Arsenic Vulnerability in Groundwater Resources in Kathmandu Valley

(Final Report)

September, 2005

A Joint Study

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Abbreviation

ENPHO	Environment and Public Health Organization
MPPW	Ministry of Physical Planning and Works
JICA	Japan International Cooperation Agency
MLD	Million liters per day
NWSC	Nepal Water Supply Corporation
NGO	Non Government Organization
GPS	Global Positioning System
VDC	Village Development Committee
GIS	Geographic Information System
MCM	Million Cubic Meter
WHO	World Health Organization
GV	Guideline value
As	Arsenic concentration
yr	Year
ppb	Parts per billion
mg/L	Milligram per liter
mm	Millimeter
m	Meter
l/s	Liters per second

Acknowledgement

JICA Expert Office at MPPW and ENPHO would like to thank Ms. Sayako TOKUDA of JICA Nepal Office for providing partial financial support to conduct this study. We also wish to thank Mr. Purna Das Shrestha (Joint Secretary at MPPW and Chairman of NASC) and Mr. Hariram Koirala (Director General, DWSS) for their valuable suggestions, and NASC for providing valuable feedback on the draft report preparation.

We are grateful to all persons, hotels, industries/factories, offices, institutions who provided us water samples and the information on deep tubewells for conducting the study successfully. We would like to thank Mr. Chandra Krishna Shrestha (Assistant Manager, NWSC) for providing information on NWSC water supply system.

We acknowledge the support of all research assistants involved in water sample collection and arsenic fluctuation monitoring in this project. We thank Centre for Integrated Urban Development (CIUD) for providing GIS working station.

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Executive Summary

A study conducted jointly by JICA Expert Office at Ministry of Physical Planning and Works (MPPW) and Environment and Public Health Organization (ENPHO) from November 2004 to April 2005 found arsenic in wells abstracting water from both shallow and deep aquifers. Deep tubewells were found more vulnerable to arsenic than shallow tubewells and dugwells in Kathmandu Valley. Thereafter, JICA Expert Office at MPPW in collaboration with ENPHO decided to conduct this study "Arsenic Vulnerability in Groundwater Resources in Kathmandu Valley" with the objective of preparing information base regarding arsenic contamination in deep aquifers of Kathmandu Valley. Present study was conducted in between April-September 2005.

As 45% of the total water supply to the Kathmandu valley comes from groundwater sources through various well fields operated by NWSC, most of NWSC's operating tubewells were sampled for this study. In case of private deep tubewells, only those wells which were permitted for sampling are included in the study.

Most wells abstract water from fluvial and the lacustrine deposits of Quaternary age that fill up the valley floor and attain thickness up to nearly 600 m in the central part of the valley (JICA, 1990).

The total area of the groundwater basin in the Kathmandu Valley is 326 km^2, which is divided into three sub basins from the standpoint of geography, geology and exploitability. These are Northern, Central and Southern districts, with areas of 156 km^2, 114 km^2 and 56 km^2, respectively.

In total 137 private, government and NWSC deep tubewells (>50 m depth) were sampled for mainly arsenic concentration for both pre-monsoon and monsoon seasons. Some of the other important water quality parameters such as iron, manganese, ammonia, nitrate, fluoride, *E. coli* etc were also tested besides arsenic. Among the total wells tested, 35 wells are of NWSC, 24 wells are of Hotels and Resorts, 20 are of various offices, 13 wells are of schools/colleges, and 12 wells are of hospital.

In pre monsoon, the highest arsenic concentration of 265 ppb was observed in Kuleswor followed by 250 ppb in Harihar Bhawan, and 212 ppb in Balkhu. The lowest arsenic concentration of less than 5 ppb was observed in 21 wells in different areas of the valley. In the monsoon, the highest arsenic concentration of 211 ppb was observed in Kuleswor followed by 173 ppb in Harihar Bhawan. The lowest arsenic concentration of less than 5 ppb was observed in 28 wells in different areas of the valley.

In the pre-monsoon, about 11.9% of tested wells were above the Nepal standard of 50 ppb, and about 59.7% of tested wells contained 11-50 ppb of arsenic. Thus, 71.6% wells were above WHO guideline value and 28.4% were below WHO Guideline value. Whereas, 56.8% wells were above WHO guideline value and 42.2% were below WHO guideline value. The distribution pattern of arsenic concentration in pre-monsoon and monsoon was almost similar. Arsenic concentrations were lower during the monsoon compared to pre-monsoon. The mean concentration of 32 ppb in pre-monsoon had reduced to 22 ppb during the monsoon. Similarly, the median concentration had also reduced from 19 ppb in pre-monsoon to 13 ppb in monsoon. In pre-monsoon, nearly one-third of wells were below WHO guideline value whereas, in monsoon, nearly half of the wells were below WHO guideline value.

This study also performed arsenic fluctuation monitoring of 15 wells exceeding Nepal standard both in pre-monsoon and monsoon. The results show that the fluctuation in arsenic was not much in the majority of the tested wells for pre-monsoon as well as monsoon.

Regarding the relation between arsenic concentration and depth, it was noticed that the deeper wells tend to have more arsenic concentration. This trend is observed for both pre-monsoon and monsoon. Majority of the wells tap multiple aquifer horizons thus water of various qualities is mixed. The aquifer horizons tapped ranges from 998 m to 1312 m above mean sea level. The maximum total screen length was of 198 m and the number of screens used range from 1-5.

The lithologs of 5 wells containing more than 50 ppb of arsenic shows that most of the wells are placed on the basement rocks and most of them extract water from both the rock as well as the sediment above consisting of mainly sand and gravel.

Mapping of arsenic tested wells was done to show the spatial distribution of arsenic in the valley. Six types of maps were prepared to show this distribution in the Valley in pre-monsoon and monsoon: 1. Distribution of Arsenic Concentration in Kathmandu Valley in pre-monsoon, 2. Distribution of Arsenic Concentration in Kathmandu Valley in monsoon, 3. Variation in Arsenic Concentration in Kathmandu Valley from pre-monsoon to monsoon, 4. Variation in Arsenic Concentration in Kathmandu Valley by geological formation from pre-monsoon to monsoon, 5. Arsenic concentration of wells by depth in Kathmandu Valley in pre-monsoon, 6. Arsenic concentration of wells by depth in Kathmandu Valley in monsoon. The spatial distribution shows that for both pre-monsoon and monsoon there is a narrow belt of Balkumari-Pulchowk-Kuleswor-Rabibhawan in the central wells of the valley with the high arsenic concentration. Some areas near this region also have high arsenic concentration.

The arsenic tested wells are located in seven types of geological formation which are Chandragiri, Chapagau, Gokarna, Kalimati, Lokundole, and recent flood plain. The majority of wells exceeding WHO guideline lie in Kalimati formation followed by Gokarna recent flood plain and Chapagaun.

The study has also attempted zoning of the Kathmandu Valley with respect to arsenic concentration into six zones of arsenic range for pre-monsoon and monsoon. The main purpose of zoning is to show the pattern of spatial dependence quantitatively. Such pattern can be used to aid the setting of the priority areas of emergency testing of arsenic and perhaps in the future to help guide a national water resource strategy.

An arsenic vulnerable map was prepared on the basis of pre-monsoon zoning map. Vulnerability map shows that northernmost part of the north groundwater district is safe whereas lower part of the district is in vulnerable within the Nepal standard. Majority of the central district are vulnerable and some part of this district are highly vulnerable. The southernmost part of the southern district is safe but northern part of this district is vulnerable with a small part lying in highly vulnerable zone. Gokarna well field and Pharping well field out of five well fields in the northern most and southern most part of the study area are found to be in the safe zone. Major part of the Bansbari well field with exception of a small area is located in safe zone. Some parts of Dhobikhola and Manohara well fields are located in vulnerable zone with 11-20 ppb and a small area of Manohara well field is located in 21-30 ppb zone. Vulnerable map also shows the

vulnerability level of wells by their uses. The study has also done vulnerability assessment of NWSC water supply system based on arsenic vulnerability map. NWSC's local supply system at Kuleswor Awash and Sipradi at Kalanki are highly vulnerable to arsenic.

Common practice to tap multiple screens when drilling a well to extract maximum amount of water has to be avoided and monitored closely. The study has found the relation between depth and arsenic concentration in the valley opposite to the relation found in Terai region, therefore, more study is recommended to see their relation in case of Kathmandu Valley.

Out of total 134 samples tested in pre-monsoon, the pH value for one-third of the water samples (34.3%) was found to be below WHO GV, 65.7% samples within WHO GV and none of the sample exceeded the maximum WHO permissible limit. Majority of water samples exceeded the WHO GV of 0.3 mg/L for iron (97.0%), 1.5 mg/L for ammonia (85.8%) and 0.1 mg/L for manganese (84.3%). Fluoride content was found high for 7.5% samples. The chloride and nitrate content, for all the water samples, was found within the permissible level for drinking water. The results of Eh values were low for almost all the samples, suggesting that the underground water in the study area is mostly in reducing condition. Despite increased depth of wells, water samples (20.1%) were contaminated with *E. coli*, which ranged from 0-640 cfu/100 mL of sample.

Based on the findings of the study, the study has made some recommendations regarding policy guidelines, drilling practice and depth of wells:

Some recommendation made for policy guidelines are as follows: addressing arsenic issue in groundwater in Urban Water Supply and Sanitation Policy, protection of arsenic safe zone for groundwater extraction, prohibition of groundwater extraction for drinking purpose from highly vulnerable zone, regular monitoring of deep tubewells in vulnerable zones, water from vulnerable zones should be treated prior to supply, development of licensing and control mechanism for permission of groundwater extraction, establishment of water quality and lithologs database management system.

Chapter 1
Introduction

1.1 Background

Over the last few decades, groundwater has become one of the major water sources of Kathmandu Valley. In Kathmandu valley, groundwater was first exploited for water supply in 1970. Development of groundwater resources began in earliest in 1984. Thereafter the extraction increased rapidly. In 1987, the groundwater extraction rate from Nepal Water Supply Corporation (NWSC) wells had nearly quadrupled the 1984 extraction rate as shown in Table 1.1.

Table 1.1

Groundwater Extraction by wells in the Kathmandu Valley

Year	Total Extraction, MLD	Percent Increase Over 1984
1984	9.0	-
1985	11.2	24
1986	25.1	179
1987	33.8	276

Source: Acres International et. al., 2002

It is important to note that about 45% of the total municipal water supply is fulfilled by groundwater resources in Kathmandu Valley (Acres International, et al., 2002). Additional industrial use of the municipal supply is not permitted for new major industries; therefore, groundwater is only the source of the water (Acres International et. al., 2002). Increasing demand of water for drinking, industry and irrigation increases demand of groundwater in days to come. Therefore, quality of groundwater is highly concerned issue to authorities who are responsible for providing access to safe drinking water and sanitation for population of about 1,645,091 in the valley (CBS, 2002).

Arsenic contamination of natural waters has become an issue of growing concern around the world during the past decade. Several studies in past have shown that South Asian region is highly vulnerable to arsenic. Arsenic in groundwater in Terai has already become a challenging issue for His Majesty's Government of Nepal (HMG/N) and other agencies working in the field of water and sanitation in that region. Of more than 400,000 water samples tested for arsenic so far, about 13.0% had arsenic concentration above WHO GV (10 ppb) and nearly 3% samples above Nepal standard (50 ppb). This is also a challenging issue for meeting the target of sustainable access to safe drinking water and sanitation of Millenium Development Goal.

A recent study "Groundwater Quality Surveillance in Kathmandu and Lalitpur Municipality Areas" conducted jointly by JICA Expert Office at Ministry of Physical Planning and Works (MPPW) and Environment and Public Health Organization (ENPHO) in November 2004 to April 2005 found arsenic in shallow as well deep aquifers. Deep tubewells are found to be more vulnerable to arsenic than shallow and dugwells in Kathmandu Valley, see Table 1.2 (JICA/ENPHO, 2005). This contradicts with the findings in the Terai where shallow tubewells are more vulnerable to arsenic than deep wells.

Table 1.2

Arsenic test result of Groundwater Quality Surveillance in Kathmandu and Lalitpur Municipality

Well Type	Monsoon			Pre-monsoon		
	Total tested	Above WHO guideline value (10 ppb)	Above Nepal Standard (50 ppb)	Total tested	Above WHO guideline value (10 ppb)	Above Nepal Standard (50 ppb)
Deep tube wells	56	50.0%	12.5%	51	68.6%	9.8%
Shallow tube wells	160	6.3%	-	149	11.4%	-
Shallow dug wells	91	14.3%	1.1%	87	11.5%	-

Source: (JICA/ENPHO, 2005a)

Vulnerability of arsenic in deep tubewells in Kathmandu Valley is a very critical issue due to it's negative impact on health as a high percentage of water demand in the valley is met through groundwater resources. Therefore, national water and sanitation policy and strategy must address clearly the issues regarding arsenic in groundwater and actions need to be initiated immediately to address this issue. Different types of information regarding arsenic in groundwater are very essential for addressing these issues effectively in policies and programmes. There are several studies regarding arsenic in groundwater in case of Terai, but data are limited in case of Kathmandu Valley. Policies developed on the basis of data and information available for Terai may not effectively address for Kathmandu due to differences such as geology, hydrogeology, settlement pattern and water supply in valley.

JICA Expert office at MPPW in collaboration with ENPHO has therefore conducted a study "Arsenic vulnerability in groundwater resources in Kathmandu Valley" with the objective of preparing information base regarding arsenic contamination in deep aquifers of Kathmandu Valley. This study has tested about 137 deep tubewells of private, government and NWSC for both pre-monsoon and monsoon, analyzed and prepared information base as a study report. It includes different types of tables, chart, maps, texts, etc.

Information and recommendations made by this study will be valuable input in developing efficient policies and strategies for authorities responsible for water and sanitation in the valley. These Information will also help to implementing agencies such as city water supply service providers, NGOs, drilling companies and anyone who are planning to use groundwater resources in deep aquifers for various purposes. This in overall will help in providing arsenic free water in the valley. Moreover, this study can also help to explore arsenic issue in mountainous region whose hydrogeology is very closer to the Kathmandu Valley.

Consumption of water contaminated with hazardous chemicals or pathogenic microorganisms possess serious health threat or various waterborne diseases. It is estimated that about 80% of all sickness and disease in the world is caused by inadequate sanitation, polluted water or unavailability of water. Thus, besides arsenic contamination, other drinking water quality parameters of interest were also tested in present study.

1.2 Objective

Main objective of this study is to prepare an information base on arsenic concentration of deep tubewells of Kathmandu Valley, which will be valuable input in planning, policy making, and implementing plans and programmes regarding groundwater resources in the valley.

Specific objectives are

- Test of arsenic concentration and important parameters in water from deep tubewells in different areas of Kathmandu Valley for both pre-monsoon and monsoon.
- Assess vulnerability of deep-water aquifer (deep tubewells) in Kathmandu valley.
- Develop information base for planning, policymaking and implementing plans/programmes regarding proper utilization of groundwater resources.in Kathmandu Valley.
- Develop information base for general public and drilling companies involving in groundwater extraction work.
- Provide policy guideline for safe groundwater extraction

1.3 Scope of study

Study area mainly covers urban areas of Kathmandu Valley. Boundary of the study area is limited to the few kilometers away from rectangle shape formed by outermost sampled wells in all directions. Most of NWSC's operating tubewells were sampled for this study. Only those wells which were permitted for sampling were included in the study in case of private deep tubewells. Tubewells with more than 50 m depth are considered as deep tubewells in the study. This study is also limited to testing and analyzing the water quality of groundwater especially for arsenic in order to know the spatial distribution of arsenic in Kathmandu Valley, improvement of water quality of contaminated wells was beyond the scope of this study.

Chapter II

Data Collection and Water Analysis

2.1 Data collection

For this study, water samples were collected two times: Phase I – Pre-monsoon (Dry Season) and Phase II – Monsoon. For Phase I, field works – data collection, water sampling and GPS observation etc were done in the period between March-May 2005. While Phase II was conducted in the period between August-September 2005.

Study design

The schematic diagram of the study design is shown in Figure 2.1.

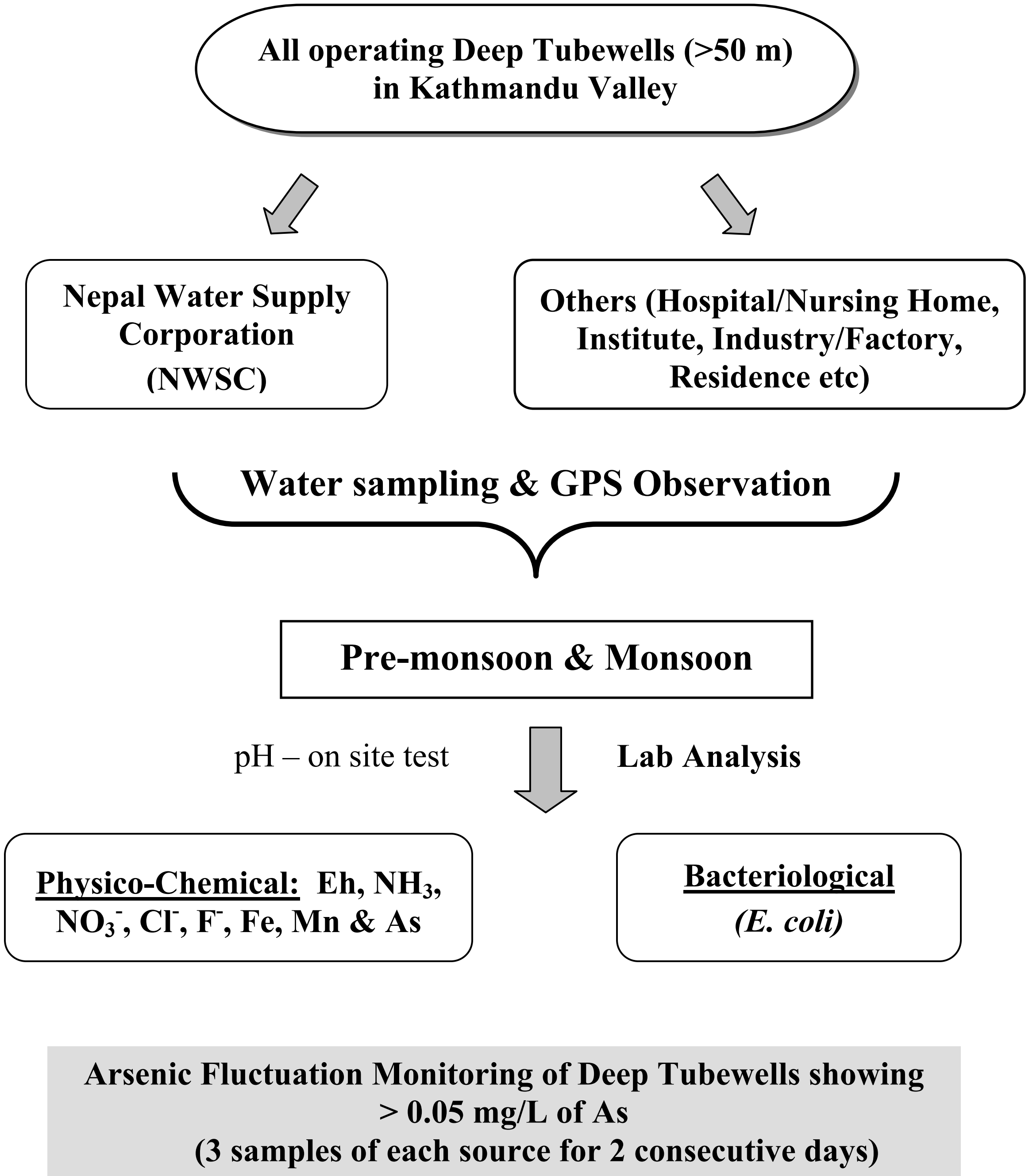

Figure 2.1: Schematic Diagram of the Study Design

2.1.1 Identification of wells for testing

First, list of the wells potential for testing was prepared with the help of available secondary sources of data. Prepared list of wells were verified with owners by telephone and personal visits. Operating condition of wells was also verified with respective owner by telephone and visits. Wells with greater than 50 m (>167 feet) depth and in operation condition were only considered as well for selection. Wells which have problem for raw water sampling (e.g. directly connected to water collection tank/reservoir or treatment system) were excluded in selection.

2.1.2 Water sampling and GPS observation

All identified wells were visited and raw water samples were collected following standard methods (APHA, 1995). Locations of the sampled deep wells were also identified at the same time using GPS. Water sample report for every sampled well is presented in Annex 1 & Annex 2. Samples with high arsenic concentration (>50 ppb) were monitored to check arsenic fluctuation. Water sample collected from March to May was considered as Pre-monsoon and from August to September as monsoon.

Water samples were collected in clean bottles after running water at least for 5 minutes. The measurement of pH was done at the sampling site using portable pH Meter. From each sampling source, water samples were collected in three bottles: (a) 500 mL polypropylene bottle for testing Eh, ammonia, nitrate, chloride and fluoride (b) 160 mL pre-acid washed polypropylene bottle for measuring arsenic, iron and manganese (c) 100 mL pre-sterilized (autoclaved) glass bottle for bacteriological analysis. The bottles for physicochemical analysis were rinsed three times with the sample water prior to filling them. The sample for arsenic, iron and manganese was immediately acidified with concentrated hydrochloric acid (HCl). The samples were carried in an ice-box and transported to the ENPHO Research Laboratory, Kathmandu, Nepal for analysis.

In present study, it was necessary to enter the residential compound or office premises for water sample collection. A letter from JICA Expert Office at Ministry of Physical Planning and Works (MPPW) was given and oral permission was taken from the security guard or others presented at the site during the visit before entering any office premises or house compound. Water samples were collected only after receiving the verbal consent.

2.2 Analysis of water samples

Water samples were tested for arsenic and other important water quality parameters. Tested parameters, methods of analysis and instruments used for analysis are shown in Table 2.1.

Table 2.1

Test parameters, methods of analysis and instruments used

S.N.	Parameters	Unit	Method of Analysis	Instrument
Physicochemical				
1	pH	-	pH meter	HANNA Instruments
2	Redox potential (Eh)	mV	Potentiometric	WTW, pH 90
Inorganic				
3	Nitrogen-Ammonia (NH_3)	mg/L	Spectrophotometric (Phenate)	PERKIN ELMER, Lamda EZ150, USA
4	Nitrogen-Nitrate (NO_3^-)	mg/L	UV Spectrophotometric	PERKIN ELMER, Lamda EZ150, USA
5	Chloride (Cl^-)	mg/L	Argentiometric titration	-
6	Fluoride (F^-)	mg/L	Spectrophotometric (SPADNS)	PERKIN ELMER, Lamda EZ150, USA SOLAAR
7	Arsenic, total (As)	mg/L	Atomic Absorption Spectrometer (AAS) with hydride generation technique	SOLAAR 969 AA Spectometer, Thermo Elemental, UK
8	Iron, total (Fe)	mg/L	Atomic Absorption Spectrometer (AAS)	SOLAAR 969 AA Spectometer, Thermo Elemental, UK
9	Manganese, total (Mn)	mg/L	Atomic Absorption Spectrometer (AAS)	SOLAAR 969 AA Spectometer, Thermo Elemental, UK
Bacteriological				
10	*E. coli*	cfu/100mL	Membrane Filtration (MF)	Millipore, USA

The collected samples were analyzed in the laboratory immediately after its delivery except for arsenic, iron and manganese concentrations. Arsenic, iron and manganese concentrations were measured either the next day or other day within one week. Sampled water with very high arsenic concentration were re-sampled and tested for the confirmation of the result.

For arsenic, assay accuracy was ensured by inclusion of reference material, NIST SRM 1640 (National Institute of Standards and Technology, Gaithersburg, MD, USA) for trace elements in water (with 26.67 ± 0.41 μg/kg arsenic. The detection limit (DL) of the HG-AAS was 0.005 mg/L for arsenic in water. The reference material produced the value within the certified range.

2.2.1 Bacteriological quality of water samples

Testing for bacteriological quality of collected water samples was done in Pre-monsoon only. Despite the increased depth of wells, 20.1% of the water samples were contaminated with *E. coli*, which ranged from 0-640 cfu/100 mL of sample.

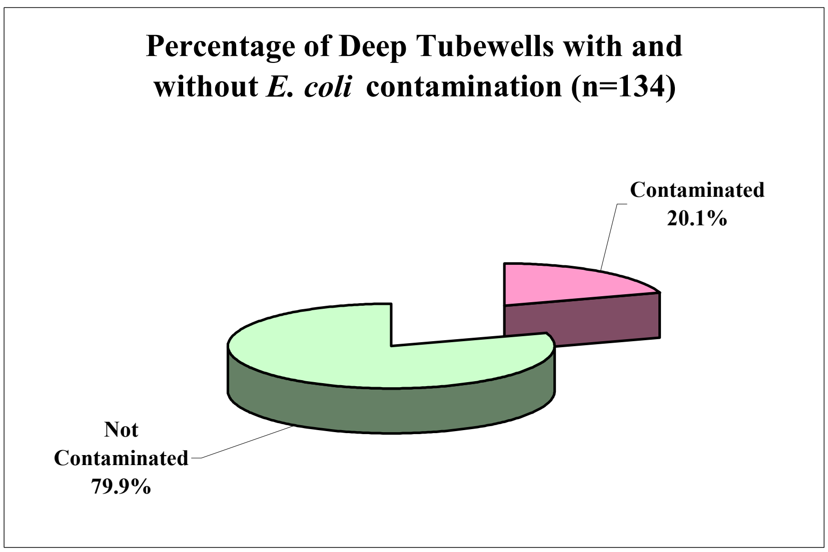

Figure 2.2

2.2.2 Physicochemical and inorganic quality of water samples

In Pre-monsoon, water samples were tested for pH, Eh, arsenic, iron, manganese, ammonia, nitrate, chloride and fluoride values. While water samples were tested for three parameters, viz., pH, Eh and arsenic in monsoon.

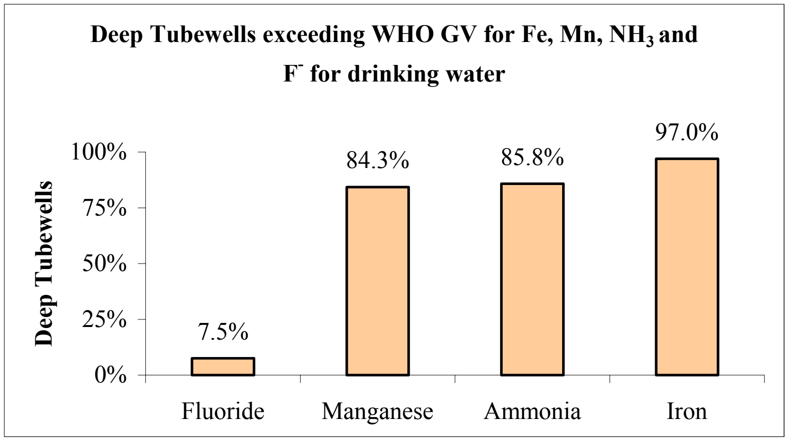

Figure 2.3

In pre-monsoon (n=134), the test results of pH values showed that almost all the water samples were slightly acidic (Annex 2). The pH value for one-third of the water samples (34.3%) was found below WHO GV, 65.7% samples within WHO GV and none of the sample exceeded the WHO permissible limit. Majority of water samples exceeded the WHO GV of 0.3 mg/L for iron (97.0%), 1.5 mg/L for ammonia (85.8%) and 0.1 mg/L for manganese (84.3%). Fluoride content was found high for 7.5% samples (Figure 2.3). The chloride and nitrate content, for all the water samples, was found within the permissible level for drinking water. The results of Eh values were low for almost all the samples, suggesting that the underground water in the study area is mostly in reducing condition Annex 2. In reducing condition arsenic mostly occur in trivalent state (As^{3+}), which is considered to be more toxic in regard to health effects. The minimum, maximum, mean, median and standard deviation values of pH, Eh, iron, manganese, ammonia, nitrate, chloride and fluoride are presented in Table 2.2. Arsenic results will be discussed in detail in other chapters.

Table 2.3 presents the correlation among pH, Eh, arsenic (As), iron (Fe), manganese (Mn), ammonia (NH_3) and fluoride (F^-) values for the water samples tested. Significant negative correlation between pH and Eh values was found. There is a weak positive but insignificant correlation between pH and arsenic values. The manganese and ammonia values exhibited a significant positive correlation with arsenic concentration (Table 2.3.).

Table 2.2
Parametric values of water samples (Pre-monsoon)

	Depth (m)	**pH -**	**Eh (mV)**	**Fe (mg/L)**	**Mn (mg/L)**	**NH_3 (mg/L)**	**NO_3^- (mg/L)**	**Cl^- (mg/L)**	**F^- (mg/L)**
(n = 134)									
Mean		6.64	26.32	6.12	0.44	34.55	1.73	6.11	0.72
Median		6.58	28	4.42	0.38	21.44	0.56	2	0.67
SD		0.37	18.49	5.9	0.37	43.75	3.35	12.21	0.46
Minimum		5.7	-33	0.09	ND (<0.05)	0.09	ND (<0.05)	<1	0.01
Maximum		7.95	78	31	2.35	324	15.54	96	2.1

ND = Not Detected

Table 2.3
Correlation among depth, pH, Eh, As, Fe, Mn, NH_3 and F^- (n=314)

Parameter	**pH**	**Eh**	**As**	**Fe**	**Mn**	**NH_3**	**F^-**
pH	1	-0.932**	0.148	-0.181*	-0.032	-0.05	-0.082
Eh		1	-0.205*	0.184*	0.003	0.004	0.069
As			1	0.096	0.187*	0.268**	0.14
Fe				1	0.671**	0.393**	0.011
Mn					1	0.415**	0.106
NH_3						1	0.383**
F^-							1

** Correlation is significant at the 0.01 level.
* Correlation is significant at the 0.05 level.

Chapter III

Data and map preparation

The quality of the output of the study is determined by the volume of available arsenic test data, area covered by sample data and the sample quality. Water sampling and testing in deep tubewells are not only expensive it is also time consuming and difficult especially in case of private wells. Private companies and individuals are not willing to provide water sample due to several reasons. Identification of wells is also very difficult because there is no any official record how many deep wells are in the valley and where are they located.

Environmental data such as arsenic concentration in groundwater represent a natural phenomenon. The arsenic data are measured on the earth surface with spatial and temporal resolution. Maps are one of the best techniques to illustrate the spatial distribution of this data. This chapter describes the process used to create a dataset of arsenic tested wells, to prepare spatial data layers, and to produce different kinds of maps.

3.1 Arsenic tested wells

The data set prepared for vulnerability assessment comprises water sample data for 137 deep tubewells, in which there are 134 sample data for pre-monsoon and 125 sample data for monsoon. Number of wells tested in VDC and municipality and by their use is presented in Table 3.1 and Table 3.2 below:

Table 3.1
Total wells tested by VDC/Municipalities

VDC / Municipality	Total wells tested	
	Pre-monsoon	Monsoon
Bhaktapur Municipality	2	1
Bungmati VDC	1	1
Chhaling VDC	2	1
Goldhunga VDC	1	-
Gongabu VDC	1	1
Harisiddhi VDC	1	1
Jorapati VDC	7	7
Kathmandu Metropolitan City	76	71

Katunje VDC	2	2
Khadga Bhadrakali VDC	1	1
Kirtipur Municipality	2	2
Lalitpur Sub-metropolitan City	14	13
Madhyapur, Thimi Municipality	6	6
Manamaiju VDC	2	2
Mulpani	3	3
Mulpani VDC	1	1
Naya Naikap VDC	1	1
Nayanpati VDC	4	4
Saukhel VDC	1	1
Sitapaila VDC	1	2
Sunakothi VDC	3	2
Tinthana VDC	1	1
Tokha Sarswoti VDC	1	1
Total	134	125

Table 3.2
Wells tested by their uses

Use of well	Total wells tested	
	Pre-monsoon	Monsoon
Business Complex	3	3
Carpet Industry	6	6
Fishery	1	1
Horticulture	1	1
Hospital	12	13
Hotel & Resort	24	23
Housing	8	7
Market	1	1
Medical product	2	2
Monastry & Hostel	2	2
NWSC	35	33
Office	20	16
Park	1	1
Private	2	2
School / College	13	12
Swimming pool	2	1
Local water supply	1	1
Total	134	125

Note: DWSS and other community based water supply system in this study is represented by *Local water supply system*

3.2 Creation of data sets of sampled wells

3.2.1 Creation of arsenic data set

A dataset of tested wells was created with all required attributes for spatial analysis, statistical analysis and mapping. This data set is composed of attributes - well ID, owner's name, name of locality, VDC/municipality, use of well, depth, pre-monsoon arsenic concentration (ppb), monsoon arsenic concentration (ppb), geographic location (East) and geographic location (North). See Annex 1 for complete data set prepared. It is important to note that arsenic concentration less than 5 ppb cannot be detected by existing laboratory test at ENPHO, therefore value for not detected arsenic is given as 4 ppb for data analysis for this study.

3.2.2 Preparation of digital spatial data sets

Basic features to prepare maps were identified and purchased from different sources based on their usefulness and availability. Topographic features covering Kathmandu Valley were acquired from Survey Department and geological features with well fields from Department of Mines and Geology.

Spatial data layers acquired in several independent sheets were checked, cleaned and merged to form a single digital map of Kathmandu Value with several spatial data layers. This map of the valley covers only the study area for arsenic vulnerability assessment. The study area was limited to the area as mentioned in scope of study. Geology map with different geological formation as of study area was also prepared based on the acquired geology data. These maps latter were used as base maps for preparing various output maps of the study.

Spatial data set for location of all sampled wells was created with reference to the location of wells collected through GPS. Spatial data set for location of wells other than sampled wells was created with the help of location data provided by the report "Urban Water Supply Reforms in the Kathmandu Valley, Groundwater Monitoring Program" (UWSR). Second data set, later, was used for vulnerable assessment of arsenic to deep tubewells in the valley.

3.2.3 Preparation of digital map

It has already been discussed about the importance of maps for presenting arsenic issue in different aspects. Major components in producing maps are arsenic test data set, results of geostatistical analysis and spatial data layers created in several steps of study. All these components were integrated with the help of Geographic Information System (GIS) in order to produce different types of maps for visualizing arsenic concentration issue in Kathmandu Valley.

Chapter IV
Hydrogeology

4.1 Meteorology and hydrology

Kathmandu valley is characterized by warm and temperate climate with a rainy season (monsoon) from June through September. About 23 meteorological stations around the valley collect the rainfall data for Department of hydrology and Meteorology. Rainfall varies substantially according to altitude from about 1300mm/yr in the valley to 3000mm/yr in the rim. In general about 80% of the total rainfall occurs during the monsoon period with July and August being the wettest month.

Bagmati River, originating in Shivapuri Mountain in the north, is the trunk river with many small and large tributaries. Major tributaries are Bishnumati River, Manohara Khola, Hanumante Khola, Dhobi Khola and Nakhu khola. All these rivers form a centripetal drainage system whereby the rivers flow from the surrounding to join the main trunk river Bagmati which flow across the central part of the valley. The Bagmati River drains away from the valley through Chobhar gorge in the south. The annual runoff at Chobhar is estimated to be 500 MCM.

4.2 General geology

Kathmandu Valley consists of two series of geological successions as shown in Table 4.1. Precambrian to Devonian rocks form the mountain ranges which surrounds the Kathmandu Valley and the valley floor. The bedrock that forms the valley floor consists of irregular and undulating buried land surface and is covered by fluvial and lacustrine deposits on top. The rocks are folded, faulted and fractured. The rock types are mainly quartzite, phyllite, schist, slates, limestone and marbles belonging to Bhimphedi and Phulchowki Group of Kathmandu Complex.

Table 4.1

The Geological units in Kathmandu Valley

Cenozoic	Holocene		Fan Gravel Soil, Taulus, Fluvial Deposits, (Gravel, Sand and silt)
	Pleistocene		Land deposits (Gravel, sand silt and clay, peat, lignite, and diatomaceous earth). Fluvial deposits (Boulder, Gravel, Sand and Silt)
			Unconformity
Lower Paleozoic	Devonian	**Phulchowki Group**	Godavari Limestone – Limestone, Dolomite
	Silurian		Chitlang Formation- Slate
	Cambrian-Ordovician		Chandragiri Limestone- Limestone, Phyllite
	Cambrian		Sopyang Formation- Slate, Calcareous Phyllite
	Early Cambrian		Tistung Formation- Meta Sandstone, Phyllite
			Unconformity
Precambrian		**Bhimphedi Group**	Markhu Formation- Marble, Schist
			Kulekhani Formation- Quartzite, Schist
			Metamorhic- Sheopuri Gneiss Igneous Rock- Pegmatite , Granite, Basic intrusive

Source: DMG/ DOI/ BGR 1998

Many mountain ridges extend to the valley bottom from the surrounding mountains, implying there are many buried ridges. The ground surface of the Kathmandu Valley bottom is flat but the buried bedrock surface is believed to be in irregular shapes and high relief (JICA, 1990).

Quaternary fluvial and the lacustrine deposits fill up the valley floor over these buried ridges. The overlying quaternary sediments attain thickness up to nearly 600m in the centre part of the valley (JICA, 1990). The fluvial and the lacustrine deposits consists of micaceous, fine to coarse sands and gravelly sands interbedded with clays and in some places carbonaceous lignite beds in the northern part. The southern part of the valley consists of generally finer facies that is a thick sequence of light and dark gray clays which covers the whole of the southern area except where the alluvial fans outcrop. The lithologs from the south indicate that the clays are 200m thick beneath the Kathmandu city and that they are very uniform with hardly any interbedded sand layers except near their base.

The fluvio-lacustrine deposits consist of the following deposits:

Arenaceous deposits: Arenaceous deposits are composed of coarse to medium grain sand with small rock fragments. They are believed to have been supplied from the northern mountainous areas underlain by gneissic rocks. Arenaceous materials are formed as steep cliffs beside river channels and are in loose condition, and thus can be easily eroded by river flows. Argillaceous deposits which are composed of clayey materials are considered to have been supplied from erosion of the limestone, which underlie the southern mountainous area. River flanks of the areas underlain by argillaceous materials appear to be very gentle in contrast to the areas underlain by arenaceous deposits.

Intermediate type of the above-mentioned two kinds of deposits is distributed in the central part of the valley between the areas composed of arenaceous deposits and argillaceous deposits. The materials seem to be supplied alternately from erosion of limestones and phyllites which underlie the western and southern mountainous areas. The materials of this type are composed of silty clay or clayey silt and intercalations of sandy layers and clayey layers.

Agglomerate of boulders and gravel with a clayey and silty matrix in the southern part of the valley bottom. These deposits are classified into two types. The upper zone is mainly composed of sub-rounded to rounded poorly sorted gravel. The lower zone is the intercalations of gravel layers and silty clay layers of 1m to 2m in thickness. The maximum thickness of this deposit is 50m to 70m approximately.

The gravel layers are mainly composed of the calcareous schistose sandstones and dip gently to the north in general. These gravel deposits are believed to be washed out from the southern river basins (JICA, 1990).

Brief descriptions of some of the geological units are given below:

Quaternary Formation:

(i) Recent Alluvial Soil: Recent deposits of flood plains and lower alluvial terraces. In northern part; sand and gravel deposits up to boulders size. In central and southern part; clay, sand and fine gravel.

(ii) Residual Soil: Humic silty loam to sandy gravels of thickness 1-3 m, at places and occur on slopes.

(iii) Colluvial Soil: Inhomogeneous deposits at footslopes with constituent of humic clay, silt and sand, at places boulder. Variable thickness > 1 m, increasing towards the center of the deposit.

(iv) Alluvial Fan Deposits: Sandy gravel, sand, and silt. Thickness increases towards the center of the fan. Finer grained material toward the margin.

Plio-Pleistocene Deposits:

Slightely Consolidated:

(i) Tokha Formation: Dark gray clay and brownish gray sand and poorly sorted, sub- angular to rounded sandy gravel peaty clay, and lignite layer present. Thickness up to 200 m or more.

(ii) Gokarna Formation: Light to brownish gray, fine laminated and poorly graded silty sand,. Intercalation of clay of variable thickness as well as in the upper part; white Thimi diatomite (1 m) present. Total thickness up to 300 m or more.

(iii) Kalimati Formation: Gray to dark silty clay and clayey silt, at places calcareous nature and phosphate mineral (vivianite). Organic clay, fine sand beds and peat layers common.

Occasionally lignite seems up to 2 m. In Kharipati area quartzic and biotitic schist boulder beds with sandy gravel and minor clayey and sandy silt layers present. Total thickness up to 450 m or more.

(iv) Lukondol Formation: Semi consolidated sandy, clayey silt interbedded with gravel and clayey sand, peat, and lignite of up to 3 m thickness. Total thickness up to 80 m.

Hard Rocks:

Precambrian to Devonian:

(i) Godavari Limestone: Green to purple argillaceous limestone and white to light brown massive dolomite, yellowish brown when weathered. Total thickness up to 300 m.

(ii) Chitlang Formation: Dark slate and argillaceous sandstone with white quartztite in lower part and 10 to 15 m thick ferriuginous beds in upper parts. Total thickness up to 10000 m.

(iii) Chandragiri Formation: Pale bluish gray to brown, medium to thick bedded, massive and finely crystalline limestone, at places with sandstone and phyllite , locally siliceous or dolomite limestone. At places sporadic lead zinc mineralization. Total thickness up to 200 m**.** (DMG/BGR, 1998).

4.3 Groundwater system

The groundwater basin in the Kathmandu Valley is believed to be isolated and independent from groundwater systems outside the valley. Several aquifer horizons, many of them interconnected, forms the groundwater system. Binnie & Partner (1973) classified the aquifer system in Kathmandu Valley into seven types as given in the following.

a) Interbedded: lateral extensive aquifers in the valley, more numerous towards the north.
b) Linear: old river channel deposits
c) Bedrock: limestone (karst) in the SE and SW rims of the valley.
d) Basal Gravel: deep gravel overlying the bedrock in the southern part of the valley.
e) River deposits: recent alluvial material.
f) Gravel fans: from the hilly rim towards the valley.
g) Gravel near the surface: usually small thickness, locally widespread occurrence

According to the investigation carried out by JICA in 1990, the main aquifer ranges from EL. 900 m to E1. 1350 m and is confined by lacustrine deposits some 50 to 200 m in thickness. The total area of the groundwater basin is 326 km^2, divided into three sub basins from the standpoint of geography, geology and exploitability, they are Northern, Central and Southern districts, whose area are 156 km^2, 114 km^2 and 56km^2 respectively. Figure 1 shows the basin and boundaries of the three districts.

Northern groundwater district:

The northern groundwater district, which include the Bansbari, Dhobi Khola, Manohara, Bhaktapur and Gokarna well field are the principal sources of water supply to Kathmandu and exploited by NWSC.

The upper part of deposits in the northern Bansbari, Dhobi Khola, Gokarna and Manohara area is composed of unconsolidated, highly permeable materials consisting of micaceous quartz sand and gravel. The unconsolidated coarse sediments are as much as 60m thick and can yield large quantities (up to 40 1/s) of water. However, the aquifers are highly stratified, and contain layers of all gradations of sediment from boulders, through mixed sands to silt and impermeable clay. Sorting is generally poor and many of the gravels contain much silt.

Aquifers are considered as being multi-layer and confined, although in some areas the aquifers may be unconfined. Dhobi Khola – Jorpati area is quite different in this regard. There is an unconfined upper aquifer which has a good Transmissivity but which has a saturated thickness of only 15 to 30 m. Beneath this there are clays, with bedrock proved at comparatively shallow depths between 94 and 157 m. There is a coarser basal layer but it is very clayey and has poor aquifer potential.

The Transmissivty of the aquifers in this district ranges from 83-1963 m^2/day. Water quality is characterized by low electrical conductivity such as 100 to 200 micro-simens/cm.

Central groundwater district:

The central groundwater district includes Greater Kathmandu. Unconsolidated coarse sediments of low permeability at the bottom of the basin form the main aquifer.

The upper part is composed of impermeable very thick (as much as 200m) stiff black clay accompanied by some lignite.

Groundwater stored in these aquifers includes marsh methane gas all over the area. Groundwater in this deep aquifer is believed to be more or less stagnant and recharged by lateral inflow only. Some of the wells were in artesian conditions during their construction. The transmissivity of the wells range from 32-960 m^2/day. Water quality of these groundwater is characterized by very high electrical conductivity such as 1,000 micro-siemens/cm in some wells located near Tripureswor.

Southern groundwater district:

The southern groundwater district is located between the southern mountains and a geological structural line from Kirtipur to Godawari. This area is characterized by thick impermeable clay formation and low permeable basal gravel. Aquifer is not well developed only recognized along the Bagmati River between Chobhar and Pharping.

4.4 Groundwater recharge and discharge

Groundwater recharge in the valley occurs in two ways:

a) By vertical percolation to the aquifers from surface and stream bed infiltration.
b) By percolation into the confined aquifers near their junction with the rock of Valley rim.

Groundwater recharge in Kathmandu valley is complicated due to the presence of widespread distribution of impermeable black clay which prevents vertical infiltration to the aquifer at depth. The clay deposits are absent near the mountains in the north. In the central part of the valley this deposit is virtually continuous from the surface to 200 m or more.

Hence, the suitable area for recharging aquifers is located mainly in the northern part of the valley and along the rivers where the recharge area is enough to receive much amount of annual precipitation. In the southern part recharge is takes place mainly along the Bagmati River.

Chapter V
Distribution of Arsenic Concentration

5.1 Basic statistics

The arsenic concentration of 137 wells (i.e., deep tube wells with more than 50 m depth) of the Kathmandu Valley was tested in two phases: pre-monsoon and monsoon. In the first phase (i.e., pre-monsoon), water samples from 134 wells were tested for arsenic and in the second phase (i.e., monsoon), water samples from 125 wells were tested. Some of the wells tested in the first phase could not be tested in the second phase due to non-operation of the wells and some of the wells that were not tested in the first phase were tested in the second phase. Thus, there were only 122 wells tested in both phases; 12 wells tested in pre-monsoon were not tested in monsoon; and 3 wells not tested in the pre-monsoon were tested in the monsoon. The number of well tested for arsenic in two phases is clearly shown in the following Venn diagram.

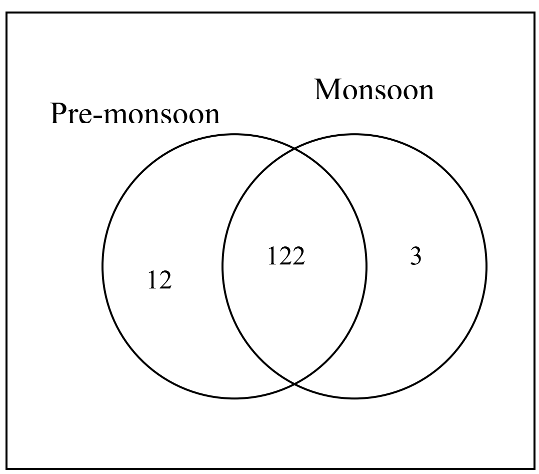

Figure 5.1. Venn diagram showing number of wells tested in pre-monsoon and monsoon

5.1.1 Arsenic concentration in pre-monsoon

Among 134 wells tested for arsenic in pre-monsoon, the highest arsenic concentration of 265 ppb was observed in Kuleswore followed by 250 ppb in Harihar Bhawan, 212 ppb in Balkhu and so on. The lowest arsenic concentration of less than 4 ppb (i.e. less that 5 ppb) was observed in 21 wells in different area of the valley. The histogram of arsenic concentration shows that the distribution of arsenic is strongly positively skewed which indicates that only few wells contain very high arsenic concentration (Figure 5.2). The percentile distribution of arsenic shows that 50% of tested wells are below 19 ppb and 75% of tested wells are below 33 ppb of arsenic concentration. The mean concentration of arsenic was found to be 32 ppb with standard deviation of 44 ppb. The basic statistics of arsenic concentration for pre-monsoon are shown in Table 5.1.

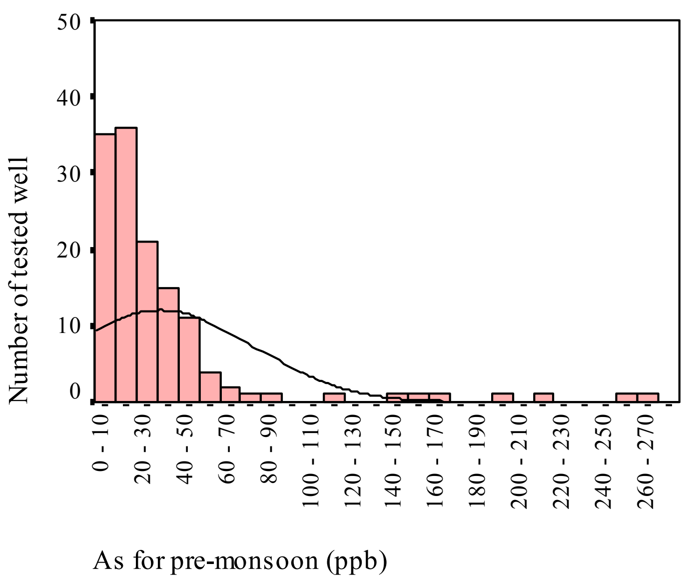

Figure 5.2. Histogram of arsenic concentration of tested wells for pre-monsoon

Table 5.1
Summary statistics for arsenic tested wells in pre-monsoon

Number of tested well	134
Mean (ppb)	32
Median (ppb)	19
Std. Deviation (ppb)	44
Minimum (ppb)	4
Maximum (ppb)	265
Percentiles (ppb)	
25th	8
50th	19
75th	33

The arsenic concentrations of tested wells are classified into three ranges – below WHO guideline of 10 ppb, between WHO and Nepal standard of 11–50 ppb and above Nepal standard of 50 ppb. About 11.9% of tested wells are above the Nepal standard of 50 ppb, and about 59.7% tested wells contain 11-50 ppb of arsenic. Thus, about 71.6% wells are above WHO guideline and about 28.4% of the wells are below WHO guideline (Figure 5.3 and Table 5.2).

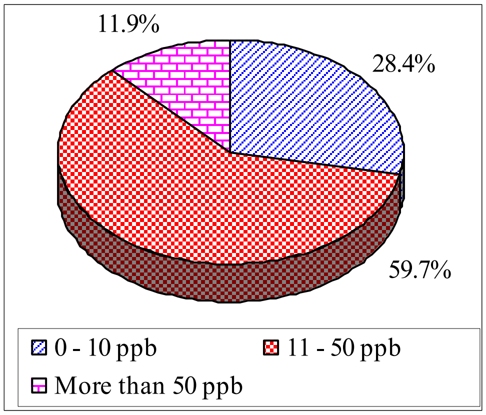

Figure 5.3. Classification of arsenic concentration in pre-monsoon

Table 5.2

Classification of arsenic concentration in pre-monsoon

Range	Number	*Percent*
0 - 10 ppb	38	*28.4%*
11 - 50 ppb	80	*59.7%*
More than 50 ppb	16	*11.9%*
Total	134	*100.0%*

5.1.2 Arsenic concentration in monsoon

Among 125 wells tested for arsenic in monsoon, the highest arsenic concentration of 211 ppb was observed in Kuleswore followed by 173 ppb in Harihar Bhawan, and so on. The lowest arsenic concentration of 4 ppb was observed in 28 wells in different area of the valley. The histogram of arsenic concentration shows that the distribution of arsenic is strongly positively skewed which indicates that only few wells contain very high arsenic concentration (Figure 5.4).

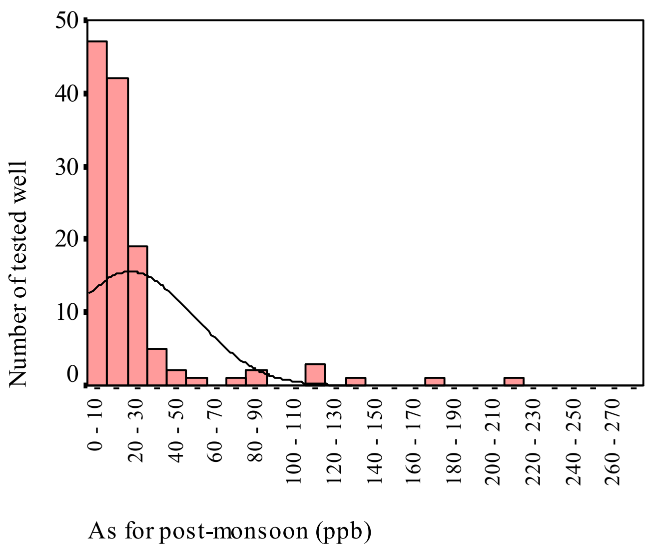

Figure 5.4. Histogram of arsenic concentration of tested wells for monsoon

Table 5.3

Summary statistics for arsenic tested wells in monsoon

Number of tested well	125
Mean (ppb)	22
Median (ppb)	13
Std. Deviation (ppb)	32
Minimum (ppb)	4
Maximum (ppb)	211
Percentiles (ppb)	
25th	6
50th	13
75th	22

The percentile distribution of arsenic shows that 50 % of tested wells are below 13 ppb and 75 % of tested wells are below 22 ppb of arsenic concentration. The mean concentration of arsenic was found to be 22 ppb with standard deviation of 32 ppb (Table 5.3). The classification of arsenic concentrations of tested wells into three classes shows that about 8.0% of tested wells are above the Nepal standard of 50 ppb, and about 48.8% tested wells contain 11-50 ppb of arsenic. Thus, about 56.8% wells are above WHO guideline and about 42.2% of the wells are below WHO guideline (Figure 5.5 and Table 5.4).

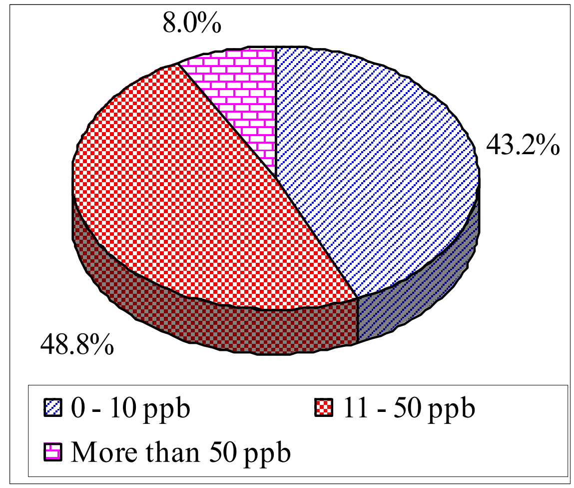

Figure 5.5. Classification of arsenic concentration in monsoon

Table 5.4
Classification of arsenic concentration in monsoon

Range	Number	*Percent*
0 - 10 ppb	54	*43.2%*
11 - 50 ppb	61	*48.8%*
More than 50 ppb	10	*8.0%*
Total	125	*100.0%*

5.2 Arsenic fluctuation monitoring of wells exceeding Nepal Standard

The major purpose of arsenic fluctuation monitoring is to see the fluctuation in arsenic values of a well in between total water extraction hours. The wells exceeding Nepal standard of 50 ppb of arsenic concentration in pre-monsoon were selected for arsenic fluctuation monitoring. However, the monitoring of one well could not be done since the owner of the well did not allow monitoring arsenic fluctuation. Thus, the arsenic fluctuation monitoring of 15 wells was done in two phases to compare with arsenic values of pre-monsoon and monsoon separately.

Three water samples were collected in between total water extraction hours of the sampling day for two consecutive days in May 2005. Thus, six water samples were tested for arsenic from each well. The results of these tests are shown in Table 5 with minimum, maximum and mean arsenic concentration of six samples for 15 wells with high arsenic concentration (i.e., more than 50 ppb). The arsenic values of these wells tested in pre-monsoon are also given in this table. The minimum and maximum arsenic concentrations of these wells are plotted in Figure 5.6, which shows that the fluctuation in arsenic is not much in the majority of tested wells for pre-monsoon. The statistical test (e.g., Man-Whitney Test) shows that there is no significance difference between the mean arsenic concentration of six samples and arsenic concentration of pre-monsoon. This is also clearly visualized in the Figure 5.7. In this figure, the mean arsenic of the six samples and arsenic values of pre-monsoon were plotted.

Table 5.5

Arsenic concentration of fluctuation monitoring wells for pre-monsoon

Well ID	Pre monsoon	Arsenic fluctuation monitoring results (ppb)						Mini-mum (ppb)	Maxi-mum (ppb)	Mean (ppb)
		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6			
49	74	76	67	110	91	76	87	67	110	85
50	212	84	96	215	97	225	225	84	225	157
17	190	97	210	325	97	175	190	97	325	182
21	158	82	78	80	172	156	172	78	172	123
80	54	54	46	54	146	59	50	46	146	68
81	68	56	63	62	76	62	64	56	76	64
91	54	44	30	38	17	15	33	15	38	30
92	69	67	48	49	59	32	36	32	59	49
93	52	45	43	47	43	42	42	42	47	44
94	169	90	116	93	83	95	73	73	116	92
95	250	124	124	125	148	129	142	124	148	132
107	51	9	8	9	9	14	16	8	16	11
119	87	62	22	66	73	47	83	22	83	59
130	110	94	91	96	99	99	103	91	103	97
137	265	200	145	212	145	206	217	145	217	188

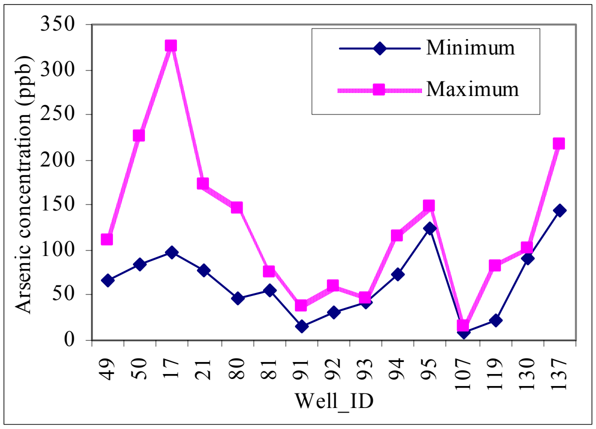

Figure 5.6. Minimum and maximum arsenic concentrations of monitored wells for pre-monsoon

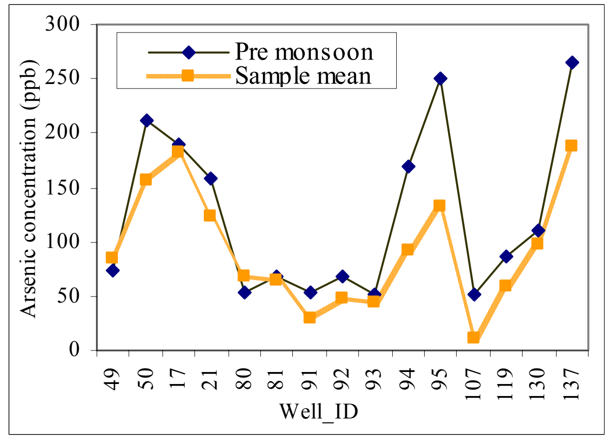

Figure 5.7. Mean arsenic of samples and arsenic concentrations for pre-monsoon

The arsenic fluctuation monitoring of these wells were also done in September to compare with the arsenic concentration of these wells in the monsoon. The same process was repeated for the monsoon too. The arsenic values of these samples with minimum, maximum and mean concentration is given in Table 5.6. The arsenic values of these wells tested in monsoon are also given in this table. There is not much fluctuation between these samples for all wells, except for the Well_ID 50, which is shown in Figure 5.8. In this case also, there is no significant difference between the mean arsenic concentration of six samples and the arsenic value of monsoon. This is also clearly observed in Figure 5.9.

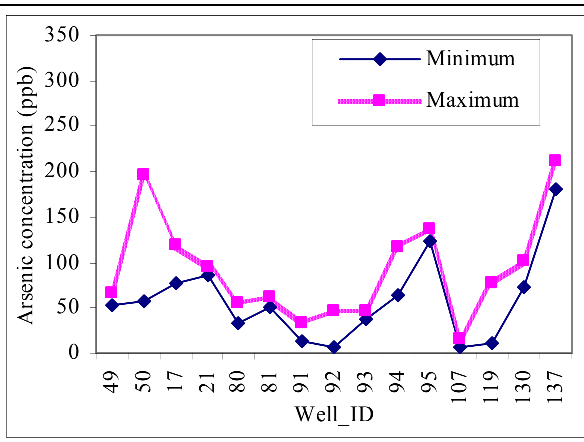

Figure 5.8. Minimum and maximum arsenic concentrations of monitored wells for monsoon

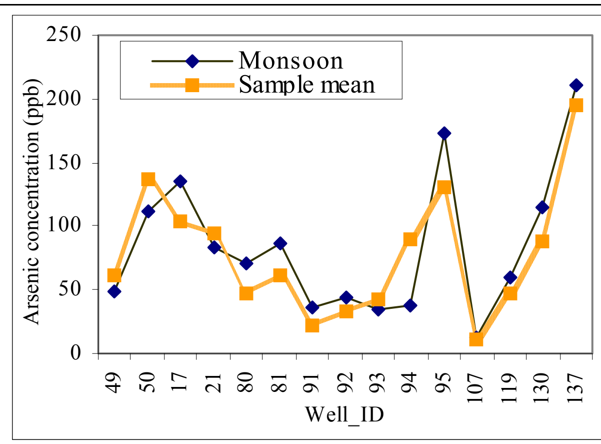

Figure 5.9. Mean arsenic of samples and arsenic concentrations for monsoon

Table 5.6

Arsenic concentration of fluctuation monitoring wells for monsoon

Well ID	Monsoon	Arsenic fluctuation monitoring results (ppb)						Mini-mum (ppb)	Maxi-mum (ppb)	Mean (ppb)
		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6			
49	48	53	65	67	56	63	65	53	67	62
50	111	58	159	171	63	177	195	58	195	137
17	136	78	113	110	92	115	119	78	119	105
21	84	107	94	95	90	92	85	85	95	94
80	71	49	38	51	34	53	55	34	55	47
81	87	87	55	55	62	54	51	51	62	61
91	36	18	14	19	33	24	27	14	33	23
92	44	40	36	39	7	46	30	7	46	33
93	35	42	44	41	37	47	47	37	47	43
94	37	116	117	103	65	70	63	63	117	89
95	173	131	136	136	125	124	133	124	136	131
107	13	9	8	6	12	14	15	6	15	11
119	59	12	48	64	13	72	77	12	77	48
130	115	95	99	101	73	78	78	73	101	87
137	211	180	207	211	194	192	188	180	211	195

5.3 Classification of arsenic tested wells by type of user

The wells tested for arsenic in this study belong to different types of users. There are seventeen types of users such as – NWSC, Hospital, Hotels and Resorts, School/College, Offices, Housing, Business complex, Private, etc. The number of arsenic tested wells corresponding to these users is given in Table 7. The majority of the wells correspond to NWSC. Among the total 134 arsenic tested wells in the valley, 35 wells are of NWSC, 24 wells are of Hotels and Resorts, 20 are of various offices, 13 wells are of schools/colleges, 12 wells are of hospital, and so on.

On classification of each user's well by arsenic concentration of pre-monsoon, more than 50% of wells of all user type exceed WHO guideline of 10 ppb arsenic concentration, except for three wells of carpet industry, Fishery, and Local water supply (i.e. DWSS and community based water supply). These three wells are safe considering the WHO guideline. The tested wells of Business complex, Hospital, Housing, NWSC, Office, School/college and Swimming pool exceed the Nepal Standard of 50 ppb of arsenic concentration in pre-monsoon. However, the number of such well reduces in monsoon, for example, all wells of Hospital and Swimming pool lie between WHO guideline and Nepal Standard in monsoon. The distribution of arsenic tested wells of various users by arsenic concentration are clearly shown in Figure 5.10 and Figure 5.11

for pre-monsoon and monsoon respectively and the numbers are given in Table 5.7 and Table 5.8 respectively.

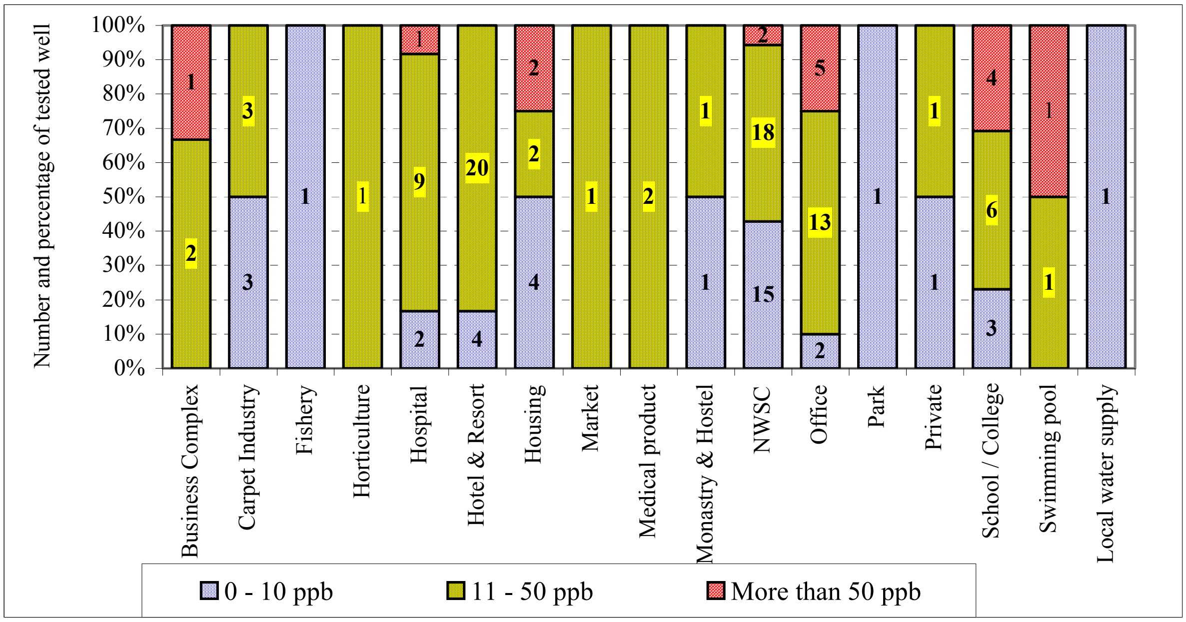

Figure 5.10. Distribution of tested wells by users and arsenic concentration for pre-monsoon

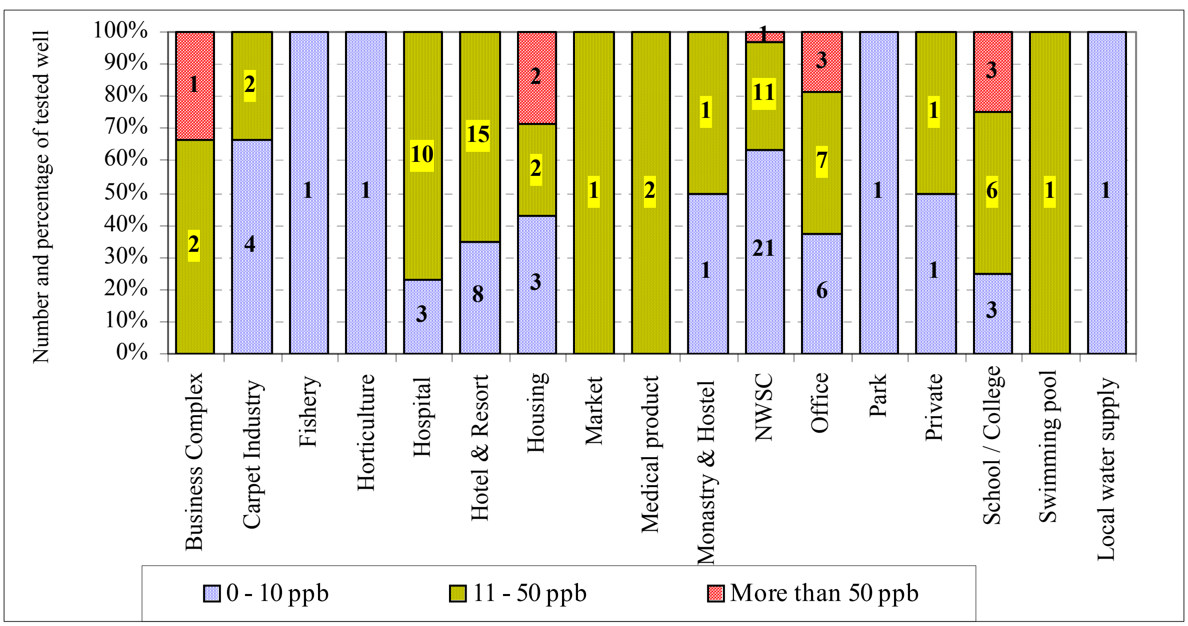

Figure 5.11. Distribution of tested wells by users and arsenic concentration for monsoon

Table 5.7

Number of wells by type of users and arsenic concentration for pre-monsoon

Type of user	Arsenic concentration			Total
	0 - 10 ppb	11 - 50 ppb	> 50 ppb	
Business Complex	0	2	1	3
Carpet Industry	3	3	0	6
Fishery	1	0	0	1
Horticulture	0	1	0	1
Hospital	2	9	1	12
Hotel & Resort	4	20	0	24
Housing	4	2	2	8
Market	0	1	0	1
Medical product	0	2	0	2
Monastry & Hostel	1	1	0	2
NWSC	15	18	2	35
Office	2	13	5	20
Park	1	0	0	1
Private	1	1	0	2
School / College	3	6	4	13
Swimming pool	0	1	1	2
Local water supply	1	0	0	1
Total	38	80	16	134

Table 5.8

Number of wells by type of users and arsenic concentration for monsoon

Type of user	Arsenic concentration			Total
	0 - 10 ppb	11 - 50 ppb	> 50 ppb	
Business Complex	0	2	1	3
Carpet Industry	4	2	0	6
Fishery	1	0	0	1
Horticulture	1	0	0	1
Hospital	3	10	0	13
Hotel & Resort	8	15	0	23
Housing	3	2	2	7
Market	0	1	0	1
Medical product	0	2	0	2
Monastry & Hostel	1	1	0	2
NWSC	21	11	1	33
Office	6	7	3	16
Park	1	0	0	1
Private	1	1	0	2
School / College	3	6	3	12
Swimming pool	0	1	0	1
Local water supply	1	0	0	1
Total	54	61	10	125

5.4 Relation of arsenic concentration by depth

Regarding the depth of arsenic tested wells, 120 wells tested in pre-monsoon and 113 wells tested in monsoon have recorded depth. The depth ranges from 50 to 318 m. For pre-monsoon, the average depth is 211 m with standard deviation of 75.7 m and for monsoon; it is 206 m with standard deviation of 76.4 m. Majority of the wells tested above Nepal standard of 50 ppb have depth more than 250 meter in both periods. The depth of tested wells is classified into three equal groups such as 50 -149 m, 150-249 m, and 250-349 m. Nearly half of the wells have depth more than 250 m, about 30% have depth between 150-249 m and one fourth of the wells have depth between 50 to 149 m in both periods (Figure 5.12 and Figure 5.13).

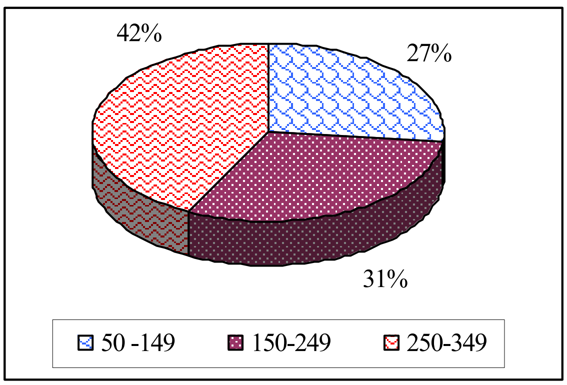

Figure 5.12. Distribution of wells by depth (m) for pre-monsoon

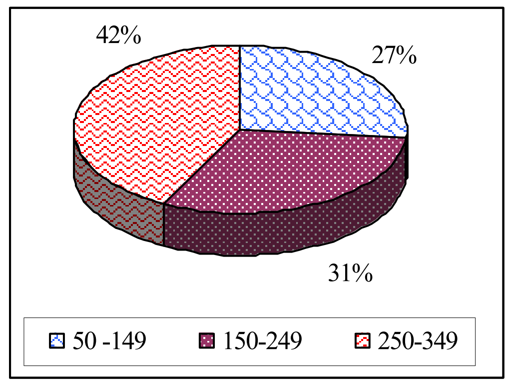

Figure 5.13. Distribution of wells by depth for monsoon

On classifying the wells of each depth group by three classes of arsenic concentration, the deeper wells have high arsenic concentration in both periods. The distribution of wells by three classes of arsenic concentration and depth groups of wells is given in Table 5.9.

Table 5.9

Classification of arsenic concentration by depth

	Arsenic concentration	**Depth group**						
		50 -149 m		**150-249 m**		**250-349 m**		**Total**
		Number	***Percent***	**Number**	***Percent***	**Number**	***Percent***	
Pre-monsoon	0 - 10 ppb	14	*48.3*	9	*24.3*	9	*16.7*	32
	11 - 50 ppb	14	*48.3*	24	*64.9*	34	*63.0*	72
	> 50 ppb	1	*3.4*	4	*10.8*	11	*20.4*	16
	Total	**29**	***100.0***	**37**	***100.0***	**54**	***100.0***	**120**
Monsoon	0 - 10 ppb	18	*60.0*	15	*42.9*	14	*29.2*	47
	11 - 50 ppb	11	*36.7*	17	*48.6*	28	*58.3*	56
	> 50 ppb	1	*3.3*	3	*8.6*	6	*12.5*	10
	Total	**30**	***100.0***	**35**	***100.0***	**48**	***100.0***	**113**

In pre-monsoon, the percent of wells containing more than 50 ppb of arsenic is only 3.4% for the first depth group (i.e. 50-149 m) and this percent increases to 10.8% in the second depth group (i.e., 150-249 m) and further increases to 20.4% in the third depth group of 250-349 m. The percent of wells containing 11-50 ppb of arsenic is also increasing from 48.3% in first depth group to more than 60% in the second and third depth groups. On the other hand, the percent of wells below WHO standard is decreasing from 48.3% in first depth group to 24.3% in the second depth group and further decreases to 16.7% in the third groups. Thus, it is clearly noticed that deeper wells have more arsenic concentration. This trend is also similar for monsoon as shown in Figure 14 and Figure 15. Regarding the correlation between depth of wells and arsenic concentration, there are very low positive correlations (i.e., 0.15 in pre-monsoon and 0.13 in monsoon), which indicate that deeper well have high arsenic concentration (Figure 5.16 and Figure 5.17).

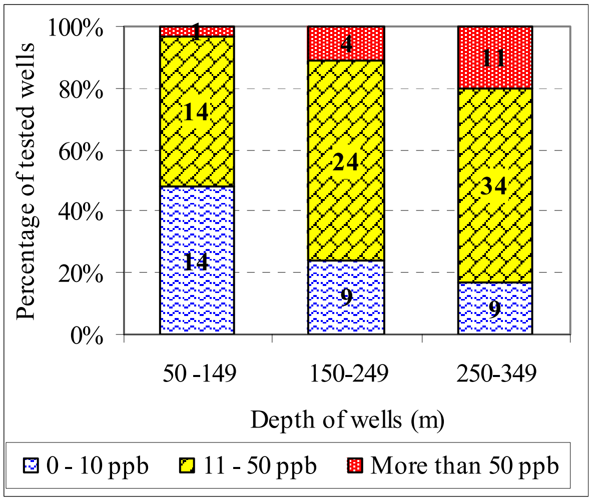

Figure 5.14. Classification of arsenic by depth group

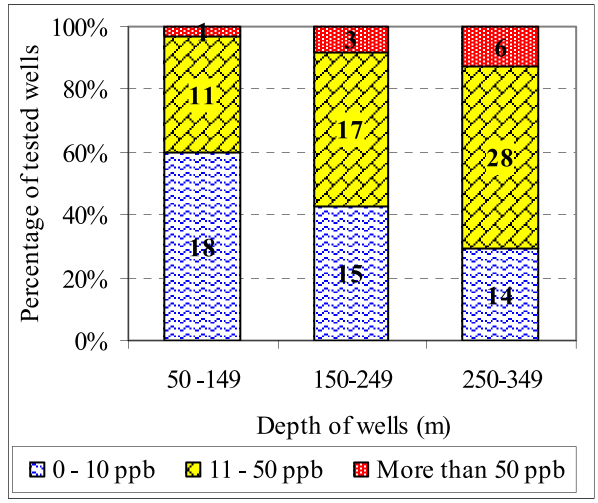

Figure 5.15. Classification of arsenic by depth group

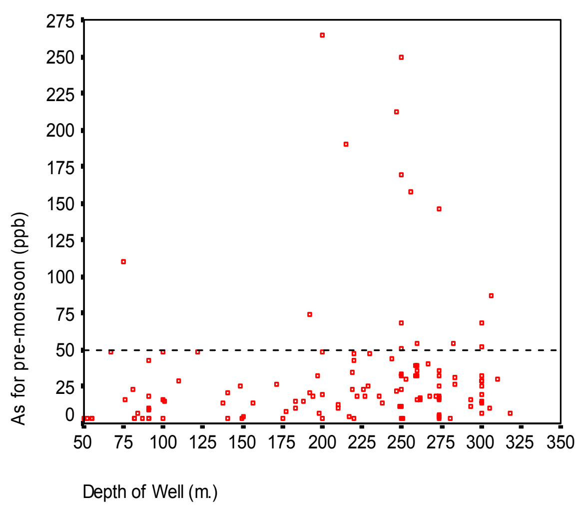

Figure 5.16. Scatter diagram of depth of well and arsenic concentration for pre-monsoon

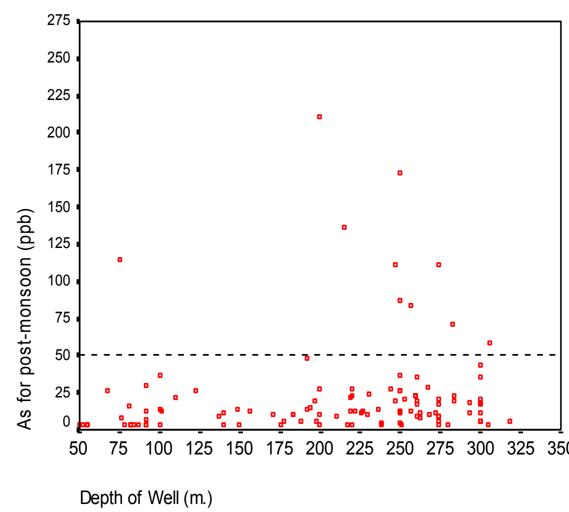

Figure 5.17. Scatter diagram of depth of well and arsenic concentration for monsoon

5.5 Arsenic concentration and the screen positions

The available lithologs from many deep wells show that the majority of the wells had more than one screen at different horizons. The wells tap multiple aquifers to abstract maximum amount of water. In doing so, water of various qualities is mixed. Most wells with arsenic concentration above 50 ppb have the screens placed on both the soft sediments and the basement rocks. It is not certain how this has affected the quality of water but two wells with above 50 ppb arsenic concentration have their screens only in the basement rocks and both have arsenic concentration above 50ppb. A well in Sanepa (i.e., Well_ID 130) has only a single screen and has the arsenic concentration of 110 ppb in pre-monsoon and 115 ppb in the monsoon. Another well of Pulchowk, near to Sanepa, (i.e., Well_ID 081) has multiple screens placed in the basement rocks and have the arsenic concentration of 68 ppb in the pre-monsoon period and 087 ppb in the monsoon.

The lithologs of 5 wells containing more than 50 ppb of arsenic shows that most of the wells are placed on the basement rocks and most of them extract water from both the rock as well as the sediment above consisting of mainly sand and gravel (Annex 3). In this region the basement rocks are at shallow depth. The basement rocks are basically limestone and the sandstone. Hence high arsenic concentration show direct relation with the placing of screens near or on the basement rock. The aquifer horizons tapped ranges from 998 m to 1312 m above mean sea level. GK3, a well has utilized the maximum screen length of 198 m to draw water. The number of screens used range from 1-5.

5.6 Variation in arsenic concentration from pre-monsoon to monsoon

The Figure 2 and Figure 4 show that the distribution pattern of arsenic concentration in pre-monsoon and monsoon is almost similar. Regarding the concentration values, it is remarkably noticed that arsenic concentrations are lower in monsoon compared to pre-monsoon. The mean concentration of 32 ppb in pre-monsoon has reduced to 22 ppb in monsoon. Similarly, the median concentration has also reduced from 19 ppb in pre-monsoon to 13 ppb in monsoon. In pre-monsoon, about one third of wells are below WHO guideline whereas in monsoon, nearly half of the wells are below WHO guideline.

The decreasing pattern of arsenic from pre-monsoon to monsoon is also clearly observed when the arsenic concentration is classified into three ranges as shown in Table 5.5. It has been mentioned earlier that among 137 wells tested, 122 wells were tested for arsenic in both pre-monsoon and monsoon.

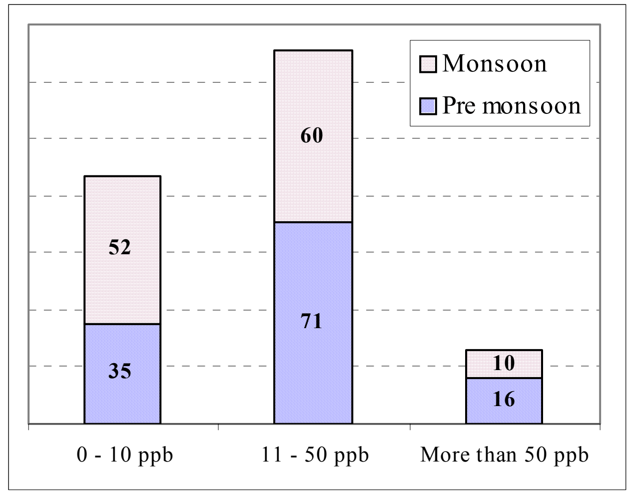

Figure 5.18. Number of wells by range of arsenic concentration

Of the total 122 tested wells in both phases, 35 wells contain below 10 ppb of arsenic in pre-monsoon whereas this figure increases to 52 in monsoon. On the other hand, among 71 wells containing 11–50 ppb of arsenic in pre-monsoon, there are such wells in monsoon. In case of wells containing more than 50 ppb, there are 16 such wells in pre-monsoon and 10 wells in monsoon. Thus, 17 wells of 11-50 ppb of arsenic tested in pre-monsoon contain less than 10 ppb in monsoon. There are 6 wells which contain more than 50 ppb of arsenic in pre-monsoon and between 11–50 ppb in monsoon. Thus, 23 wells change from one class to other class of arsenic classification during monsoon (Figure 5.18 and Table 5.10).

Table 5.10

Classification of arsenic concentration by pre-monsoon and monsoon

Arsenic concentration		Monsoon				
		0 - 10 ppb	11 - 50 ppb	> 50 ppb	Total	%
Pre-monsoon	0 - 10 ppb	35	-	-	35	*28.7*
	11 - 50 ppb	17	54	-	71	*58.2*
	> 50 ppb	-	6	10	16	*13.1*
	Total	52	60	10	122	*100*
	Percent	*42.6*	*49.2*	*8.2*	*100*	

Considering the arsenic value of each of tested wells in both phases, the arsenic concentration of almost all well reduces from pre-monsoon to monsoon, which is clearly visualized in Figure 5.19. In this figure, all 137 wells are plotted along the x-axis and the y-axis represents the values of arsenic. It is clearly observed that arsenic values are reducing from pre-monsoon to monsoon indicating the effect of monsoon in arsenic concentration. The statistical test also shows that the average arsenic concentration of pre-monsoon is significantly different from that of monsoon.

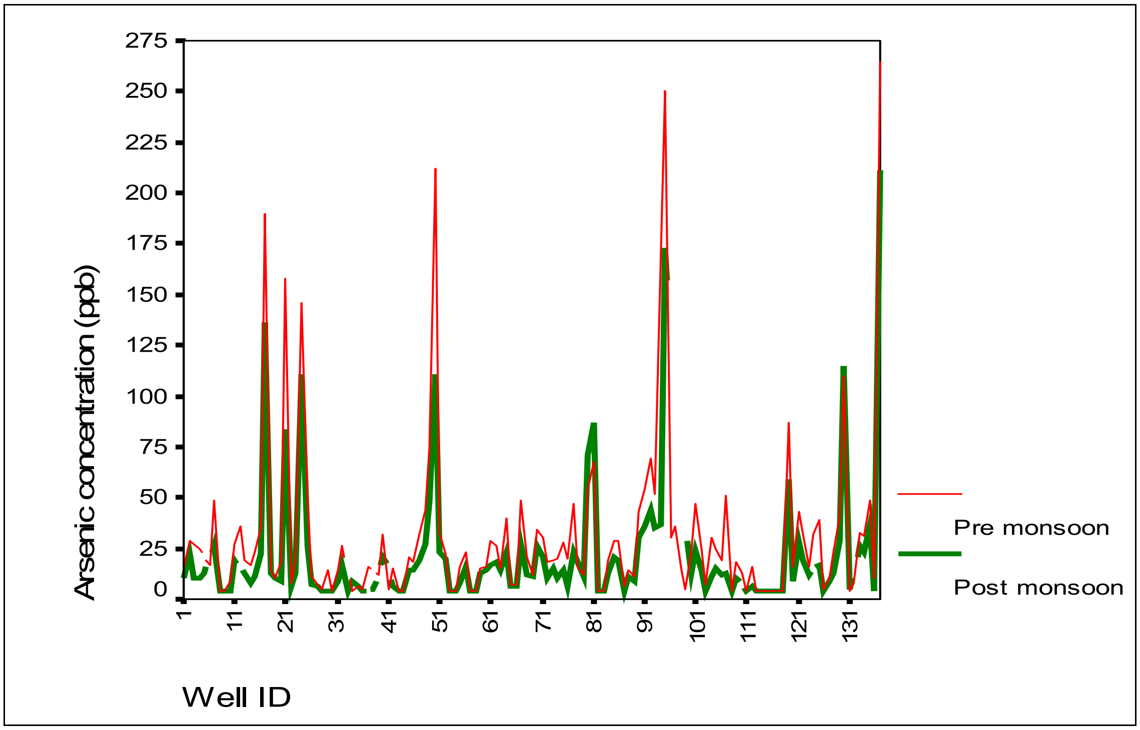

Figure 5.19. Variation of arsenic concentration from pre-monsoon to monsoon

The Figure 5.20 also shows that there is very close relation between pre-monsoon and monsoon regarding the arsenic concentration. The distributions of arsenic concentration for two periods are very similar. The correlation between arsenic concentration of pre-monsoon and monsoon is 0.94, which is highly significant at 0.01 level of significant based on 122 tested wells. The following scatter diagram of arsenic values of two periods suggests the strong correlation between arsenic concentrations of pre-monsoon and monsoon.

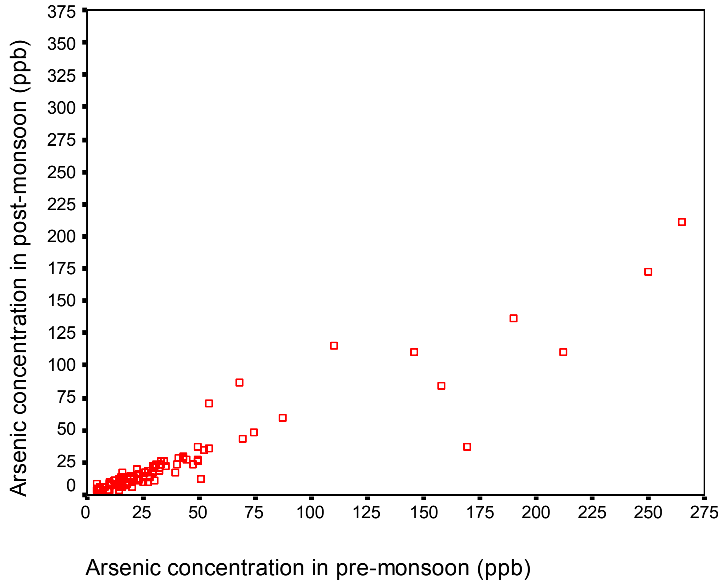

Figure 5.20. Scatter diagram of pre-monsoon and monsoon arsenic concentration

5.7 Spatial distribution of arsenic concentration

5.7.1 Mapping of arsenic concentration

The location information of wells tested for arsenic in pre-monsoon and monsoon was also collected in this study. All tested wells have geographical coordinates (i.e., longitude and latitude). These wells are located in the map of Kathmandu Valley. Two types of map are used to locate the wells, which are Topographic map and Geological map. All tested wells are located in the Topographic map with four features – boundary, road, river and land use and in the Geological map with geological formation. The major purpose of mapping of arsenic concentration is to show the spatial distribution of arsenic in the valley. The map provides the exact location of arsenic tested well in geographical coordinates with the arsenic concentration in one of the three ranges: 0-10 ppb, 11-50 ppb and >50 ppb. As the wells are distributed over about 450 sq km (i.e., 18 km x 25 km) of the central part of the valley, the boundary of the map is limited to this area and is defined as “study area”.

Six types of maps are prepared to show the spatial distribution of arsenic concentration in Kathmandu Valley in pre-monsoon and monsoon separately. These are

- Map 1 - *Distribution of Arsenic Concentration in Kathmandu Valley (Pre-monsoon, 2005)*
- Map 2 - *Distribution of Arsenic Concentration in Kathmandu Valley (Monsoon, 2005)*
- Map 3 - *Variation in Arsenic Concentration in Kathmandu Valley (Pre-monsoon – Monsoon, 2005)*
- Map 4 - *Variation in Arsenic Concentration in Kathmandu Valley by Geological Formation (Pre-monsoon – Monsoon, 2005)*
- Map 5 - *Arsenic Concentration of Well by depth in Kathmandu Valley (Pre-monsoon, 2005)*
- Map 6 - *Arsenic Concentration of Well by depth in Kathmandu Valley (Monsoon, 2005)*

The Map 1 provides the locations of 134 wells tested for arsenic in pre-monsoon. It shows that most of the tested well of northern part are safe regarding the WHO guideline. The majority of wells of the central part are above WHO standard. The wells located in the central settlement below the Bagamati River of the Lalitpur area have high arsenic concentration exceeding the Nepal standard. In the far-western and far-eastern part of the valley, the arsenic concentration is seen low. However, very few wells of this part were tested.

The Map 2 provides the locations of 125 wells tested for arsenic in monsoon. It also shows the same pattern of spatial distribution of arsenic concentration as in Map 1 of pre-monsoon. Comparatively, the number of wells exceeding WHO standard and hence Nepal standard, are less in the Map 2 of Monsoon. Such variation in arsenic concentration of each tested well from pre-monsoon to monsoon is clearly visualized in the Map 3. In this map, square symbol represents the arsenic concentration of pre-monsoon and the overlaid circle represents the arsenic concentration of monsoon of the same tested well. The map clearly shows that for the both the pre-monsoon and the monsoon, there is a narrow belt of Balkumari-Pulchowk-Kuleswor-Rabibhawan in the central west of the valley with high arsenic concentration exceeding Nepal Standard of above 50 ppb. A well of Kuleswor with the highest arsenic value of 265 ppb in pre-monsoon also lies in this region. Some areas near to this region such as Thapathali, Tripureswor also have comparatively high arsenic concentration exceeding WHO guideline value.

5.7.1.1 Arsenic concentration and the geology

The Map 4 provides the locations of tested wells with respect to geological formation of the valley and with one of arsenic concentration ranges. There are 16 types of geological formation shown in the map of study area. However, the arsenic tested wells are located only in 7 types of geological formation, which are - Chandragiri, Chapagau, Gokarna, Kalimati, Lokundol, Recent floodplain, and Tokha. The distribution of number of tested well by geological formation is shown in Figure 5.21 and Table 5.11.

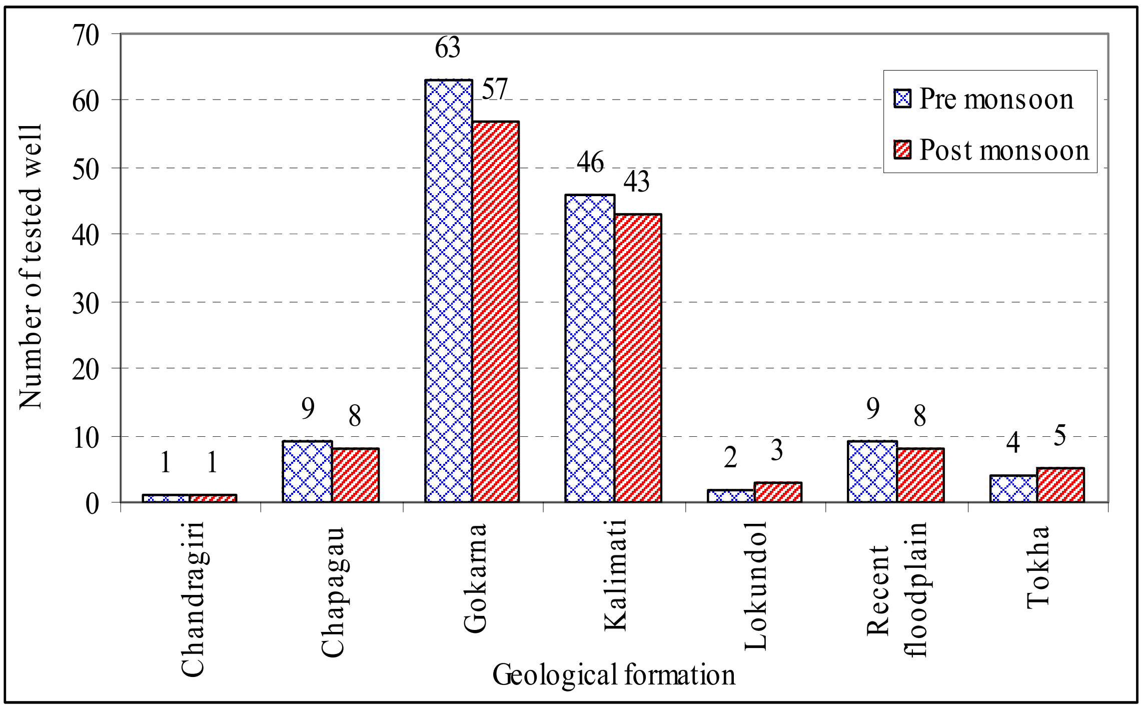

Figure 5.21. Number of tested wells by geological formation

Table 5.11

Distribution of arsenic tested wells by arsenic concentration and geological formation

	Geological formation	0 - 10 ppb		11 - 50 ppb		More than 50 ppb		Total	% in total
		Number	%	Number	%	Number	%		
Pre-monsoon	Chandragiri	1	100.0			0.7		1	0.7
	Chapagau	4	44.4	3	33.3	6.7	22.2	9	6.7
	Gokarna	16	25.4	46	73.0	47.0	1.6	63	47.0
	Kalimati	8	17.4	25	54.3	34.3	28.3	46	34.3
	Lokundol	1	50.0	1	50.0	1.5		2	1.5
	Recent floodplain	4	44.4	5	55.6	6.7		9	6.7
	Tokha	4	100.0			3.0		4	3.0
	Total	**38**		**80**		100.0		**134**	100.0
Monsoon	Chandragiri	1	100.0			0.8	0.0	1	0.8
	Chapagau	3	37.5	3	37.5	6.4	25.0	8	6.4
	Gokarna	27	47.4	30	52.6	45.6		57	45.6
	Kalimati	10	23.3	25	58.1	34.4	18.6	43	34.4
	Lokundol	2	66.7	1	33.3	2.4		3	2.4
	Recent floodplain	6	75.0	2	25.0	6.4		8	6.4
	Tokha	5	100.0			4.0		5	4.0
	Total	**54**		**61**		100.0		**125**	100.0

Regarding the geological formation of the study area, the highest number of tested well (63 in pre-monsoon and 57 in monsoon) lie in the Gokarna formation, followed by Kalimati formation (46 in pre-monsoon and 43 in monsoon), and so on. Very few wells tested for arsenic are distributed over other formations. On classification of these wells with respect of arsenic concentration range, the majority of wells exceeding WHO guideline lie in Kalimati formation followed by Gokarn, Recent floodplain, and Chapagau. Some of these wells in Kalimati, Chapagau and Gokarn formations, further, exceed the Nepal Standard. The arsenic value of one well in Gokarn formation having more than 50 ppb in pre-monsoon reduces to 13 ppb in monsoon. All tested wells belonging to Chandragiri and Tokha formations are below WHO guideline in both pre-monsoon and monsoon. However, the number of wells tested for arsenic of lying in these formations are very few, for example, only one well of Chandragiri formation was tested in both periods and 4 wells in pre-monsoon and 5 wells in monsoon lying in Tokha formation were tested (Figure 5.22 and Figure 5.23).

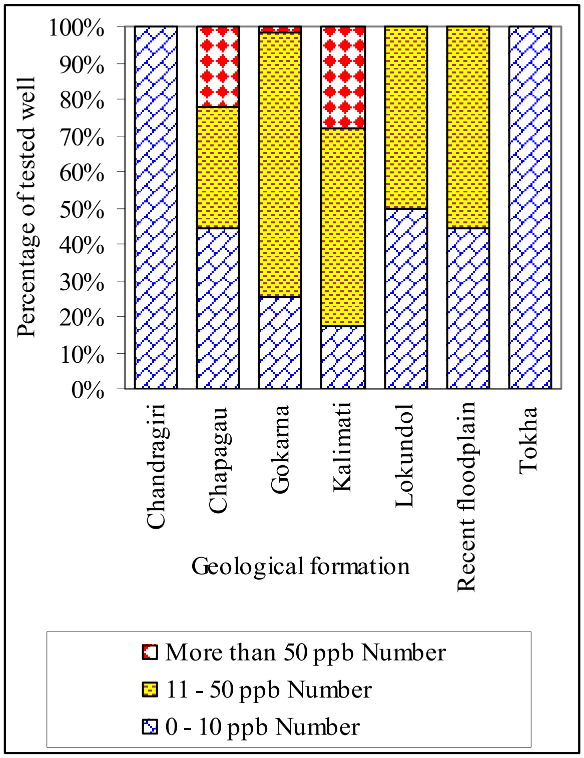

Figure 5.22. Distribution of wells tested in pre-monsoon by arsenic concentration and geological formation

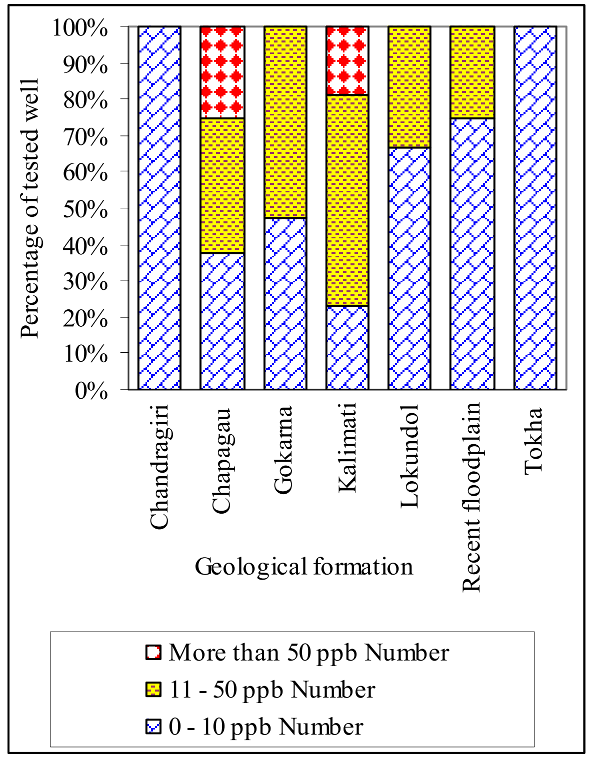

Figure 5.23. Distribution of wells tested in monsoon by arsenic concentration and geological formation

The spatial distribution of all tested wells with classification of arsenic concentration with respect to geological formation is visualized clearly in the Map 4. Generally, arsenic concentration in any particular well, especially the deep well, is influenced by subsurface geology or the aquifer horizon exploited rather than the surface geology. Arsenic concentration in Terai region is much influenced by the type of deposits (Shrestha et al 2004). In general, coarse region with grained sediments have low arsenic, which is also observed in this study. Wells in the northern most part, i.e. in Tokha formation and northern half part of Gokarna formation generally have arsenic concentration below 10 ppb or only slightly higher. This is also true in the southern part where although there are only few wells, all of them have arsenic concentration below 10 ppb. In Terai, higher arsenic is associated with fine grained sediments. This is also true in this study. The thick Kalimati layer of the Kalimati Formation does seem to influence the arsenic concentration in the wells to some extent.

5.7.1.2 Arsenic concentration and the hydrogeological boundary

As the distribution of hydrogeological boundary is based on the geology and the hydrogeological parameters, the influence is very of much imminent in the arsenic concentration. Most wells in the northern part of the northern groundwater district have arsenic concentration below or near 10 ppb due to relatively coarser grained sediments which make up the aquifer material. Although the boundary between the northern groundwater district and the central groundwater district crosses right across the Gokarna formation in the west and the Kalimati formation in the east, the Kalimati layer is relatively thin and not continuous as compared to the south as shown in the Map 4.

The majority of the arsenic tested wells exceeding WHO guideline of 10 ppb of arsenic concentration are restricted to the Central Groundwater District. Wells with very high arsenic content are concentrated in a very small area of Hariharbhavan, Kalanki and Kuleswor area. Only five wells lie in the southern groundwater district and all have arsenic concentration below WHO guideline.

5.7.1.3 Arsenic concentration and the depth

The Map 5 presents the locations of 120 arsenic tested wells in pre-monsoon, whose depth were recorded. The wells are classified into one of the three ranges of arsenic concentration- 0-10 ppb, 11-50 ppb, and more than 50 ppb; and one of the three groups of depth: 50-149 m, 150-249 m, and 250-349 m. Similarly, the Map 6 shows the locations of 113 wells tested for arsenic in monsoon, which have depth measurement. Here also, each well is classified into one of three depth groups and ranges of arsenic concentration.

The six types of maps discussed above are presented in the following pages.

Map 1 - *Distribution of Arsenic Concentration in Kathmandu Valley (Pre-monsoon, 2005)*

Map 2 - *Distribution of Arsenic Concentration in Kathmandu Valley (Monsoon, 2005)*

Map 3 - *Variation in Arsenic Concentration in Kathmandu Valley (Pre-monsoon – Monsoon, 2005)*

Map 4 - *Variation in Arsenic Concentration in Kathmandu Valley by Geological Formation (Pre-monsoon – Monsoon, 2005)*

Map 5 - *Arsenic Concentration of well by depth in Kathmandu Valley (Pre-monsoon – Monsoon, 2005)*

Map 6 - *Arsenic Concentration of well by depth in Kathmandu Valley (Pre-monsoon – Monsoon, 2005)*

5.7.2 Zoning of Kathmandu Valley

This is one of the major and complex tasks of the study. This aims to zoning of the Kathamandu Valley with respect to arsenic concentration. The main purpose of zoning is to show the pattern of spatial dependence quantitatively. Such pattern can be used to aid the setting of priority areas for emergency testing of arsenic, and perhaps in the future, to help guide a national water resource strategy.

The zoning of the valley involves geostatistical analysis of arsenic concentration of the wells distributed over the valley. So far, it has been observed that the arsenic concentration varies from well to well. That means it is spatial in nature. So, it is important to study the behavior of arsenic concentration spatially taking into consideration the location of each well. A well known approach of such analysis is geostatistics. It assumes that the arsenic values of adjoining wells are correlated to each other spatially and this correlation is measured by a function known as 'Variogram'. The variogram model is explained by three parameters – range, sill and nugget effect. Usually, the variogram values increases as the separation distance between the pairs of the data values increases. For large separation distances, the variogram value generally remains stable at around some value, which is known as the 'sill'. The distance at which the variogram value remains stable is called the 'range'. The range describes the zone of influence, as there will be no longer correlation within distances beyond the range. The discontinuity of the variogram at the origin is known as the 'nugget effect' and is due to measurement errors and micro-variabilities of the sample values. (Journel and Huijbregts, 1989). Once the parameters of variogram are determined from the sample arsenic values, the variogram model is fitted to the data and then, the fitted model is used to estimate the arsenic values of unknown location and to produce a map of arsenic concentration as an interpolated grid surface of the study area.

The spatial continuity of arsenic concentration in the Kathmandu valley was measured by variogram for pre-monsoon and monsoon separately. The variogram for the $\log_{10}$-transformed arsenic concentration of pre-monsoon and monsoon were computed up to lag distance of 15 km at intervals of 500 meter. As the distribution of arsenic data of pre-monsoon and monsoon are very similar, the variogram models also found very similar for pre-monsoon and monsoon. The spherical model with range of 9 km, sill of 0.99 $(ppb)^2$, and nugget effect of 0.36 (ppb)2 was fitted to the arsenic data of pre-monsoon. Similarly, the spherical model with range of 9 km, sill of 0.68 $(ppb)^2$, and nugget effect of 0.32 (ppb)2 was fitted to the arsenic data of monsoon. Then, the maps of arsenic concentration as an interpolated grid surface were created by Ordinary Kriging Method using geostatistical software GS+. The corresponding maps of standard errors of the estimates were also created for both pre-monsoon and monsoon.

Thus, four types of maps were prepared for zoning of the Kathmandu valley with respect to arsenic concentration, which are

- Map 7 - *Zoning of Kathmandu Valley by Arsenic Concentration (Pre-monsoon, 2005)*
- Map 8 - *Zoning of Kathmandu Valley by Arsenic Concentration (Monsoon, 2005)*
- Map 9 - *Standard Error of Estimated Arsenic Concentration in Kathmandu Valley (Pre-monsoon, 2005)*
- Map 10 -*Standard Error of Estimated Arsenic Concentration in Kathmandu Valley (Monsoon, 2005)*

The Map 7 and the Map 8 reveal the zoning of the valley with respect to arsenic concentration into six zones of arsenic range - 0-10 ppb, 11-20 ppb, 21-30 ppb, 31-40 ppb, 41-50 ppb and greater than 50 ppb – for pre-monsoon and monsoon, respectively. The Map 9 and the Map 10 provide the corresponding standard error of estimated values of arsenic concentrations for pre-monsoon and monsoon respectively. These maps are shown in the following pages.

Map 7 - *Zoning of Kathmandu Valley by Arsenic Concentration (Pre-monsoon, 2005)*

Map 8 - *Zoning of Kathmandu Valley by Arsenic Concentration (Monsoon, 2005)*

Map 9 - *Standard Error of Estimated Arsenic Concentration in Kathmandu Valley (Pre-monsoon, 2005)*

Map 10 - *Standard Error of Estimated Arsenic Concentration in Kathmandu Valley (Monsoon, 2005)*

Chapter VI
Vulnerability Assessment

Vulnerability of arsenic in groundwater resources were categorized in three classes - Highly vulnerable (Above 50ppb), Vulnerable (11-50 ppb) and Safe (0-10 ppb) according to arsenic concentration above Nepal standard, within Nepal standard and within WHO standard respectively. Arsenic concentration within Nepal standard in the map for zoning was further classified into four classes from 11-20 ppb to 41 to 50 ppb as discussed in Chapter V.

Vulnerable area in pre-monsoon is larger compare to the vulnerable area in monsoon reference to the zoning maps for pre and monsoon; therefore, the arsenic vulnerability map for Kathmandu Valley is produced on the basis of zonning map for pre-monsoon. Arsenic vulnerability map is a topographic map of Kathmandu valley with arsenic concentration zones, NWSC's well fields, groundwater districts and location of deep tubewells using for different purposes in the valley. Geographic coordinates of the wells other than sampled wells located in the map are taken from the report "Urban Water Supply Reforms in the Kathmandu Valley, Groundwater Monitoring Program (UWSR)", (Annex 4). It is important to note here that no verification has been done for the locations of these wells.

Vulnerability of arsenic in different aspects based on this map were analyzed and discussed in following paragraphs.

6.1 Vulnerability to groundwater district

Chapter IV has discussed about groundwater system of Kathmandu Valley, which is also shown in the arsenic vulnerability map. It shows that northernmost part of the north groundwater district is safe whereas lower part of the district is in vulnerable within the Nepal interim standard. Majority of the central district are vulnerable, some part of this district even are highly vulnerable which is demarked in the map by red zoning line. Whereas farthermost south of the southern district is safe but upper part of this district is vulnerable and small part of the upper part is even highly vulnerable.

6.2 Vulnerability to well fields of NWSC

There are five well fields of NWSC shown in the vulnerability map. Gokarna well field and Pharping well field in the northern most and southern most part of the study area are in safe zone. Major part of the Bansbari well field with exception of small area is located in safe zone. Major part of Dhobikhola well field and Manohara well field are located in vulnerable zone with 11-20 ppb but the small area of Manohara well field is located in 21-30 ppb zone.

6.3 Vulnerability to wells

Vulnerability map shows wells which have been using for different purposes such as NWSC, local water supply systems (DWSS/community water supply), housings, school/colleges, hospitals, hotel and resorts, business complexes, offices, industries and others. Other category includes private wells, swimming pools, vegetable markets etc. Geographic coordinates of wells which are not included in testing were taken from UWSR. List of wells included in vulnerable map is given in Annex 4. Table below shows the distribution of wells with type of users and corresponding vulnerability zone. Well users other than NWSC, local water supply, housing and school/college generally do not use water from well for drinking purposes, therefore, arsenic contamination for such users are not very serious issue. But high concentration of arsenic issue for users such as NWSC, local water supply system, housing, school/college has to taken seriously. Local water supply systems are located in vulnerable zone but not in highly vulnerable zone. But some of NWSC wells, housing, school/college wells are located in highly vulnerable zone. Vulnerability of arsenic in water supply system due to NWSC wells will be discussed in following paragraph. Some recently developed residential colonies (housing) near the urban centers which have high arsenic content and are likely to be used for drinking purposes owing to the fact that many of these residential areas may not be receiving adequate amount of treated water from the city water supply system.

Map of Arsenic Vulnerability in Kathmandu Valley

Table 6.1

Users	Distribution of wells by vulnerability zone							Total
	0-10ppb	11-50ppb					**Above 50ppb**	
		11-20	**21-30**	**31-40**	**40-50**	**Total**		
NWSC	27	24	20	2	3	49	3	79
Local water supply	2	1	1	1	-	3	-	5
Housing	2	1	2	1	-	4	2	8
School / College	5	2	5		1	8	8	21
Hospital	-	4	3	5	2	14	2	16
Hotel & Resort	1	6	32	2	2	42	2	45
Business Complex	-	-	-	3	2	5	1	6
Office	-	1	4	11	2	18	4	22
Industry	8	13	5	6	1	25	4	37
Others	3	1	4	2	7	14	1	18
Total	48	53	76	33	20	182	27	257

6.4 Vulnerability to NWSC water supply system

All NWSC wells located at northernmost and southernmost of the study area are safe. But most of the NWSC wells are located in vulnerable area. Moreover, majority of these wells are located at 11-20 ppb zone. Few wells are even located in highly vulnerable area. Therefore, it is important to know the vulnerability of arsenic due to these wells in the NWSC water supply system, since water from NWSC network is the main source of drinking water in the valley. There are two types of NWSC water supply systems, one with reservoir and another is local supply system. Local supply systems are for providing water at local area and system with reservoir are for larger part of the urban areas. Following tables show the arsenic tested wells with arsenic concentration, their corresponding reservoirs or supply system and distribution area. Table 6.2 is for system with reservoir and Table 6.3 is for local supply system. Regular, *Italic*, and **Bold** number in following columns represent arsenic concentration 0-10 ppb, 11-50 ppb and above 50 ppb respectively.

Majority of wells in most of the systems with reservoirs are within WHO standard except in case of Bode and Lokanthali. Therefore, only the distribution areas covered by Bode and Lokanthali can be potential vulnerable areas within 11-50 ppb.

Table 6.2

Water supply system through reservoir						
System with Reservoir	Treat-ment	WellID	Well	Arsenic Concentration (ppb)		Distribution Area
				Pre-monsoon	Monsoon	
Bansbari/ Maharajgunj	Yes	026	NWSC, BB-0	*11*	7	Ward 3,4,29,30 (partial), 17(Partial), 26 (partial), 18(partial), 2, 19(partial)
		027	NWSC, BB-6	7	6	
		028	NWSC, BB-3	5	ND	
		029	NWSC, BB-1	*14*	ND	
		030	NWSC, BB-2	ND	ND	
Balaju	Yes	034	NWSC, MK-3	ND	9	North West of KMC - 16,15,17,18,19,13,
		035	NWSC, MK-4	6	6	
		037	NWSC, MK-2	*16*	-	
Mahankal Chaur	Yes	041	NWSC, DK-5	5	-	7, 8, 9, 10 (partial), 31, 32, 33, 34 (partial), 24, 25, 20, 21, 22, 23, 19 (partial), 25, 26 (partial), 27 (partial), 28(partial), 30 (partial), 1, 5, 11 (partial), 12 (partial), 13 (partial)
		043	NWSC, GK-2	ND	ND	
		044	NWSC, GK-3	ND	ND	
		045	NWSC, MH-3	*21*	*14*	
		046	NWSC, MH-4	*18*	*14*	
		047	NWSC, MH-6	*32*	*19*	
Sainbu	Yes	053	NWSC, PH-1	ND	ND	Lalitpur (west,Mid),Sainbu VDC, Khokana,Bungmati,Chunikhel
		054	NWSC, PH-2	ND	ND	
Lokanthali	Yes	051	NWSC, Lokanthali	*33*	*23*	Thimi 17,16,15(partial), kmc35 (partial)
Bode	No	086	NWSC TW No 4	*29*	*19*	Ward 1-15, Bhaktapur west, KMC 10, 34 (partial)
Bansabari, Bhaktapur		087	NWSC Bansbari well	6	ND	Bhaktapur north, south, east

Note : ND (<5 ppb) - Not detected

Majority of local supply systems have wells with 11-50 ppb, therefore, distribution areas under these systems are vulnerable. Moreover, there are two local systems shown in table with highly vulnerable wells. Distribution areas under these systems are highly vulnerable to arsenic.

Table 6.3

Local water supply system						
Local system	**Treat-ment**	**WellID**	**Well**	**Arsenic Conc. (ppb)**		**Distribution Area**
				Pre-monsoon	**Monsoon**	
Kuleswor	Yes	049	NWSC, Kuleswor Awash	**74**	*48*	Kuleswor Awash ward 14
Sipardi (Balkhu)	Yes	050	NWSC, Kalanki	**212**	**111**	Ward 14, 13
Sitapaila	No	033	NWSC, Sitapaila		ND	15 (partial), Sitapaila VDC
Balaju Chakrapath	No	038	NWSC, Balaju		5	Gongabu VDC, 29 (partial)
Gongabu Awash	No	039	NWSC, Gongabu Awash	*12*		Gongabu Awash
Shankha Park	Yes	031	NWSC, Shankhpark	*14*	9	3, 4(partial)
Tripureswor	No	048	NWSC, Tripureswor	*44*	*27*	11(partial), 21(Partial)
Tahachal Campus	Yes	032	NWSC, Tahachal	*26*	*17*	13(Partial),15(Partial)
Baniyatar	No	036	NWSC, Baniyatar	5	ND	Gongabu VDC
Lagan	Yes	052	NWSC, Lagan	*22*	*20*	Lagan area, ward 21 (partial)
Sinamangal	Yes	040	NWSC, Sinamangal	*32*	*21*	Sinamangal ward 9
Khadga Bhadrakali		108	NWSC, Well No. 9	ND	ND	Bansbari area
Jagate		089	NWSC, Jagate	*11*	9	Jagate area
Local supply from Bansbari well field	No	026	NWSC, BB-0	*11*	7	Gongabu VDC, Mahankal VDC, Dhapasi VDC
		027	NWSC, BB-6	7	6	
		028	NWSC, BB-3	5	ND	
		029	NWSC, BB-1	*14*	ND	
		030	NWSC, BB-2	ND	ND	
Local supply from Mahadev khola well field	No	034	NWSC, MK-3	ND	9	Manamaiju VDC (partial)
		035	NWSC, MK-4	6	6	
		037	NWSC, MK-2	*16*	-	
Local supply from Dhobikhola well field	Yes	042	NWSC, DK-3	*15*	6	Mahankal area
Local supply from Manahara wellfied	No	045	NWSC, MH-3	*21*	*14*	Mulpani, Gothatar VDC
		046	NWSC, MH-4	*18*	*14*	
		047	NWSC, MH-6	*32*	*19*	

Note : ND (<5ppb) - Not detected

6.5 Arsenic concentration at distribution line

Arsenic concentration in water from distribution line of water supply system with the source of highly contaminated wells were sampled and tested to check the vulnerability of water users at household level. Water sample were taken from raw water before treatment, after treatment and some house taps connected to the supply line. The test result is presented in Table 6.4.

The arsenic concentration in raw water of all sources mentioned in the table was above WHO guideline and eight samples were even above Nepal Standard. Although, the arsenic values of these samples reduced after treatment, they were still above the WHO guideline; none of these sources were found safe. However, at household level, the water from NWSC-Kalanki, NWSC-Kuleswore and USAID were further reduced and found safe. Thus, the arsenic concentration has been found reduced from treatment to the house level. It might be due to distance or something else. It recommended for further research.

Table 6.4

Arsenic concentration of water samples from distribution line

SN	Source	Arsenic concentration (ppb)						
				Sample Collected on: 22 Sep 2005				
				Sample Analysed on: 23 Sep 2005				
		Pre-Monsoon	Monsoon	Raw (recent)	Treated Sample	User (House) House 1	House 2	House 3
1	NWSC, Kalanki	**212**	**111**	**152**	*12*	7	10	ND (<5)
2	NWSC, Kuleshwor Awash	**74**	*48*	*33*	*24*	10	*12*	10
3	Oriental Colony	**265**	**211**	**154**	**136**	**68**	-	-
4	Lalitpur Nussing Campus	**110**	**115**	**67**	**53**	*27*	-	-
5	Sun Rise Homes	**158**	**84**	**64**	*32*	*34*	-	-
6	USAID	**69**	*44*	*23*	*18*	ND (<5)	-	-
7	HMTTC	**54**	**71**	**61**	*36*	*18*	-	-
8	UNDP Complex	**190**	**136**	**75**	*24*	*24*	-	-
9	Sanchaya Kosh	**250**	**173**	**131**	**52**	*11*	-	-
10	Dept of Livestock	**146**	**111**	**118**	-	*36*	-	-
11	Institue of Engineering	**169**	*37*	*46*	*19*	*12*	-	-
12	Prasuti Griha, Hospital	**52**	*35*	*30*	-	*25*	-	-
13	Dashrath Rangashala	**54**	*36*	*14*	*18*	*15*	-	-

ND = Not Detected (<5 ppb)

Conclusions and Recommendations

1. This study has confirmed that arsenic concentration in Kathmandu's groundwater is a concern and that some of the areas within the Valley particularly the areas within the Central Groundwater Zone are vulnerable to arsenic contamination.
2. The majority of wells exceeding WHO guideline lie in Kalimati formation followed by Gokarna recent flood plain and Chapagaun.
3. During the pre-monsoon season, 71.6 percent of the tested samples had arsenic concentrations above WHO guideline value (10 ppb) and 11.9 percent had arsenic concentrations above the Nepal standards (50 ppb).
4. Arsenic concentration is slightly lower in the monsoon, indicating the possibility of dilution due to recharging. During this season, 56.8 percent had arsenic concentration above WHO guideline value 8 percent had arsenic concentration above national standards.
5. Northernmost part of the north groundwater district is safe whereas lower part of the district is in vulnerable within the Nepal standard.
6. Majority of the central ground district are vulnerable, some part of this district even are highly vulnerable.
7. The southernmost part of the southern groundwater district is safe but northern part of this district is vulnerable with a small part lying in highly vulnerable zone.
8. Gokarna well field and Pharping well field out of five well fields in the northern most and southern most part of the study area are found in safe zone.
9. Major part of the Bansbari well field with exception of small area is located in safe zone.
10. Some parts of Dhobikhola and Manohara well fields are located in vulnerable zone with 11-20 ppb and a small area of Manohara well field is located in 21-30 ppb zone.
11. NWSC's local supply system at Kuleswor awash for Kuleswor Awash and Sipradi at Kalanki for ward 14 and 13 are highly vulnerable to arsenic due to their corresponding wells at highly vulnerable area.
12. The deeper tubewells in the valley have higher arsenic concentration compared to the lower depth tubewells.

13. Areas identified as being vulnerable to arsenic contamination, however, have several wells that supply drinking water to sensitive areas such as schools, hospitals and residential colonies.
14. There seems to be a significant positive correlation between Arsenic concentration and the concentration of ammonia and manganese in the ground water.

Recommendation for policy guidelines

1. Issues regarding arsenic contamination in groundwater resources in Kathmandu valley must be addressed in proposed Urban Water and Sanitation Policy.
2. Safe zones identified by this study must be protected for extracting groundwater for drinking purposes.
3. Extraction of groundwater for drinking purpose from highly vulnerable areas of the valley identified by this should be prohibited.
4. Regular monitoring and reporting of wells located in vulnerable areas are essential if they are using for drinking purposes.
5. Some of the NWSC city/local water supply systems do not have treatment plans; every drinking water supply system should have treatment plant for safe drinking water. Water from vulnerable zones should be treated prior to supply.
6. There is no authentic agency for regulating groundwater extraction. Groundwater has been extracting and using haphazardly. Licencing and control mechanism should be developed for permitting groundwater abstraction and regular monitoring of water quality of installed tubewells.
7. This study has experienced that the private deep tubewell owners were not willing to provide water sample for testing. The authentic agency as mentioned above should have access for testing or inspection of the well at any time.
8. The database system should be established to update the water quality data reported from well users or responsible agencies, especially for wells located in arsenic vulnerable areas. This will help in creating information base for identifying location for safe groundwater for decision makers, planners and implementers.
9. Establishment of database management system to update lithologs of all tubewells installed in the valley, so that wrong practice of tapping water through multiple screen

can be monitored. Moreover, this information together with information about vulnerable zone will help in identifying depth for good aquifer.

Recommendation for drilling practice

Groundwater Kathmandu valley has been extracted haphazardly in an unplanned manner. It is a common practice to tap multiple screens when drilling a well to abstract maximum amount of water, although this practice has been decreased among the professional drilling companies in recent years. Usually all aquifer horizons are tapped using slotted screens. However this also connects aquifers of variable groundwater quality. Not only deep aquifers, even shallow and deep aquifers have been tapped in a single well. As a result there are possibilities of contaminating even good aquifers by water from contaminated aquifers.

Generally the annular space between borehole wall and the casing is sealed by bentonite or concrete, however, this does not seem to have been practiced in the wells in Kathmandu valley (DMG/BGR, 1998). The space is generally filled with gravel pack from bottom of the well to the surface. This establishes a hydraulic connection between different horizons through the gravel pack. As this is practiced in most cases, this has also affected the piezometric level. The piezometric level recorded is the mixed head level of all the aquifer tapped. Such practice has to be avoided and monitored closely.

Recommendation regarding depth of wells

This study shows that the deeper wells in the valley have higher arsenic concentration compared to the lower depth wells. It contradicts with the assumption "deeper wells have lower concentration" as in the case of Terai and other South Asian region (State of Arsenic, 2003). More study is needed to see the relation between depth and arsenic concentration.

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