulations and policies related to water resources use, development and management have been formulated in Nepal, only a few are explicitly related to groundwater resources development and management. Some of the acts and regulations are summarized in Table 12.2.

Though many acts and regulations formulated are related to water resources utilization, development and management, their use and priorities vary considerably. Almost all the acts prioritize drinking and sanitation purposes whereas other newly developed rules and regulations for the groundwater use emphasize on irrigation and agricultural purposes. Acts like National Water Plan, Urban Water Supply and Sanitation Sector Policy, and Bagmati Action Plan advocate the optimum utilization and development of the groundwater resources. Whereas, regulations like Drinking Water Management Board Rules, Water Supply Management Board Act and KVWSMB Strategic Plan focus on the proper management and conservation of the resources including the over and illegal extraction and exploitation. Similarly, policies like the Groundwater Policy, Irrigation Policy and Regulations and the three year Interim Plan have tried to maintain a holistic approach to develop, maintain and conserve the groundwater resources.

12.5 CONCLUSIONS

Water resources development and management should always be flexible enough for changes and complexities that occur due to natural systems as well as artificial intrusions. In this article, several institutions are identified which are working in the areas of development and management of groundwater resources in Nepal, Kathmandu Valley in particular. These institutions range from policy formulation and coordination to the implementation level. Nepal has been conscious of the potential developmental role of water resources and consequently many institutions have been created, policies formulated and several legislative instruments enacted and attempts made to use them to achieve desirable benefits. Unfortunately, there has been a huge gap lacking holistic approach, wider dispersion and a lack of coordination in the instructional mechanisms. It is also found that many institutions have overlapping roles and responsibilities for groundwater development and management which sometimes create confusion in the implementation level. Till day, no policy exists which is aimed at regulation of groundwater extraction in the Kathmandu Valley. Furthermore, separate and detailed discussions about groundwater are missing in the existing water resources policies and strategies. Hence, a strong central planning and coordinating institution based on the principles of Integrated Water Resources Management with the support from effective executing agencies that can mobilize beneficiaries at grassroot levels are needed for the proper management and protection of the groundwater resources..

Table 12.2 Summary of Policies, Acts, and Regulations related to groundwater resources development and management (NPC, 1995; Magar, 2005; GWRDB, 2011; KVWSMB, 2011; MoEn, 2011a, b; MoIr, 2011a, b; MoPPW, 2011)

S.N.	Policies/Acts/Regulations	Year of formulation	Key objectives
1.	*Water Resources Act & Water Resources Regulations*	*1992 and 1993*	• *To make rational utilization, conservation, management and development of water resources ensuring timely legal arrangement for achieving the goals* • *To ensure protection of drinking water along with pollution control, water quality problems and groundwater recharge issues*
2.	*Agricultural Perspective Plan*	*1995-2015*	• *To emphasize the use of groundwater as the source of irrigation during the plan period*
3.	*National Water Supply Policy*	*1997*	• *To provide clean, safe and adequate quantity of water and reduce incidences of water related communicable diseases and utilize time saved in fetching water by women and children to productive works*
4.	*Local Self- Governance Act*	*1999*	• *To provide authority to local bodies at the village level and set out duties to supply drinking water, prepare projects related to irrigation and river control and provides wells, groundwater and taps to develop the village area*
5.	*Water Resources Strategy*	*2002*	• *To provide access to safe and adequate drinking water and sanitation for ensuring health security* • *To increase agricultural production, ensuring the nation's food security* • *To prevent and mitigate water-induced disasters*

6.	*Irrigation Policy & Regulations*	*2000 and 2003*	• *To provide round the year irrigation facility to the irrigable land by effective utilization of the current water resources of the country* • *To deal with irrigation water user associations in transferring of projects, and protection, repair and maintenance of the irrigation system*
7.	*National Water Plan*	*2005*	• *To promote Integrated Water Resources Management by coordinating development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without comprising the sustainability of the ecosystem*
8.	*Water Supply Management Board Act*	*2006*	• *To make water supply and sanitation service accessible, regular, well managed and maintain a standard quality*
9.	*Water Tariff Fixation Commission Act*	*2006*	• *To provide qualitative and reliable water supply and sanitation services to consumers at reasonable price, by fixing the tariff of these services*
10.	*Drinking Water Management Broad Rules*	*2006*	• *To achieve accessible, regular, managed, and quality drinking water and sanitation facilities within the Kathmandu Valley*
11.	*Three Year Interim Plan*	*2007*	• *To supplement and undergo activities under Water Resources Strategy and Water Plan to promote sustainability of irrigation projects through management and capacity building of the farmers*
12.	*Urban Water Supply And Sanitation Sector Policy*	*2008*	• *To attain the socio-economic development and improved health status of urban population through the provision of sustainable water supply and sanitation services*
13.	*Groundwater Policy (Draft)*		• *To manage and regulate groundwater resources, monitor extraction and restrict its illegal extraction wherever seen urgent inside the Kathmandu Valley*
14.	*KVWSMB Strategic Plan*	*2008-2025*	• *To provide regular, qualitative water supply, controlling groundwater extraction and promoting pollution free industries to all the population of the Kathmandu Valley*
15.	*Bagmati Action Plan*	*2009-2014*	• *To improve the water qualities of the rivers to help improve the groundwater quality and increase the river discharge*

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

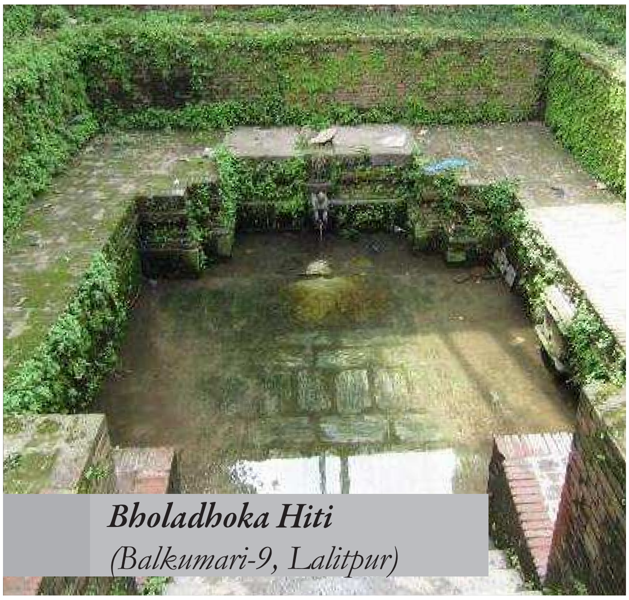
Stone Spout

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)

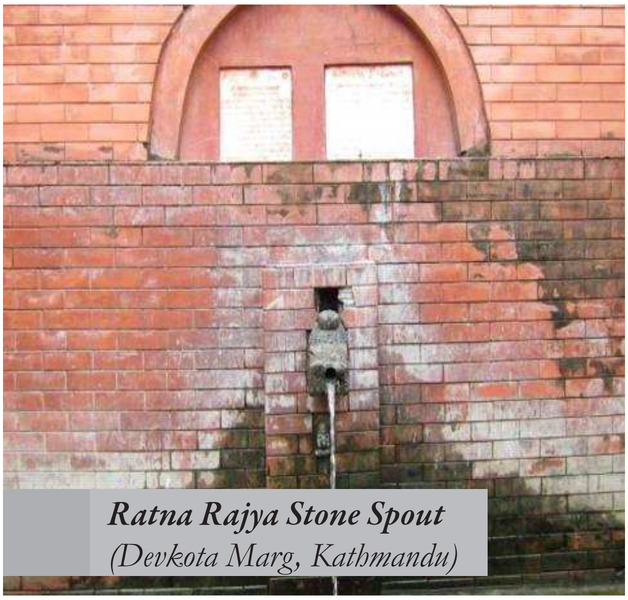
Establishment: Unknown

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.



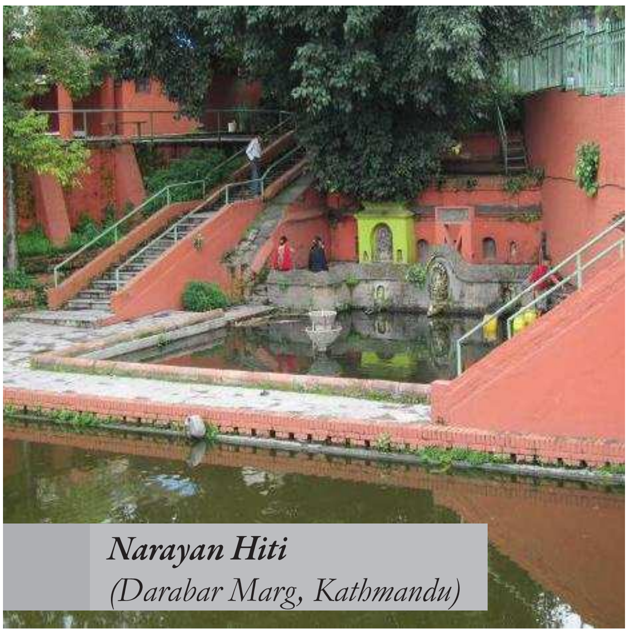
Ratna Rajya Stone Spout
(Devkota Marg, Kathmandu)

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.

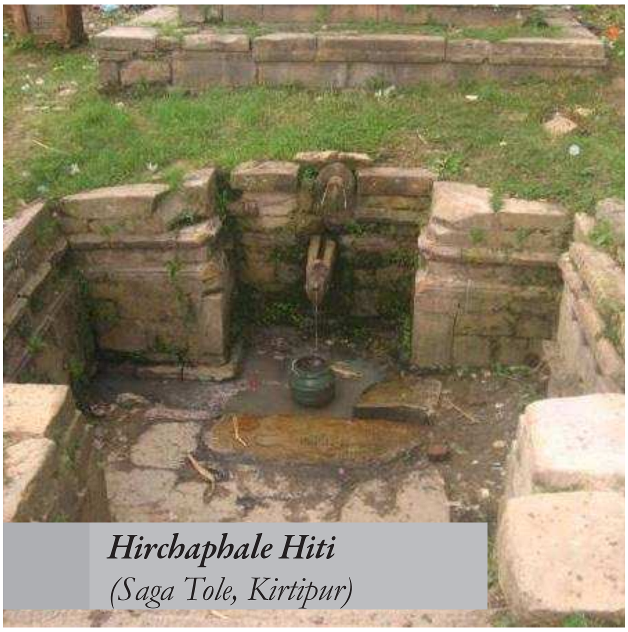
Cultural importance: Use in the rituals of Bhatbhateni Temple.

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.

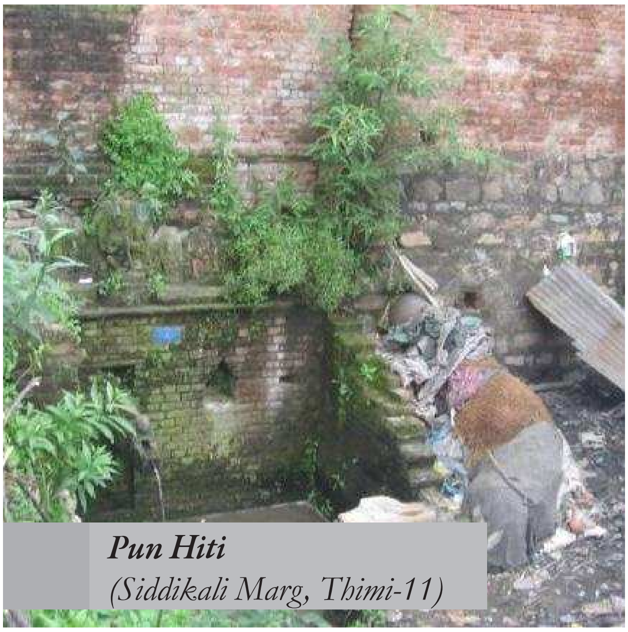


Hirchaphale Hiti
(Saga Tole, Kirtipur)

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)

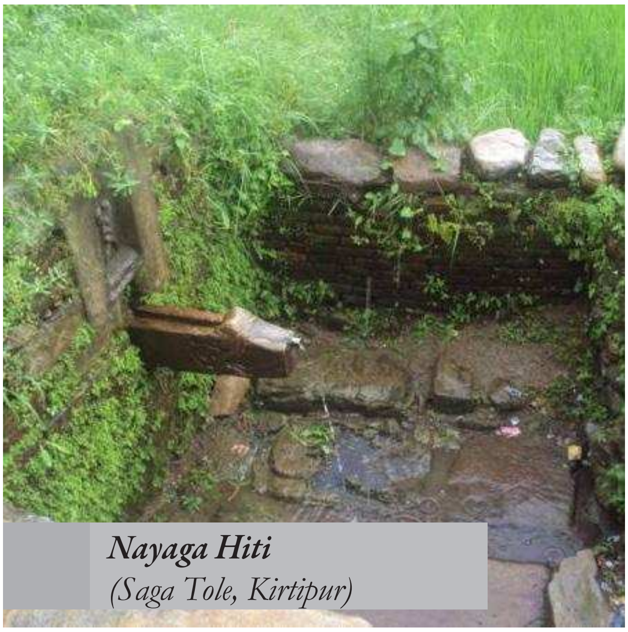
Establishment: Not available

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)

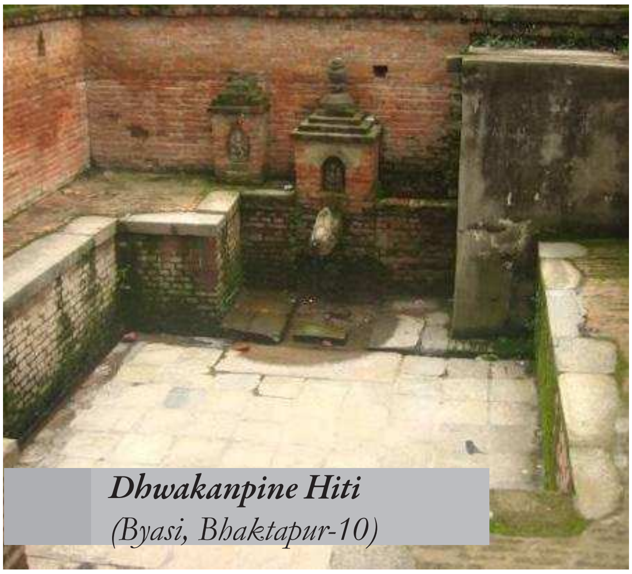
Establishment: Not available

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)

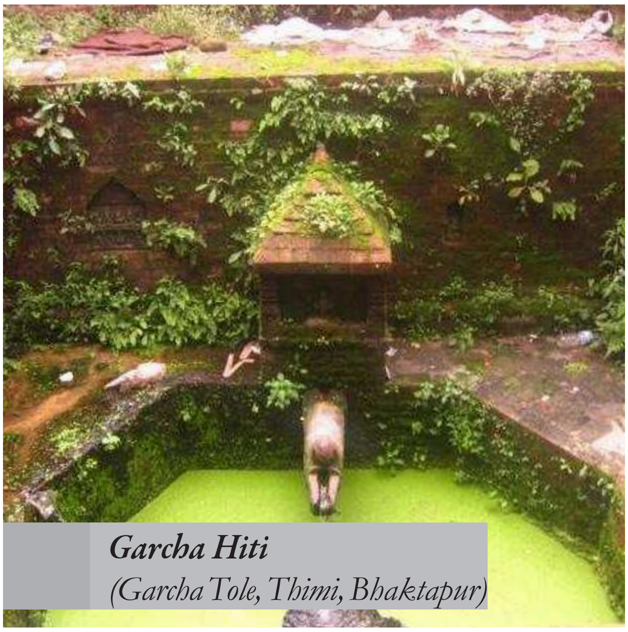
Establishment: Not available

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

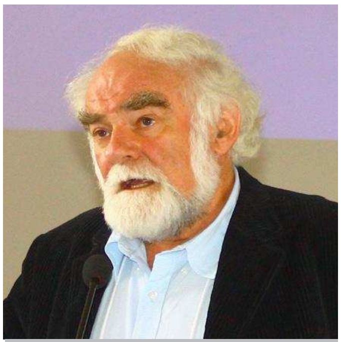
Location of source: Taleju Temple

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
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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
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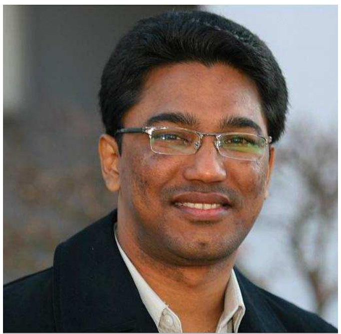
Ms. Kataoka is a director of Freshwater sub-group in Institute for Global Environmental Strategies (IGES) in Japan. Ms. Kataoka gained her LLM from the Graduate School of International Cooperation Studies of Kobe University, Japan. Prior to joining IGES in 2001, she worked at the Global Environment Centre 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.

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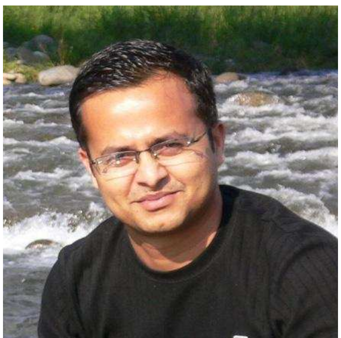


Dr. Saroj Kumar Chapagain (Associate Editor/Author/ Reviewer)

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
(Research Associate)

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
(Research Associate)

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
(Research Associate)

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)

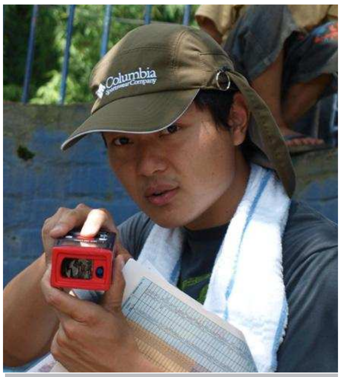
Mr. Bhattarai completed his M. Sc. in Water Resources Engineering (2009) and B. E. in Civil Engineering (2004) from Tribhuvan University (Nepal). He is currently working as a Research Associate in Water Engineering and Management at Asian Institute of Technology (Thailand). He has a few years of experience 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.

Dr. Suresh Das Shrestha
(Author/Reviewer)

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.

Dr. Kanako Yoden (Author)

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)

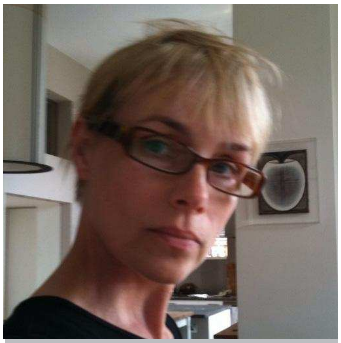
Dr. Shrestha holds a PhD in Environmental Water Resource (2002) from Indian Institute of Technology Madras (India), M.Eng. in Water Resource Engineering (1990) from Asian Institute of Technology (Thailand) and B.Eng. in Civil Engineering (1988) from University of Roorkee (IITR) Roorkee (India). Currently 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.

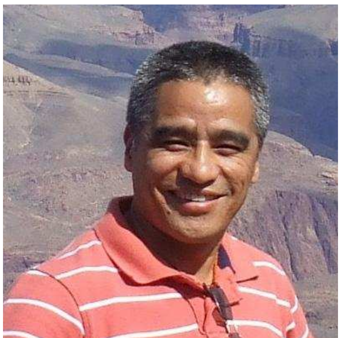


Ms. Maureen Papas
(Reviewer)

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)