Community-Based Water Supply: Tubewell Program in Lumbini Zone, Nepal

by

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B.S., Environmental Engineering (2000)
Tufts University

Submitted to the Department of Civil and Environmental Engineering
in Partial Fulfillment of the Requirements for the Degree of
Master of Engineering in Civil and Environmental Engineering

at the

Massachusetts Institute of Technology

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ABSTRACT

The rural population in Nepal is suffering from unsafe drinking water. Water contaminated with pathogens is causing gastro-intestinal diseases among people, especially in the rural area, where a piped public water supply is not available. A community-based tubewell program, implemented by FINNIDA through the RWSSSP has been successful in providing portable water to the rural population in the Lumbini Zone over the past 10 years. However, microbial contamination has been found in about 50% of RWSSSP wells. A field evaluation was carried out in January the Lumbini Zone in 2002 to investigate the potential causes of the contamination and measures needed be taken to mitigate the problem. Water quality testing using the H_2S bacteria presence/absence test and a preliminary study of shock chlorination were conducted in the field. An analysis of the cause of contamination has shown that the use of cow dung in the construction process is the major factor contributing to the microbial contamination. An evaluation of FINNIDA's tubewell program is presented and recommendations for the tubewell program are given in this thesis.

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I would like to dedicate this thesis to my beloved grandparents.
Ar Gong, we will always miss you.

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LIST OF ABBRIVIATIONAS AND ACRONYMS

DIDC	Department of International Development Co-operation
DWSS	Department of Water Supply and Sewerage
FINNIDA	Finnish International Development Agency
HES	Health Education and Sanitation
HMG/Nepal	His Majesty's Government of Nepal
IBS	International Buddist Society
MEng	Master of Engineering
NGO	Non-Governmental Organization
O&M	Operation and Maintenance
RCL	Residual chlorine level
RWSSSP	Rural Water Supply and Sanitation Support Program
UC	Users' Committee
UNDP	United Nation Developmental Program
VDC	Village Development Districts
VLOM	Village Level Operation Maintenance
VLOMM	Village Level Operation and Maintenance Management
VMW	Village Maintenance Worker
WHO	World Health Organization

1 Introduction

1.1 Nepal

Nepal is officially known as the Kingdom of Nepal. It is a mountainous and beautiful country in Asia, landlocked by the Tibet region of China on the north and India on the south, east, and west (See Figure 1-1). Kathmandu is the capital and the largest city in Nepal.

Figure 1-1. Map of Nepal

Nepal has a population of 23.9 million (2000 estimate). Eighty-eight percent of the population lives in rural areas. In 2000, the population was increasing at an annual rate of 2.3 percent[1].

Nepal covers an area of 148,000 square kilometer (slightly larger than the state of Arkansas). It is divided into four topographical zones: the Great Himalayas, the Middle Himalayas, the Outer Himalayas, and the Terai region. The Great Himalayas is the highest zone, in northern Nepal. The Terai region, a flat, fertile lowland, is the southernmost topographic zone in Nepal. Nearly half of Nepal's population lives in the Terai region. The Terai region has a tropical monsoon climate characterized by rainy summers and the southwest winds of the monsoon, and almost dry winters. The Terai region is susceptible to flooding, which occurs regularly with the summer monsoon runoff from the mountains[2].

Despite its cultural and scenic wealth, Nepal is among the poorest and least developed countries in the world with 42% of its population living below the poverty line. In 2001, the literacy rate was estimated at 61%, with a large gap between male and female literacy rates. Only 44% of the female population was literate in 2001 compared to 77% of the males. Urban areas have higher literacy rates than rural areas[2].

In Nepal, women are generally subordinate to men and have less access to education, economic resources, and political power, although the severity of this discrimination varies from one ethnic group to another. Generally, women work harder and longer than men, taking care of household chores, fetching water and farming.

Nepal's gross national income (GNI) was US$5.4 billion in 2000, with a per capita GNI of US$230[1]. Factors that have contributed to Nepal's underdevelopment include its landlocked geography, rugged terrain, lack of natural resources, and poor infrastructure. The country's economy is heavily dependent on foreign aid. It has a narrow range of exports, a large economic disparity between the mountain areas and the more developed Terai region and a system of inefficient public enterprises and administration.

1.2 The Drinking Water Crisis

There is a global drinking water crisis due to supply shortage and water contamination in developing countries. About 1.7 billion people in the developing world have no access to safe drinking water[3♣]. As a result of this crisis, at any given time, about 50% of all people in the developing world are suffering from water-borne disease such as diarrhea, cholera, ascaris, dracunculiasis, hookworm or trachoma[4]. Some 250 million new cases of waterborne diarrhea are

♣ In the table given by SOWC, the percentage of population with access to safe water is 72, therefore, the percentage of population without access to safe water is 28. If the world population is 6 billion, then the number of people without access to safe water is 1.7 billion.

reported worldwide each year resulting in more 10 million deaths[5]. Nepal, being one of the poorest and least developed countries in the world, is also suffering from this crisis.

Nepal is rich in water resources. The country is drained by more than 6000 rivers with considerable flow variation. There is a reasonable amount of groundwater reserve in the Terai region for irrigation and drinking purposes. However, only 43% of the rural population has a safe water supply and 90% of urban population has piped water supply[6]. Moreover, in cities, the piped water supply is only provided a few hours each day and the pipe system is not properly maintained, therefore, microbial contamination is high, especially in the distribution system. In the rural areas, where there is no piped water supply and most people use traditional sources of water such as surface water bodies or wells, where microbial contamination of water is an even bigger problem.

The drinking water problem, combined with lack of sanitation facilities, has serious health impacts on the Nepali people. Each year, especially during the monsoon season, water borne epidemics hit different parts of the country. Many people become ill or even die in these epidemics. More than 50% of hospital patients in Nepal were found to be suffering from gastro-intestinal disorders normally caused by water-borne pathogens[6].

The long-term solution to this drinking water quality problem would be to have piped, disinfected water as well as sewage treatment facilities. However, extreme poverty, combined with other social and political problems, has made the installation of a centralized public water supply and treatment system impossible in Nepal. Therefore, in order to protect public health, a decentralized water supply program seems to be a more feasible solution. One such program is the community-based tubewell program.

1.3 Tubewell Program

Groundwater is the main source of drinking and irrigation water in most of the Terai region. Therefore, tubewells are widely used to abstract groundwater in the region. A tubewell is a small diameter (40 millimeters) pipe equipped with a handpump, which is made of cast iron or steel, as shown in Figure 1-2. There are household (private) tubewells and community (public) tubewells. In the Terai area, on average about 8 households share one public tubewell[♣]. Some of the private household wells are used by outsiders, too. There has been an effort to install tubewell by various agencies in Nepal, because:

- Handpumps are among the simplest community water supply technologies. Compared with electric or diesel pumps, handpumps require substantially less financial resources and easier to maintain.
- Water from a tubewell has been assumed to be of much better quality than water from a dugwell or surface water such as river water.

Figure 1-2. A Tubewell

FINNIDA[♦] is one of the international aid agencies that have been implementing tubewell programs in the rural area of Lumbini Zone in Nepal. Through the Rural Water Supply and Sanitation Support Project (RWSSSP), funded by FINNIDA, HMG/Nepal[♠] and the users themselves, FINNIDA has supported 400,000 people to build a water supply and to improve

♣ A study on community handpumps in the Terai region by the UNDP-World Bank Water and Sanitation Program found that the average number of households served by a community handpump was 9 and the average number of people served by a community handpump was 69 (Mudgal, et al., 1995)

♦ Finish International Development Agency (FINNIDA) is the former name of Department of International Development Co-operation (DIDC) of Finland. In practice, however, because FINNIDA has become very well known in the field, therefore, the name "FINNIDA" has continued to be used locally, instead of DIDC.

♠ The majority of the funds was provided by FINNIDA in the first 2 phases. In Phase III, FINNIDA's financial contribution is about 42%. See Appendix C for details of the funding.

sanitation through Phases I and II of the project during 1990s, and plans to provide an additional 216,000 people with water supply in Phase III (1999-2003)[7].

1.4 Project Motivation and Goal

Implementation of tubewell programs has improved the living condition of the rural population by providing them with better water quality and saving their time spent on fetching water. However, field tests done by FINNIDA has shown that about 50% of the RWSSSP tubewells tested positive for hydrogen sulfide producing bacteria[8] (referred to as H_2S bacteria hereafter). Past MIT Master of Engineering (MEng) study has also found that total coliform, E.coli and H_2S bacteria were present in the tubewells constructed by the International Buddhist Society (IBS), which is also located in the Lumbini Zone[9]. Total coliform, E.coli and H_2S bacteria are indicator organisms of fecal contamination in water.

How can groundwater be contaminated with bacteria such as fecal coliform? In most cases, the microbial contamination is caused by unsanitary practices of constructing or using the wells. These practices may include:

1. Sludge drilling which uses cow dung slurry. This is the prevalent method of constructing a tubewell in Nepal.
2. Use of contaminated water to prime the tubewell. Often contaminated water is used to prime the tubewell when the water level in the well is low and suction cannot be created.
3. Inadequate sealing or protection of the well. Some tubewells will have no platform, and are surrounded by animal sheds and animal waste.
4. Improper drainage that causes accumulation of wastewater in the pit near the well.
5. Flooding during monsoon.

In order to tackle the problem of microbial contamination in tubewells, in January 2002, I went to Butwal, where the RWSSSP office is located. During this visit, a well survey of several Village Development Districts (VDCs) was conducted. Well data, which were collected by RWSSSP for three districts (Kapilvastu, Nawalparasi, Rupandehi), were brought back to MIT. Analysis was performed on the data to determine the causes of the microbial contamination. A preliminary field study of shock chlorination was also conducted to test the suitability of shock chlorination as a way to eliminate microbial contamination in tubewells. These tests and analyses have facilitated the accomplishment of the goal of the project, which is to develop an effective operation and maintenance (O&M) program to prevent future contamination and give recommendation to FINNIDA so their human and financial resources can be better utilized in providing safe drinking water in Nepal.

2 Tubewells

2.1 History of Tubewells

During the late 70s and early 80s, various problems were observed with the rural water supply systems in developing countries, especially among the poorer sections of the rural population. Many of those systems were mechanized and highly centralized. The problems included the high cost of running these systems, inadequate maintenance, unavailability of spare parts, inability to repair broken units at community levels and thefts of fuel. These problems made people realize that unless more decentralized and more efficient programs were developed, the poor rural population would still be without reliable and convenient water sources. After 7 years of study in 30 countries, a concept called Village Level Operation Maintenance (VLOM) was developed by UNDP and the World Bank[10].

The VLOM concept was originally a technological approach to achieve the sustainability objective of rural water supply, based on the use of community managed alternatives, one of the most widely used of which is the handpump. To satisfy this definition of VLOM, a pump would need to be[11]:

- Easily maintained by a village caretaker, requiring minimal skills and a few tools
- Manufactured in-country, primarily to ensure the availability of spare parts
- Robust and reliable under field conditions
- Cost effective

Handpumps presented a reliable and affordable water supply option, as they are inexpensive, simple to operate and can be easily adopted in most rural areas in different and conditions.

VLOM rapidly gained its recognition and has been developed into a social, economic, technological concept. The terminology now is extended to Village Level Operation and Maintenance Management (VLOMM). This broader concept also covers the maintenance system needed to keep a VLOM pump in working order, rather than just the technological requirement of the pump. Details in different VLOMM projects vary in different areas or countries, but a typical approach would consist of the following components[11].

- Project staff helping villagers form user committees prior to surveying and construction of the tubewell.
- The committees organizing community labour and contributions to capital costs, and after construction co-ordinating operation and maintenance, including fund-raising.
- Local leaders and committee members signing a contract with the project agency specifying the responsibilities of each stakeholder.
- Project staff training designated users in repair and maintenance and providing basic tools, possibly including an initial supply of spare parts.

Based on this VLOMM concept, it was hoped that the villagers would manage the O&M of the program, thereby transforming the social structure of their community, spreading the word among themselves and broadening the scope from water supply to sanitation, and even to other public and economic activities.

However, in reality even with the guidance of the VLOMM concept, many rural water supply programs have failed. The problem of unavailability of spare parts still exists in many remote areas. Users lack the sense of ownership of the pump in some cases, therefore, preventive maintenance is rarely undertaken; and when the pump is actually broken down, no money is collected for repair. RWSSSP's tubewell project will be presented in the following section and the problem with this tubewell program in Nepal will be discussed in detail in Chapters 3 and 5.

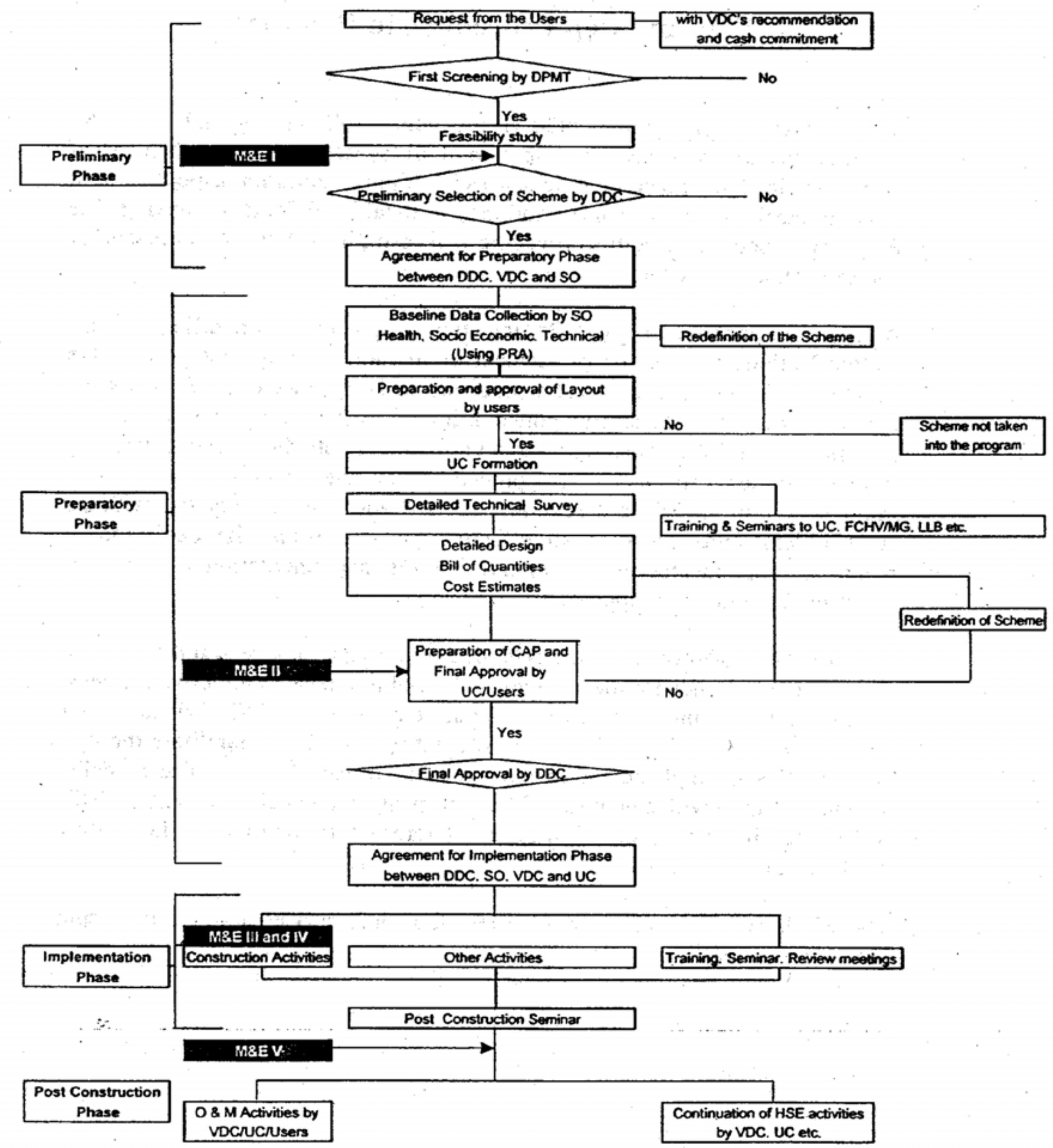
2.2 RWSSSP's Tubewell Program

In 1990, FINNIDA started a project in six districts of the Lumbini zone in the Western Development Region to assist HMG/Nepal in providing potable drinking water and sanitation to its population as well as developing facilities for solid and liquid waste disposal system in rural areas. To avoid the problem of duplication, the project was launched in those VDCs, where there were no water supply systems and where other aid agencies were not operating. This project is called Rural Water Supply and Sanitation Support Program (RWSSSP). Today, the RWSSSP has developed into its third phase (Phase III, 1999-2003), which includes a tubewell program, a rainwater collection program and a sanitation facilities (namely latrine) program. The overall objective of RWSSSP Phase III is full coverage of adequate and sustainable water supply and at least 40% coverage of sanitation facilities[12].

A step-by-step approach is the procedure used in all RWSSSP schemes as shown in Figure 2-1. It can be summarized as follows[8, 13] (a detailed description of the roles and responsibilities of major stakeholders is shown in Appendix B):

1. Request to RWSSSP for a tubewell comes from the users, with VDC's recommendation and cash commitment.
2. Approval of the request based on their prioritizing criteria. The criteria include:
   - Scarcity of drinking water
   - Poverty and backwardness of the community
   - Distribution of development activities
   - Adjoining the VDCs where the tubewell program has been completed
3. Formation of a water users' committee (UC) for the tubewell. A UC, consisting of members from the households who will be using the well, must be formed to supervise installation, operation and maintenance of the tubewell. Two members (one man and one woman) from each household will join the UC. A Village Maintenance Worker (VMW) will be selected to be responsible for the maintenance of the tubewell.
4. Collection of funds. The UC will collect contributions of NRs 100 to 300 from the beneficiary households. The exact amount of the contribution collected depends on the VDC and the number of households using that tubewell. The UC will also select the site where the well will be constructed based on a field survey and the preference of the users.
5. Seminar and training to UC and VMW. RWSSSP will organize seminars for UC to help them to understand their role and the responsibility, and assist the UC in preparing a Community Action Plan and following it. RWSSSP will also give the VMW a 3-day training course and a tool kit for repairing the handpump.
6. Construction of the tubewell. RWSSSP will provide the handpump, pipe and other construction materials to the UC. UC will manage all the construction activities in a timely

manner as specified in the Community Action Plan. A *Mistri*[♣], who is trained to build wells, will be hired to construct the well, but at least one member from each beneficiary household will come out to help the *Mistri*.



PRA = Participatory Rural Appraisal
VDC =Village Development Committee
DDC = District Development Committee
DPMT = District Project Management Team
CAP = Community Action Planning
SO = Support Organization
LLB = Local Latrine Builders
M&E = Monitoring & Evaluation
FCHV = Female Community Health Volunteer
MG = Mothers' Group
O&M = Operating & Maintenance
HSE = Hygiene & Sanitation Education

Figure 2-1. RWSSSP Step-by-Step Flow Chart *(Source: RWSSSP)*

♣ Mistri is the Nepalese word for mason.

7. Regular UC meeting and maintenance. The UC will hold regular meetings to discuss any issues regarding tubewell or use of the tubewell and ensure services of the VMW to look after the well. The UC will also collect money to establish an Operation and Maintenance Fund and manage the fund properly.

In the RWSSSP model, users are regarded as the managers and owners of the tubewell. Funds collected from the users are put in a bank account of the UC. RWSSSP's role is to facilitate the users in the implementation and management of the tubewell, and conduct trainings and seminars in Health Education and Sanitation (HES) for the users.

2.3 Types of Tubewell in Nepal

Generally, three types of tubewells can be found in Nepal: flowing artesian wells, shallow tubewells with suction handpumps and deep tubewells with lift handpumps.

An artesian well is a well in which the water level rises above the top of the confined aquifer[♣]. In some cases, the water level actually rises above the ground surface, then the well is known as a "flowing artesian well"[14]. In Nepal, a flowing artesian well equipped with a pipe or a tube is usually referred to as an "artesian tubewell". Water flows out of the tube continuously without the need of pumping, as shown in Figure 2-2.

Figure 2-2. An Artesian Well

[♣] An aquifer is a saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients

Shallow tubewells are most common in the Terai region. Of the various models of handpumps in use, Nepal No. 2 and No. 4 are smaller in size and commonly used as a household (private) handpump; Nepal No. 6 is larger in size and usually used at the public level[15]. The majority of the tubewells constructed (about 90%) by RWSSSP in the Terai region are shallow tubewells, all of which are No. 6.

A suction handpump mainly consists of a handle, a head cover, a cylinder (pump body), and a piston (plunger assembly) as shown in Figure 2-3. Figure 2-4 illustrates how a suction handpump works. In Step A, the handle is pressed down to the lowest position, and the piston moves up to the highest position. The upstroke of the piston creates a vacuum inside the cylinder. The pressure inside the cylinder is now lower than atmospheric pressure. Pushed by the air pressure, the water rises to fill the evacuated space. In Step B, the handle is released, the piston moves downward and the water flows through the piston. In Step C, the piston is in the lowest position and starts moving upward. The piston valve is pushed closed and the base valve is opened. In Step D, the piston pushes the water upward while new water enters the pump through the base valve. The cycle starts all over again. Suction handpumps are used to extract water from shallow aquifers. The maximum suction is about 9 meters.

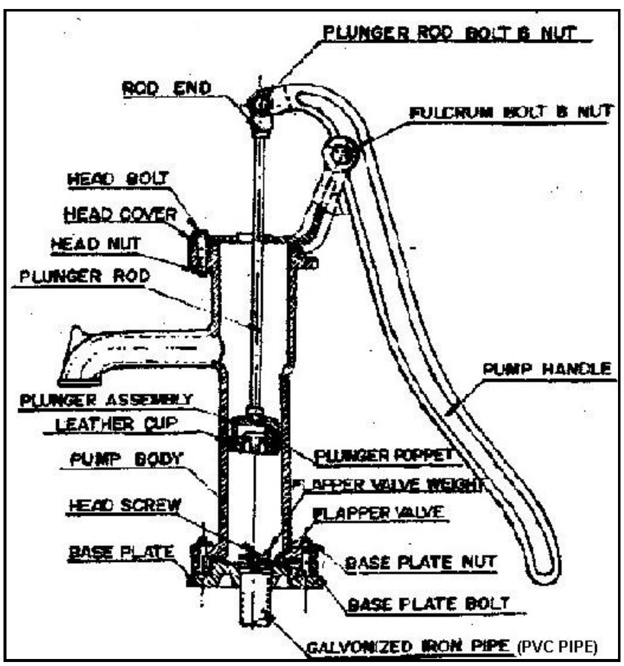


Figure 2-3. Details of a Suction Tubewell (Nepal No.6)

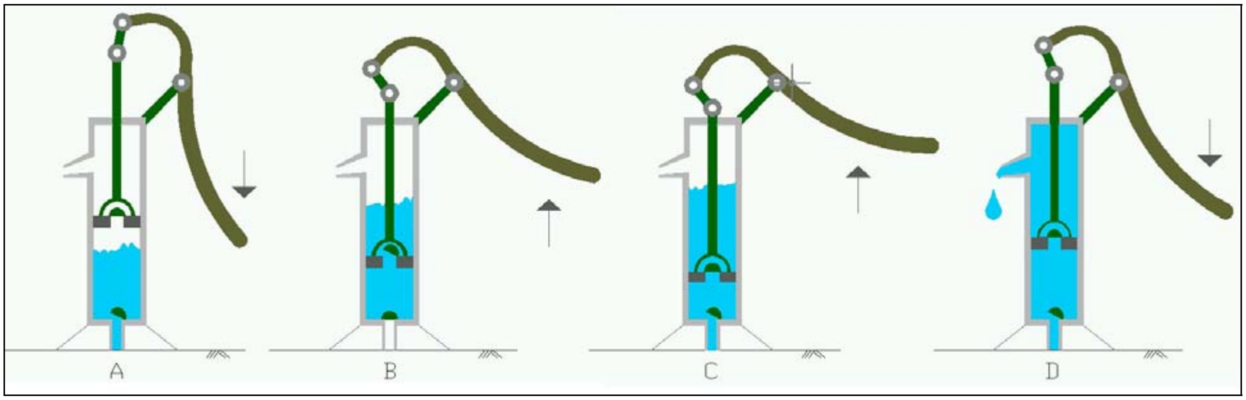
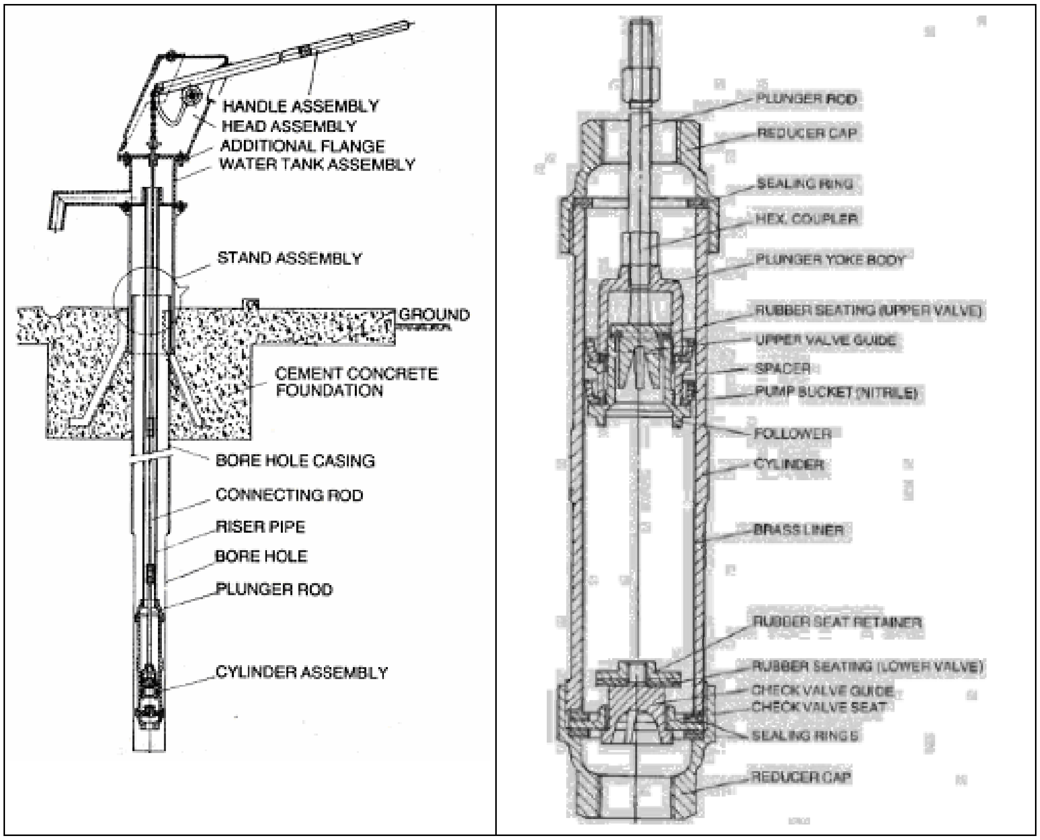


Figure 2-4. How a Suction Handpump Works

In a lift handpump, the working principle is similar, but the prison assembly is inside a cylinder, which is connected to the handle by a connecting rod, deep down in the borehole. Lift handpumps are used to extract water from deep aquifers. Therefore, tubewells fitted with lift handpumps are referred to as deep tubewells. The lift handpumps used in RWSSSP are India Mark II/III as shown in Figure 2-5. Figure 2-6 shows the details of a lift tubewell.

Figure 2-5. A Lift Tubewell



(a) Schematic View (b) Cylinder Assembly

Figure 2-6. Details of a Lift Tubewell (India Mark II)

A tubewell should be sealed with a concrete platform at the base and connected to a drainage channel, as shown in Figures 1-2 and 2-2. The drainage channel drains off excess water and keeps the surrounding of the platform dry. In a well-constructed platform, the disposal channel drains into a soakage pit, which is a pit dug at the end of the drainage channel and filled with gravel or broken bricks. The pit receives water coming through the channel and keeps the surrounding dry. A platform serves three important purposes:

1. Provide protection against possible groundwater contamination by preventing seepage of wastewater into the aquifer.
2. Provide a firm and dry operational area for the well users.
3. Prevent lateral movement of the handpump body.

A platform can be circular or rectangular in shape. Figure 2-6 shows the details of a circular platform.

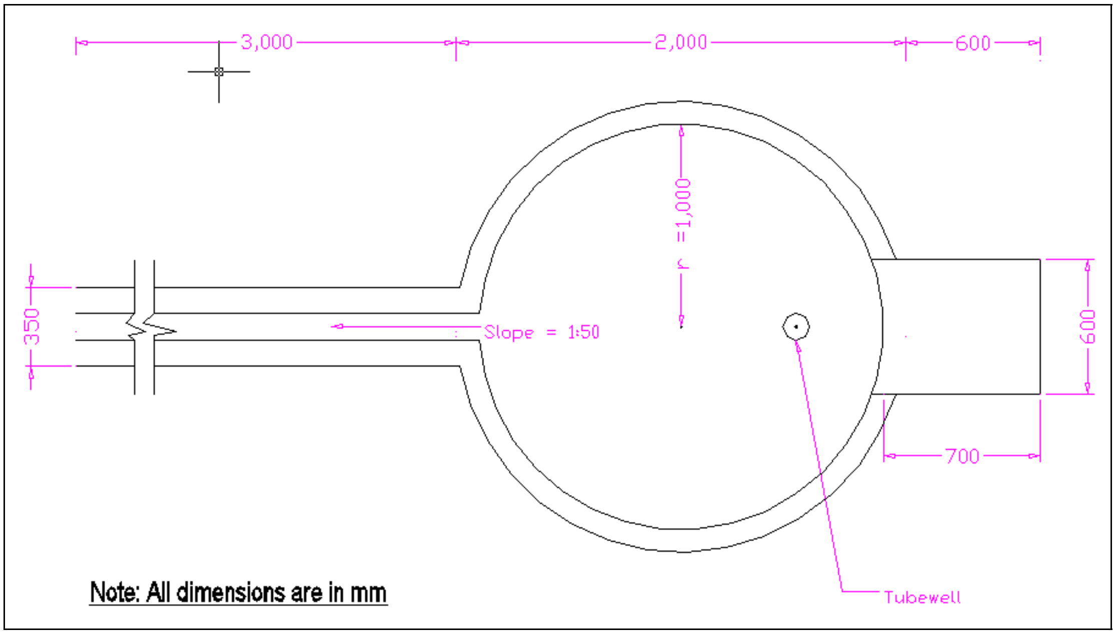


Figure 2-7. Details of a Typical Circular Platform

Deep tubewells cost more to construct than shallow tubewells, because deep tubewells require special drilling equipment. The cost of construction, including slugging, skilled and unskilled labor, pipes, fittings, hand pump and platform, is approximately NRs 10,000 (US$133) for a suction well, and NRs 150,000 (US$200) for a lift well[16].

In the RWSSSP coverage area, on average about 8 households share one public tubewell. The advantages of using tubewells are:

- Groundwater is much cleaner than surface water. Tubewells are sealed to protect the source, therefore, they are better than dugwells, which are often not covered.
- Handpumps do not require electricity or fuel to be powered, therefore, are easier to use and maintain than electric or diesel pumps. Compared with electric or diesel pumps, hand pumps require substantially less financial resources.

3 Contamination Problem

3.1 Problem Statement

Despite the benefits that tubewells offer and the effort by various NGOs to install tubewells in Nepal, there appears to be a microbial contamination problem with tubewell water. Over the past two years, RWSSSP has been conducting water quality monitoring of their wells using the H_2S bacteria Presence/Absence (P/A) test, and has found that about 50% of the water sample taken from tubewells showed the presence of H_2S bacteria in Lumbini Zone. H_2S bacteria are indicator organisms of fecal contamination; their presence indicates the possible presence of pathogens of fecal origin, which can causes illnesses such as diarrhea. Generally, the microbial contamination is caused by unsanitary practices of constructing or using the wells. These practices may include:

- Sludge drilling which uses cow dung slurry. This has been the prevalent method of constructing tubewells in Nepal. However, recently after suspecting cow dung might be one of the factors that causes contamination, RWSSSP started substituting bentonite for cow dung to build tubewells.
- Using contaminated water to prime the well. Often dirty external water is used to prime the well when the water level in the well is low and suction cannot be created. In a UNDP-World Bank handpump study, it was found that 42% of the No.6 handpumps required priming, and almost 15% to 20% of the sampled handpumps required priming before every use[15].
- Inadequate sealing or protection of the well. Some tubewells have no platform or a broken platform, and are surrounded by domesticated animals and animal waste. Animals can walk around the well freely, they might introduce bacteria to the mouth of the handpump through contact.
- Some tubewells are built near latrines or animal sheds. The nearer the tubewell is built to a latrine or an animal shed, the higher the risk of contaminated water percolating into the well.
- Improper drainage that causes accumulation of wastewater in the platform or the pit near the well.
- Flooding during monsoon.

During the visit to Nepal in January 2002, a survey of 45 tubewells was conducted in Lumbini Zone. Well data, which were collected by RWSSSP in the past two years for three districts (Kapilvastu, Nawalparasi, Rupandehi), were brought back to MIT. Analysis was performed on the data to determine the causes of the microbial contamination. A preliminary field study of shock chlorination was also conducted to test the suitability of shock chlorination as a way to eliminate microorganisms in tubewells. The overall goal of this thesis research is to develop an effective operation and maintenance program for tubewells

3.2 H_2S Bacteria P/A Test

As discussed before, H_2S bacteria are a type of indicator organism. H_2S bacteria test has the following advantages[17]:

- It requires simple ingredients that are readily available in developing countries.
- The growth medium is in the form of a dried paper strip, which can be safely stored at room temperature for at least 6 months.
- The test can be carried out without the use of an incubator or other special laboratory equipment.
- The black positive reaction is easy to read.
- Even untrained personnel can reliably carry out this test because of its simplicity.

H_2S bacteria P/A test is the method used by RWSSSP to monitor the microbial quality of the tubewell water. Tubewell water samples are collected and left in 20-ml bottles that contain the H_2S bacteria medium for 48 to 72 hours at room temperature (22-30°C). The water will turn black if it contains H_2S bacteria; otherwise the colour will not change. RWSSSP bought the H_2S bacteria medium from ENPHO, a Non-Governmental Organization (NGO) that provides environmental services and is based in Kathmandu. ENPHO prepared the medium in a 20-ml capped bottle to RWSSSP. For this reason, 150 bottles of H_2S bacteria medium were prepared at MIT and brought to Nepal for my own microbial testing (see Appendix D for the list of ingredients and the procedure of preparing H_2S bacteria medium).

3.3 Field Work

3.3.1 Water Quality Testing

To confirm the extent of the microbial contamination in Lumbini Zone, I conducted water quality testing using the H_2S bacteria P/A test. The testing procedure is described below:

1. Washed hands with antibacterial soap before sampling.
2. Put the bottle containing the H_2S bacteria medium under the tubewell spout to collect the water. Put the sample bottle in a closed container after the water was collected. Sometimes, when water could not be pumped from the well, externally procured water was added into the handpump to prime the well. In this case, because the microbial quality of the externally procured water was unknown. The water sample was collected after the well was pumped and water was allowed to flow out for five minutes.
3. Two sets of sample were collected for each tubewell tested. One set was left at ambient temperature with no incubation, the other set was put in a phase-change incubator, invented by Amy Smith at MIT, to determine if incubation was necessary during the coldest month of January in the Terai Region with the H_2S P/A test. The phase-change incubator is capable of maintaining a constant temperature of 37 °C for 24 hours. All samples were discarded after 72 hours.

Precautions were taken to minimize the possibility of cross contamination or contamination through handling; it is unlikely that the sampling procedure contributed to any finding of microbial contamination in tubewell water.

3.3.2 Results of Incubation vs. Non-Incubation of H_2S Bacteria Test

Generally if the well was contaminated, it was found that incubation in the phase-change incubator made the sample turn back faster than that without incubation. The non-incubated sample would still turn black eventually within those 72 hours. The time gap between when an incubated sample turned black and when its non-incubated counterpart turned black was 20 to 24 hours. Therefore, incubation of the H_2S bacteria test in the phase-change incubator was not deemed necessary, because the contaminated sample would still turn black given a long enough reaction time. Seventy-two hours were an appropriate (long enough) amount of time to develop a color change if the water contained H_2S bacteria under ambient air conditions, which ranged from about 15 to 25 °C in Nepal.

As a result, 19 out of the 45 wells tested were found to be positive with H_2S bacteria, i.e., 42% of the samples[♣]. This finding generally agrees with RWSSSP's finding of 50% of wells contaminated with H_2S bacteria.

3.3.3 Inspection of Tubewells

Inspection of tubewells was also conducted along with water quality testing. Fifty tubewells were inspected, 45 of which were sampled used in the water quality testing mentioned above. The following are some of the major problems identified.

First, some of the platforms were in bad condition in which case, dirty water could infiltrate into the well. Second, some handpumps were broken– nuts and bolts were missing– but no repair was to be carried out. A rope or an iron wire would be used to replace the missing nuts or bolts. Mud would be used to fill the cracks on a pump body to stop leaking. A broken handpump is not water-tight, therefore, bacteria can get into the well. Figure 3-1 shows an example of a broken platform and an example of a broken handpump. Third, in some cases, the users were not concerned about these problems, since the well was "working" anyway. Fourth, in some other cases, the users reported the breakdown to the user committee, but the user committee just ignored the problem, or no funds were available to fix the problem. This is a clear indication of inadequate maintenance.

In summary, four major problems were identified during the inspection of tubewells. They are:

1. Platforms in bad condition leading to wastewater infiltration.
2. Broken handpumps.
3. User who were unconcerned about tubewell problems.

[♣] For a record of the raw laboratory data, see Appendix E.

4. User committees that ignored tubewell problems.

Figure 3-1. A Broken Platform and A Broken Handpump

3.4 Data Analysis

Data for 163 wells were analyzed to determine the possible causes of the microbial contamination. These data were collected by RWSSSP staff in the past two years as part of their own well survey and are shown in Appendix F. These 163 wells include the 45 wells mentioned in Section 3.3.1. The average depth of those 163 wells is 27 meters and the average age is 6 years. Six parameters, which might be the causes for the microbial contamination of the wells, have been investigated. These parameters are:

1. Number of users (people using the well) per well
2. Age of the wells
3. Distance to the nearby latrine
4. Distance to the nearby anima shed
5. Depth of the wells
6. Use of cow dung as slurry in the construction of tubewells

Each parameter is divided into "bins". For example, for the numbers of users parameter, the bin is 10 users per well (0-9, 10-19, 20-29, and so on until the last bin, which is 1440-1450). The number of H_2S bacteria contaminated wells and uncontaminated wells is counted for each bin and the percentage of contaminated wells within that bin is calculated. Figures 3-2 to 3-5 show the results of the analysis of the first four parameters graphically.

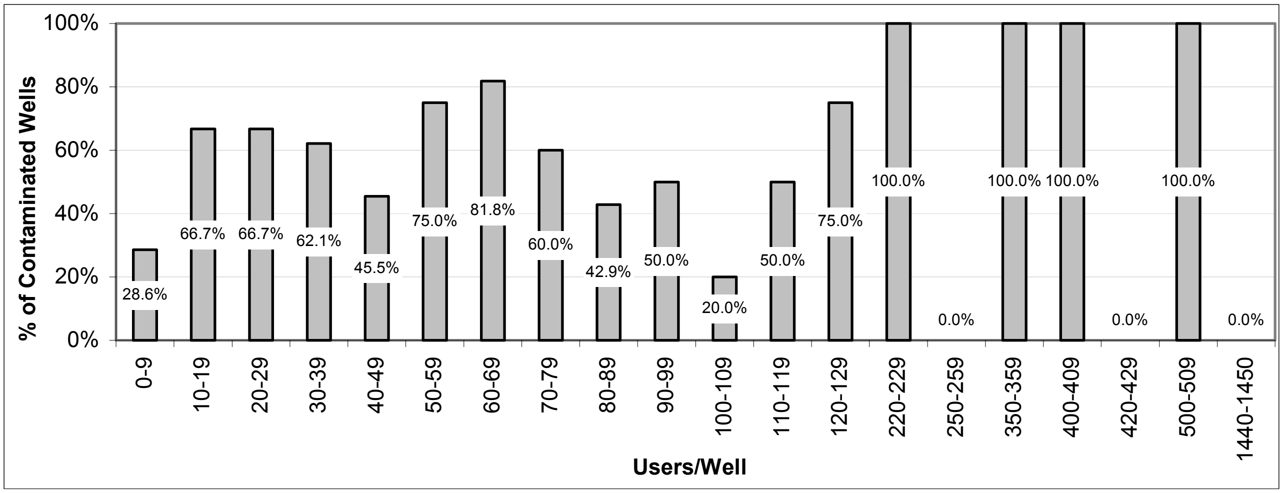


Figure 3-2. Percentage of H_2S Bacteria Contaminated Wells vs. Number of Users per Well

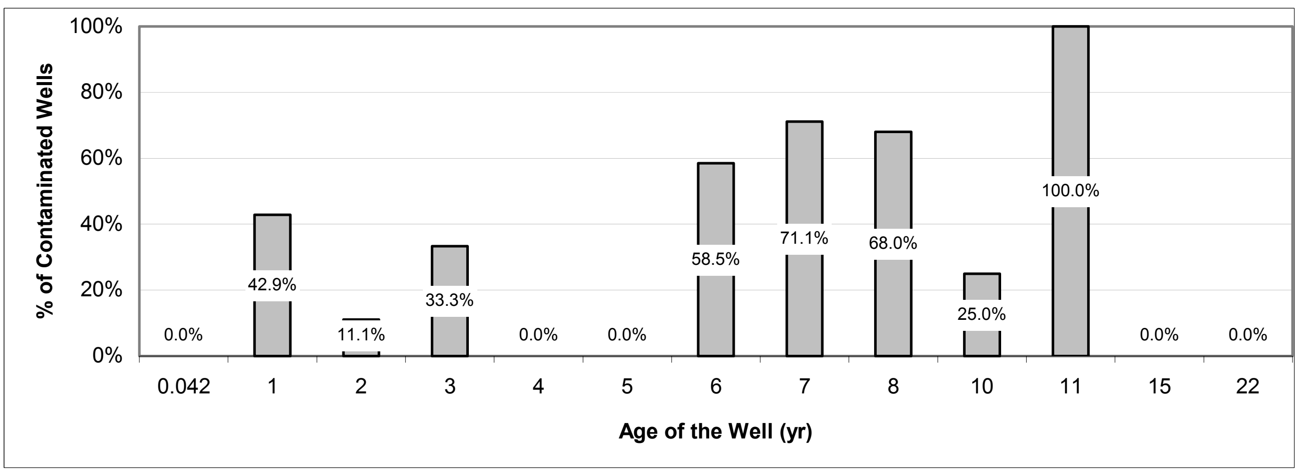


Figure 3-3. Percentage of H_2S Bacteria Contaminated Wells vs. Age of the Well

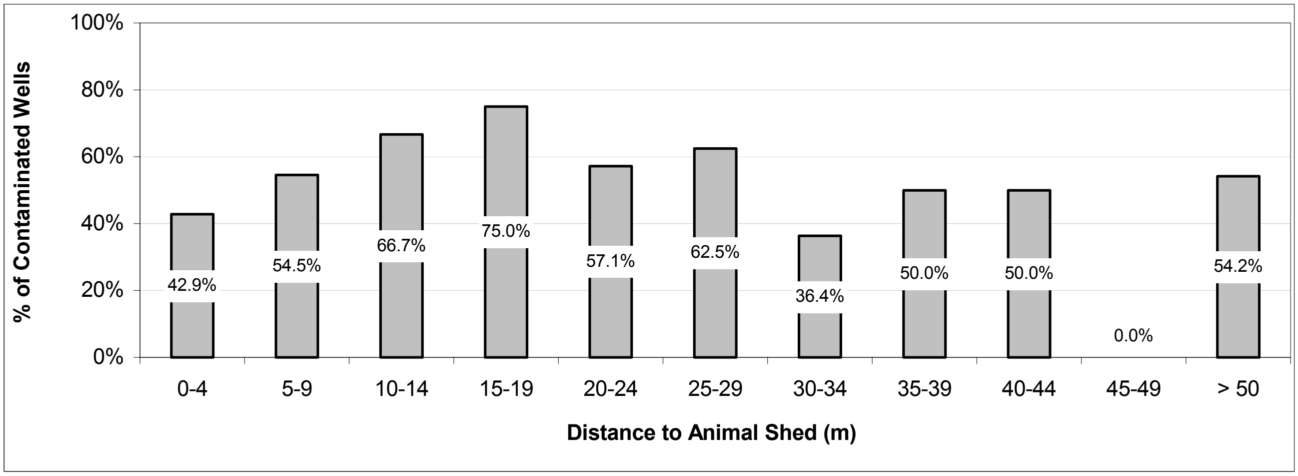


Figure 3-4. Percentage of H_2S Bacteria Contaminated Wells vs. Distance to Latrine

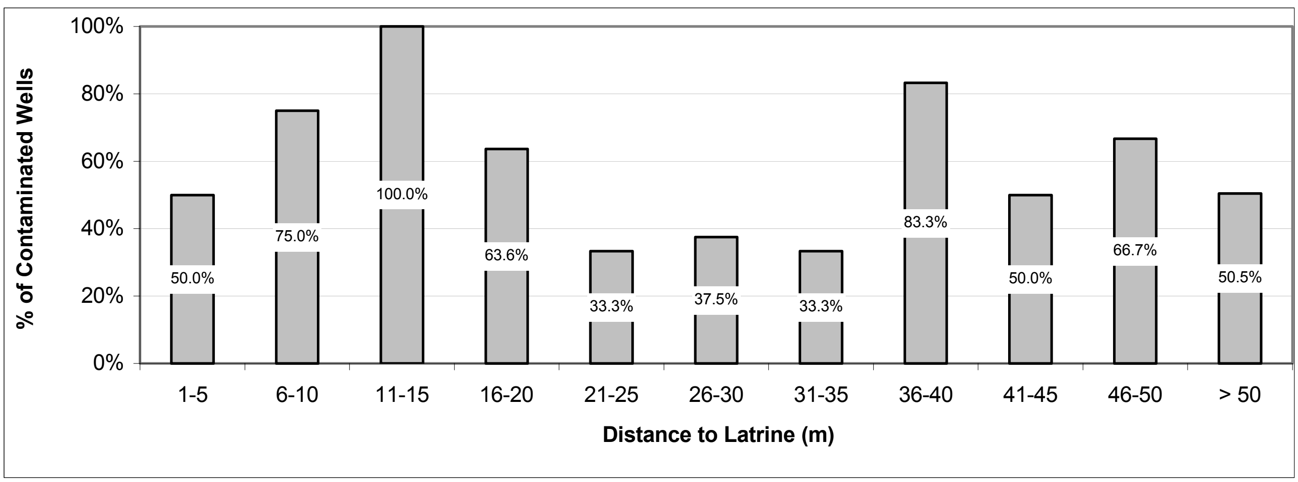


Figure 3-5. Percentage of H_2S Bacteria Contaminated Wells vs. Distance to Animal Shed

Figures 3-2 to 3-5 show that the first four parameters do not contribute to the H_2S bacteria contamination– the percentage of contaminated wells varies randomly as the values of the parameters increase. These random changes in the percentage of contaminated wells imply that the first four parameters are very unlikely to be the causes of the contamination.

Figure 3-6 shows the analytical result for the fifth parameter. It seems that there is a slight trend of reduction in the percentage of H_2S bacteria contamination as the depth of well decreases. In 1991, FINNIDA commissioned a groundwater resource study[18]. It was found in the study that most of the tubewells withdrew water from the topmost aquifer (first layer) for domestic use. The water redrawn from this aquifer was not microbially safe, because direct percolation of wastewater from the surface was high. For this reason, RWSSSP has been constructing tubewells, which withdraw water from the second aquifer, 18 to 69 meters deep[19]. It was also found that the actual depth of the aquifer differed from place to place.

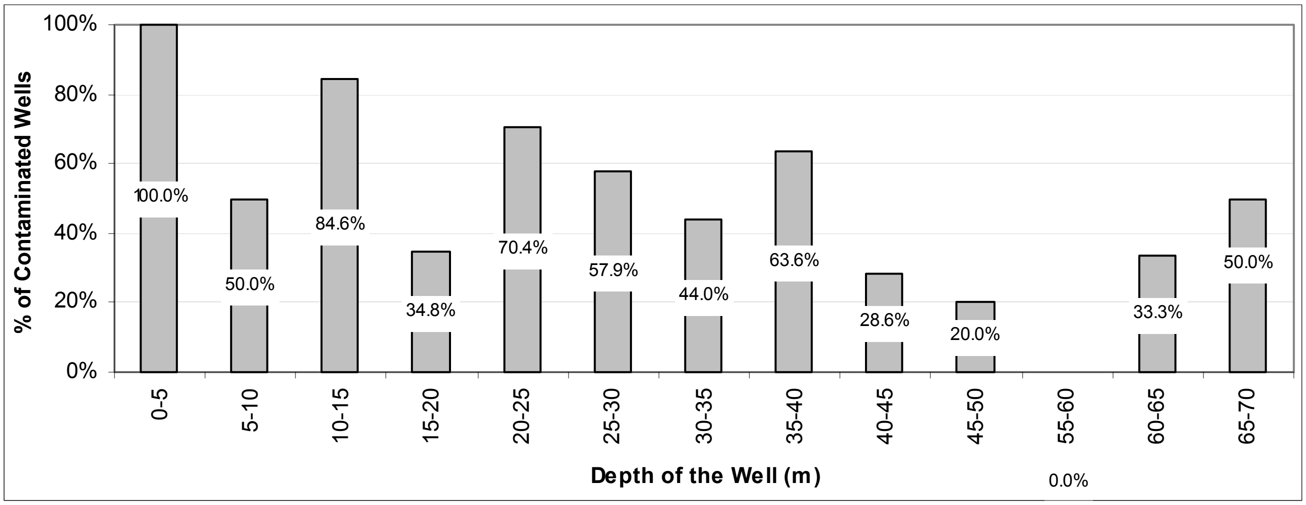


Figure 3-6. Percentage of H_2S Bacteria Contaminated Wells vs. Depth of the Well

Because all RWSSSP tubewells are constructed into the second aquifer, it will take a long time (on the order of years) for the contaminated surface water to travel from the surface to the aquifer. Bacteria will have died out within that period. Therefore, even though one might assume that the nearer a tubewell is to a latrine or a animal shed, the higher the risk of contamination there would be, the data analysis of these two parameters shows that the distance to latrines or to animal sheds do not contribute to the problem of contamination. Nevertheless, it is still good practice not to build the wells near latrines and animal sheds, because the foundation or platform of the well may be damaged and dirty water that leaks from the latrine or animal sheds may percolate through the soil and reach the second aquifer.

Table 3-1 shows the numbers of tubewells that were constructed with and without cow dung within that 163 well data set. It also shows how many of these wells were found to be contaminated with H_2S bacteria. The result is also shown graphically in Figure 3-7. As seen from the figure, there is an increase in the percentage of contaminated wells "with cow dung" compared to "without cow dung" to (17.8% increase). This indicates that the use of cow dung in the construction process may be a contributing factor to the H_2S bacteria contamination.

Table 3-1. Use of Cow Dung in Construction		
		Number of Wells
Without Cow Dung	Not Contaminated	17
	Contaminated	11
With Cow Dung	Not Contaminated	58
	Contaminated	77

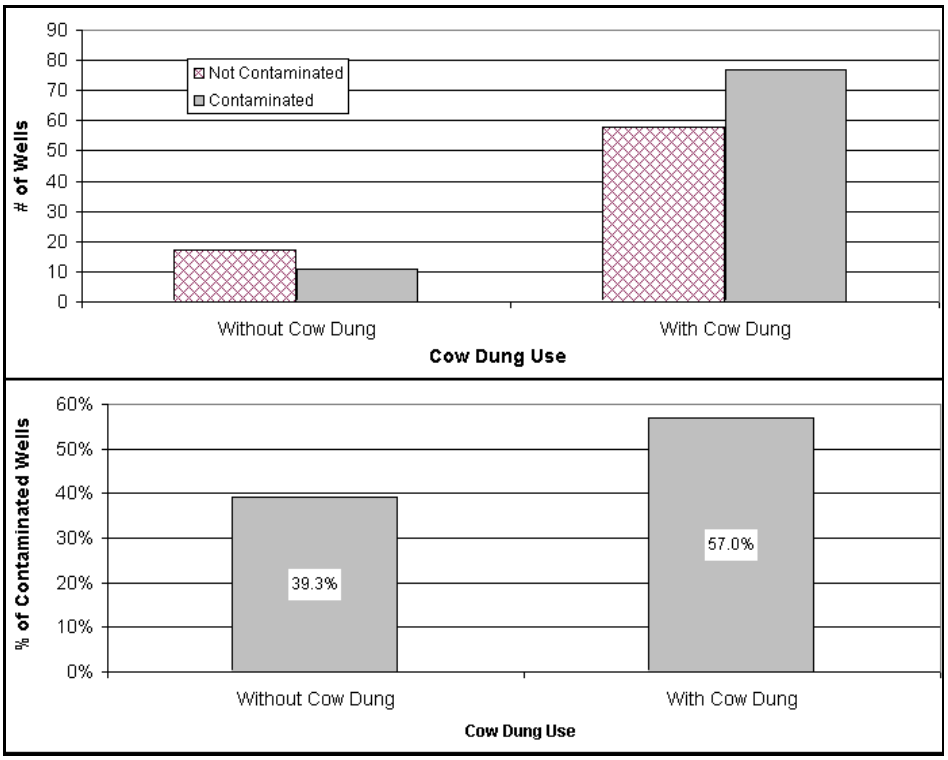


Figure 3-7. Level of H_2S Bateria Contamination vs. Use of Cow Dung

Using cow dung is a traditional way of building tubewells in Nepal. The primary concern with using cow dung is not primarily the fecal pathogens in the cow dung, because fecal pathogens will die out quickly after leaving their host. How long pathogens remain viable in water after they leave their host varies with the species. Typically, the pathogens lose their viability and ability to infect exponentially with time. Hence, cow dung will not affect the microbial quality of the well water in long term. In her microbial water quality survey in Lumbini, Nepal, MEng student Hannah Sullivan found that wells that were constructed with cow dung just several days prior to sampling show extremely elevated level of contamination by fecal coliform bacteria, sometimes on the order of 10,000 CFU per 100 milliliter (CFU/100 ml)[20].

Sullivan suggests that these elevated levels of contamination are due to the use of cow dung slurry in well construction, but are not indicative of long-term contamination, because "the highest level of contamination found in wells older than one month was 14 CFU/100 ml, indicating that contamination from the use of cow dung slurry does not persist in tubewells water longer than one month after well construction is completed". However, the main problem is that cow dung is mainly organic matter, which will disintegrate over time. The wells may have cracks and holes around the PVC pipe underneath the platform, resulting in short circuiting of wastewater there. The empty space can store dirty water, which in turn may seep into the tubewell, contaminating the groundwater. It is recommended that the condition underneath the platform of tubewells constructed with cow dung should be investigated, either by conducting a dye test or digging the platform up to examine the extent of the disintegration.

Many of RWSSSP's tubewell were constructed using cow dung. However, recently RWSSSP has stopped using cow dung and used bentonite instead in building new tubewells. Nevertheless, all the tubewells should be disinfected after construction and before use, because contamination can be introduced to the water through other means in the construction process. The disinfecting method is called shock chlorination, which will be discussed in later chapter.

Field observations and literature review also suggest that other causes of microbial contamination could be floodwater during monsoon, priming of the well with dirty external water, free access of animals to the wells and inappropriate maintenance of the wells.

4 Shock Chlorination

4.1 Chemistry of Shock Chlorination

Shock chlorination is the one-time introduction of a strong chlorine solution into a water distribution system (well, pump, distribution pipeline, hot water heater, etc.). It is a relatively inexpensive and straightforward disinfection method to eliminate microorganisms such as iron bacteria, sulfate-reducing bacteria, fecal coliforms, and pathogens in wells. Shock chlorination should be recommended:

- When water monitoring indicates the presence of bacteria in a well.
- Upon completion of a new well.
- After repair of an existing well.
- Following contamination by flood water.

Bacteria may be introduced during drilling of a well or when pumps are removed for repair and laid on the ground. However, some bacteria can exist naturally in groundwater. A well creates a direct path for oxygen to travel into the ground where it would not normally exist. When a well is pumped, the water flowing in will also bring in nutrients that enhance bacterial growth[21].

Chlorine destroys microorganisms by penetrating their cell walls and neutralizing the enzymes that are essential for their survival[22, 23]. When a large amount of chlorine, either in a liquid compound or a solid compound, is applied into the well, the following reactions take place[23]:

- First, it combines with inorganic compounds (hydrogen sulfide, ferrous iron, manganese); there is no disinfection at this stage.
- The remaining chlorine then reacts with organic matter (algae, phenols and slime growth). While some bad tastes and odours may be eliminated, there is only a slight disinfection action and trihalomethanes, which are carcinogenic, chlorinated organics, may be formed.

- After the demand exerted by inorganic and organic matter has been met, chlorine will combine with nitrogen compounds (primarily ammonia) to form chloramines. This combined residual chlorine form results in long lasting disinfection, produces minimal chlorine taste or odour and controls organic growths.
- Finally, once even more chlorine is added to the water, the chloramines are destroyed and excessive chlorine, known as the free residual, forms hypochlorous acid (HOCL), which is a potent, fast reacting disinfectant. Free chlorine can prevent the growth of bacteria in the water system[22]. The adequate free chlorine residual level is in the range between 0.2 mg/L and 0.5 mg/L, as defined by the World Health Organization (WHO).

The effectiveness of shock chlorination depends on the following factors:

- Extent of the microbial contamination. If there are large numbers of aerobic or anaerobic bacteria in the water, a high chlorine dosage is required to ensure that all disease causing organisms have been destroyed.
- pH. Hypochlorous acid will dissociate into hydrogen (H^+) and hypochlorite (OCl^-) ions. Hypochlorite is 80 to 250 times less effective as a disinfectant than HOCl. The higher the pH, the more dissociation will occur. At pH of 5 almost all of the chlorine residual is in HOCl form, at pH of 9, almost all of the residual is in OCl^- form. Hence, WHO recommends that for effective disinfection the pH of the water needs to be below 8.
- Temperature. Temperature affects the rate of disinfection– usually the higher the temperature, the faster the rate of disinfection[22].
- Turbidity. Disinfection of bacteria will only begin after the chlorine demand exerted by turbidity (inorganic and organic compounds) is met. In addition, chlorine is a surface-active agent so it cannot effectively penetrate into solids to kill the concealed bacteria. In established municipal water treatment systems, water is filtered to remove turbidity prior to chlorination; but this is not feasible for the tubewell systems in Nepal. New wells often have turbid water that contains elevated concentrations of iron and organic slimes. As a result, much higher chlorine doses are required to shock chlorinate new wells. More importantly, new wells must be effectively developed prior to disinfection since the presence of organics (including residual drilling fluid) and fine particulate matter can

make disinfection ineffective and can result in the formation of compounds that have unacceptable health or aesthetic characteristics[23].

4.2 Procedure of Shock Chlorination

The general procedure of shock chlorination is:

1. Determine the depth of water in the well, L. For example, if you have a 20-meter deep well, and the water level is at 10 meters, the well contains 10 meters of water (20 -10 = 10 meter).
2. Calculate the volume of water, V, to be treated. The volume of water is equal to the depth of water in the well multiplied by the cross sectional area, A, of the well. Mathematically, this can be expressed as:

   $$V = L \times A = L \times \frac{\pi \times D^2}{4}$$

   where D = the diameter of the well.
3. Determine how much chlorine needs to be added to effectively disinfect the calculated volume of water. Newly constructed wells should be chlorinated with 250 milligrams of available chlorine per liter of water (250 mg/L) [23].

   For example, if the volume of the water, V, that you calculate from the above formula is 0.05 m^3 (50 L), and the concentration of chlorine that you need is 250 mg/L, then the amount of chlorine that you need is 12,500 milligrams (12.5 g). If the disinfectant being used is bleaching powder with 70% strength♣, then the amount of bleaching powder that you need is 17.8 g.

   If sodium hypochlorite is used, just pour the chlorine into the well. If calcium hypochlorite is used, dissolve the chlorine powder or tablets in a 20-liter (5-gallon) bucket of water before adding it to the well. Be sure the bucket is plastic and has been thoroughly washed. Add no more than 100 g of calcium hypochlorite to each bucket. When mixed with water, an insoluble residue will likely be formed. This residue should be allowed to settle and the clear

♣ That means 75% available chlorine in the bleaching powder.

supernatant containing the chlorine should be decanted. Pour the clear solution into the well[23].

If possible, agitate the water to evenly mix the chlorine. This will thoroughly mix the chlorine solution and well water. For instance, lower a rope, to which a stone is attached, into the well and move it up and down; Figure 4-1 shows a schematic of the application of shock chlorination.

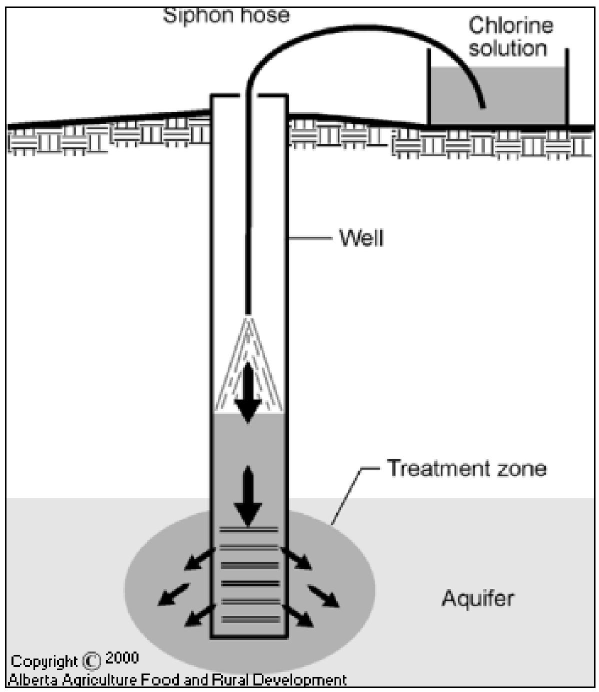


Figure 4-1. Siphoning Chlorine Solution

4. Leave the chlorine solution in the well for at least 12 hours and preferably for 24. After 12-24 hours, pump the strongly chlorinated water out of the well. The pump will be disinfected by using it to remove the excess chlorine. Choose a disposal place, where contact with plant and animal life is minimal, for the chlorine solution. Distribute the wastewater on gravel roads or other areas without plants or aquatic life.

   If a chlorine smell is not present in the discharge water after this contact time, the chlorination procedure should be repeated.

5. Discharge the water in the system to waste until the smell of chlorine disappears. Some chlorine may persist in the system for 7-10 days[24]. The amount of chlorine remaining in the water will not be harmful. In about a week, collect a water sample for bacteriological examination. Two consecutive "safe" tests will probably indicate that the treatment has been effective.

   If tests show continuing bacteriological contamination, a second shock chlorination is recommended. If the water supply continues to develop microbial contamination problems after being shock chlorinated, regular, frequent chlorination may be necessary, although this may be a burdensome expense for aid organizations or user committees. Other options include repairing the well, constructing a new well or abandoning the water source if necessary.

4.3 Safety Practices and Health Concerns

Chlorine is a very reactive substance. It is corrosive and can even be deadly. Safety practices are needed in order to handle chlorine and apply shock chlorination safely. Before beginning the shock chlorination process, you should store ample clean water in a big container. If concentrated chlorine accidentally comes in contact with your eyes or skin, use this clean water to flush the affected area for 10-15 minutes. If chlorine solution gets into your eyes, see a doctor after thoroughly flushing the affected eye.

A second safety practice is to wear appropriate safety clothing and equipment. Wear goggles to avoid contact with the strong chlorine material and your eyes. Wear a pair of rubber gloves to protect your hands and shoes and long pants to totally cover your toes and feet. To prevent discoloration of your clothing, wear a waterproof suit, coveralls, old clothing or a full-length apron.

Remember that chlorine is very volatile so it is dangerous to work with in confined areas. Make sure the work area is well ventilated. Care must be taken when mixing and adding chlorine to a well since exposure to it can result in severe skin or eye irritations and blisters. It is also poisonous; inhaling concentrations of 30 mg/L can lead to harsh coughing and inhaling concentrations of 1,000 mg/L can be fatal[23].

Chlorine compounds are volatile so they will degrade with time. Purchase only what is needed and use it all. Always read and follow manufacturers' recommendations. When using chlorine bleaches, do not purchase bleaches that have scents or other additives. Do not add other cleaning materials to the chlorine solution. Some combinations of chlorine and acids or ammonia can produce toxic gases[25].

Shock chlorination introduces very high levels of chlorine into a water system. During the disinfection process, water from the system is not suitable for consumption or extended contact by people or animals[24].

There has been considerable concern in developing countries over the heath risks (primarily cancer) that are potentially associated with the by-products from disinfection of water by chlorine. These disinfection by-products, such as trihalomethanes, are formed when organic matter is present in the water before it is chlorinated. Most experts consider that these risks are minimal compared to the known risk of consuming water that are contaminated with pathogens[22]. As stated by WHO in 1993:

> *Where local circumstances require that a choice must be made between meeting either microbiological guidelines or guidelines for disinfectants or disinfectant by-products, the microbiological quality must always take precedence, and where necessary, a chemical guideline can be adopted corresponding to a higher level of risk. Efficient disinfection must never be compromised.*

The level of disinfection by-products can be reduced by optimizing the treatment process, particularly by removing organic substances before the water is chlorinated.

4.4 Field Shock Chlorination in Nepal

4.4.1 Scarcity of Well Information

The procedure described in the previous section is the standard method of shock chlorination. However, it is difficult to follow this standard in a country like Nepal, where resources are scarce and information is lacking. For example, there is no record of the depth of the water table or any proper hydrologic study done for most of the tubewells. Therefore, the depth of the water table was not known at the time when I conducted shock chlorination in Nepal. The only information available was the depth of the well and the diameter of the well.

4.4.2 Shock Chlorination Experiments on Two Tubewells

Two tubewells, one newly constructed and one 10-month old, were shock chlorinated. The depth of the newly constructed well was about 24 meters and the depth of the old one was about 42 meters; the diameters of both of the wells were 40 millimeters[26]. The chlorine product available there was 25% strength bleaching powder (calcium hypochlorite)[♣]. Since the depth of the water table was unknown for both of the wells, the amount of bleaching powder needed was estimated– I estimated that the amount of bleaching powder needed was 100g.

The new well that was shock chlorinated was Well 1475 in a VDC called Bhalward, only constructed two days before, and it tested positive for H_2S bacteria one day after construction and before the shock chlorination. The well was constructed with bentonite. The 100g of the bleaching powder was dissolved into a 20-liter plastic bucket. The upper part of the handpump was removed, and the chlorinated water was poured into the well through the circular opening. No mixing or agitation was done because the circular opening was very small. The upper part of the handpump was reinstalled onto the well, but the handle was not reinstalled, so that people could not pump the highly chlorinated water. The public was informed about the disinfection process[♦] and that they should not use the water for 24 hours and we would return in 24 hours to put the handle back.

♣ Bleaching powder is not available locally in Lumbini Zone. RWSSSP staff purchased the bleaching powder for me from ENPHO, who in turn obtained it from an imported source in India.

♦ The RWSSSP technician told the villagers that something was put into the well to make the water "clean".

We went back to the site after 24 hours. The handle was put back. Residual chlorine level (RCL) in the first few drops of the water that was pumped was measured with the Total Chlorine♠ Test strip, manufactured by SenSafe™, the colour shown on the test strip was black, indicating that the RCL was out of the maximum detection limit (10 mg/L) of the test strip. As more water was pumped out, a very strong chlorine smell was noticed. However, after five minutes of pumping, the RCL in the water was measured again and the test strip showed no sign of residual chlorine in the well water. Then a water sample was taken to test the presence of H_2S bacteria and turned out to be positive with H_2S. We noticed that the well water was turbid and I was told that this well might not have been properly developed. Therefore, disinfection was not complete due to the high turbidity in the water. I decided to shock chlorinate the well with 100g of bleaching powder again. I let the chlorinated solution stay in the system for 24 hours again. The next day, the well water was still turbid. The RCL result was the similar to that of the day before: the RCL detected in the first few drops of the well water was higher than the maximum range of the test strip. After pumping for about 6 minutes, the RCL was measured with the test strip again; the colour of the test strip turned to very slightly blue, indicating a RCL of 0.05 mg/L.

The old well that was shock chlorinated was Well 3, in VDC called Tikuligad. This well had tested positive with H_2S bacteria in testing previously conducted by RWSSSP staff. A water sample was collected before the shock chlorination and it turned black after 24 hours, confirming the presence of H_2S bacteria. One hundred grams of bleaching powder was dissolved and then poured into this well. The pubic was informed about this activity. This time, I decided to make sure that the contact time was long enough, so the chlorinated solution stayed in this well for 48 hours instead of 24 hours. However, the result of RCL was similar to that as observed as in the first case– the first few drops of the water had very high RCL and the RCL dropped to zero after a short period of pumping. A water sample was collected after the shock chlorination, no sign of H2S bacteria was found.

♠ total chlorine = free chlorine + monochloramines

4.4.3 Finding

Upon returning from Nepal to MIT, I have carried out additional literature reviews on shock chlorination and talked to people who are qualified in this field. The findings from this further research and fieldwork in Nepal are:

- New wells need to be properly developed. Disinfection by chlorine will not be effective if there is still much organic matter in the well water.
- The procedure described in the previous section is more suitable in established domestic water distribution systems. Different emphases and approaches are needed for simple well systems in developing countries like Nepal.
- It is difficult to achieve good mixing of chlorine and water in the wells, chlorine tends to settle to the bottom of wells and high chlorine concentrations must reach the outside of the well tiles and the surrounding gravel pack. Therefore, agitation or mixing of the water is necessary.
- Availability of the depth of the water table seems not important, although it will definitely help to know how much chlorine product is needed for a certain chlorine concentration, so that no resource is wasted. As long as the amount of chlorine put into the well is large enough to the meet the demand exerted by inorganic and organic compounds and to disinfect the bacteria, the excess chlorine, if any, will be pumped out of the system, therefore, it will not have harmful effect on the users. However, the strong smell that we noticed at the experimented wells in Bhalward and Tikuligad probably indicated that the amount of bleaching powder used could be less than 100g. On the other hand, if no smell of chlorine is present, probably insufficient chlorine is used, and the shock chlorination procedure should be repeated and the chlorine concentration increased.
- Shock chlorination is effective in disinfecting the wells, but it cannot prevent the water from future contamination, because residual chlorine fails to stay in the well system. Chemical transport takes place very slowly through aquifer; within the contact time (24 to 48 hours) chlorine may only travel a few centimeters radially at most. This means only a small volume of water contains residual chlorine is there in the aquifer[27]. This volume will not sustain the demand of the users all at, as noticed in the field application, residual chlorine dropped to zero after several minutes of pumping.

4.4.4 Recommendations

Based on the above findings, the following actions are recommended regarding shock chlorination in Nepal:

- Involve the community in an early stage about the process and explain what will happen and why, show and discuss with them the results of the bacteriological analysis[28]. Tell the users to store enough water for use during the time the well is not for use or designate an alternative source of water.
- Before shock chlorination, clean area surrounding the tubewell, including the platform and the drainage channel.
- Ensure proper mixing of chlorinated water with well water by pumping the mixed water out and pouring it back in the well. Procure three 20-L plastic buckets for the mixing. After pouring the initial chlorinated water in, pump and fill the three buckets with the well water, and pour those three buckets of water back into the wells.
- Wash the wall of the handpump and the platform of the well with the chlorinated water that is pumped out after the contact time.
- Many of the tubewells were built in vegetated areas or close to water bodies. The chlorinated water from the two wells that I shock chlorinated was just pumped out and flowed to those areas. Proper disposal of the chlorinated water was difficult in the rural area, where resources were scarce and there was no centralized wastewater treatment system. If shock chlorination is to be applied in the future, a better way of disposing of the unconsumed chlorine should be developed.
- Protect all people involved with gloves and clothing and keep sufficient fresh and clean tissue at hand in case eyes or skin needs to be washed.
- Shock chlorination should be applied twice a year– at the beginning of the year and after monsoon to all wells if resources are available or to the wells that were contaminated with H_2S bacteria.
- Test the well water for H_2S bacteria after one or two weeks to evaluate the result of shock chlorination. Do not be disappointed if it appears that there is still contamination. Often two or three consecutive treatments will be necessary, especially with wells where the contamination source is persistent and pathway of contamination is long [28].

- Even when the disinfection is successful initially, organize the community for alternative household-level water treatment, such as household chlorination[20] and biosand filtration[29]. It is important to realize that water treatment in the rural area needs continuous attention and support.

5 Tubewell Maintenance Program

5.1 Case 1

On the first day out in the field, RWSSSP's staff and I went to a VDC named Gajehada. We saw a suction well in one user's backyard. The age of the well was 10 years. In its first 2 years, it was an artesian well. After water stopped flowing out naturally, they had to make it into a suction tubewell. The water level in the well kept dropping. Now no one used the well, because the handle was very hard to press and not much water was coming out of the well anyway. In order to obtain water for the sample, the RWSSSP field technician had to put in externally-procured water to prime the well. The technician told me that the problem with the well may be that the wrong model of handpump was used– instead of Nepal no. 6 they used Nepal no. 4. The well was now abandoned, and according to the technician, the users had no money to fix the problem. I looked around, the platform was in good condition, the surrounding environmental was very clean, it would be a very good spot for a tubewell, if they could fix the well.

5.2 Case 2

Chhotki Majhganwa is the most unsanitary village that I visited. The village was very crowded. Some tubewells were next to animal sheds, and animal waste was everywhere. One of the tubewells in that village was broken for several months. No water could be pumped; no water sample could be taken. The age of the well was unknown. The users believed that the washer inside the handpump was damaged[♣]. They claimed that they were aware of a UC existed, and that the UC had money in the bank (to which they themselves had contributed) and that the money was for maintenance, but no one reported this problem to the UC. They said that the UC knew of the problem, because people belonged to the UC had seen the well, and the UC would have come by now if they really wanted to fix the well. At the same time, people were not willing to fix the well themselves.

[♣] The washer is made of plastic. It keeps the valve water-tight, so that the vacuum can be created in upstroke of the piston. If the washer is damaged, the vacuum can no longer be created.

Again the platform was very well constructed; therefore, money had been wasted to build such a nice well. The users did not even take the initiative to fix a washer. The same amount of money could be used to sponsor children to school, in which case it might be much more effective and useful for improving the life of the Nepalese people. I left the village by shouting and yelling that they should report this problem to the UC and chase them until they come to fix it. I told them that they had money in the bank and it was their right to have the well fixed and they should fight for their right. They looked at me and smiled. Did they understand? I begged the technician to translate to them what I said, and she summarized what I said in three Nepalese words. They smiled at me again. It was the same friendly, gracious and naïve expression that I had seen everywhere in rural Nepal. My heart sank.

5.3 Other Problems

Although they are simple personal stories, the above cases indicate that a better maintenance and management program is needed for the success of the tubewell program. What happened to the village maintenance workers (VMWs) in the above cases? Ironically, I was told that sometimes some VMWs sold the tool kits given to them by RWSSSP to get cash– the kits are never needed to be used anyway.

At one construction site, I asked the technician how the people chose this particular site to dig a well, he told me "because the users like this spot" and they thought that "groundwater would flow here" since it was at a lower spot when one looked at the general topography of this area. Although it is stated in the Guideline for "Community Based Tubewell Program"[13] and RWSSSP's documentation that a field survey and a feasibility study are required prior to the well construction, this kind of study seems seldom done in reality. Water level fluctuates between seasons. Lack of feasibility studies result in technical problems, such as the wells drying up during the dry season, or permanently lowering the water table of the area.

Another problem in the tubewell program is that as soon as the handpump is installed, a platform is supposed to be constructed. However, sometimes, due to financial constraints or delays in the decision-making process, the cement needed to construct the platform cannot be purchased on time. The following picture shows a tubewell under construction. Contaminated water might percolate into the well through the mud after the tubewell is constructed. At this particular site, I was told that the platform would not constructed for 22 days, because the UC had not purchased the cement early enough.

Figure 5-1. Construction of a Tubewell

5.4 Maintenance and Management Recommendations

In all the places that I visited, the users were generally satisfied with the RWSSSP. FINNIDA was highly respected and very well known to the villagers. The villagers' lives have been greatly improved because of tubewell program and the time saved in fetching water. In one village, a user told me that before the RWSSSP tubewell was constructed ten years ago, they were using water from a dugwell. The water quality from the dugwell was very bad, and the villagers believed that it was cause of a local epidemic, which resulted the deaths of seven people, who were all suffering from the symptoms of diarrhea. The village has not had any abdominal or gastro-intestinal problems ever since they started using water from the tubewell instead from the dugwell.

However, RWSSSP has its own maintenance program, it has not been entirely effective in protecting the wells and educating the users about their privileges and responsibilities.

To properly protect the tubewells and avoid microbial contamination of the well water, the tubewell maintenance program should include the following:

- Monitoring of well water quality. H_2S bacteria present/absence test should be performed bi-annually to monitor water quality of the well.
- Shock chlorination. Shock chlorination is an effective way to disinfect wells, it should be carried out each spring and fall as a regular maintenance procedure for all tubewells, or at least for the wells that test positive with H_2S bacteria. In addition, it should be applied to newly constructed wells. Apart from disinfecting the water source, shock chlorination can effectively eliminate iron bacteria, which are neither pathogenic or directly harmful, but can cause a slime coat that can reduces yields (especially in small diameter wells) and other problems such as red staining of laundry.
- Evaluate the program yearly. Although the ideal principles of this scheme are very good, in reality these principles are not enforced, and good ideas are ignored. The current practice is that once the tubewell is constructed, RWSSSP steps out of the picture. RWSSSP should perform yearly evaluation of the system to ensure that the principles of the program are enforced.
- Training of tubewell mechanics. If possible, the work of a VMW should not be a volunteer activity. It should be a paid job by the UC.
- Women's involvement. Women's involvement should be encouraged, such as encouraging women to be the president of the UC or the tubewell mechanic. Experiences from other tubewell programs around the world have proved that women's involvement is a very important factor in the success of the program[30].
- Cleaning the platform and drainage channel. Algae can grow on the platform. Trash can accumulate on the platform and the channel. Therefore, cleaning the platform and the channel regularly is important to ensure that dirty water will not percolate into the well.
- Health and hygiene education program. An education program should be conducted in the rural areas to teach people about the importance of handling and storing water safely, and personal hygiene. Experiences from other tubewell programs around the would have also showed that having a health education motivator for a zone is very useful in the success of their water supply program. The International Buddhist Society has been hiring women as health education motivators in their tubewell program. A motivator will

be appointed on her qualification and experience, the monthly salary is NRs 4000 to NRs 6000, which is equivalent to US$53 to US$80[31].

5.5 Education, Education, Education

Tubewell programs tend to have problems such as the lack of initiative by users in protecting or maintaining the wells properly. NGO's assistance and donor funds are always needed and in such cases, the programs cannot be sustainable. This problem is noticed in Nepal, too. If the users do not take responsibility for maintaining the wells, no one can help them. Villagers need to recognize that contaminated water and unsanitary practices lead to poor health and are the causes of the children's illness and even death.

This suggests that education is critical in the success of any tubewell program. If people do not know what is hygienic or not, no tubewell program will succeed. By education, I do not just mean health and hygiene education, but also education about their rights and responsibilities in meeting their basic need for safe drinking water.

6 Conclusion

The rural population in Nepal is suffering from unsafe drinking water. Water contaminated with pathogens is causing gastro-intestinal diseases among people, especially in the rural areas, where facilities, such as a piped water supply system, are not available. This water problem, combined with a lack of sanitation facilities, has serious health impacts on the Nepalese people. The long-term solution to this water crisis would be for every community to have piped, disinfected water as well as sewage treatment facilities, but the Nepalese government simply does not have sufficient resources to provide such services. Therefore, a decentralized, community-based tubewell program seems to be a good answer, at least in the Terai region, where groundwater resources are rich. One such tubewell program, as part of the Rural Water Supply and Sanitation Support Program (RWSSSP) implemented by FINNIDA in Lumbini Zone, has been successful in providing people with portable water within easy access over the past 10 years. However, there are still problems associated with the program.

First of all, past studies have found that some of the tubewells are contaminated with H_2S bacteria and coliform bacteria. These microorganisms are indicators of the presence of pathogens of fecal origin in water. In January 2002, I went to Nepal and conducted a well survey including water quality testing of 45 wells using the H_2S bacteria presence/absence test. The results of the testing were that 42% of water samples tested positive with H_2S bacteria.

One of the major causes of the contamination of tubewells was found to be the use of cow dung as the slurry in the construction process of a tubewell. Using cow dung is a traditional way of building a well, although DIDC has recently stopped using cow dung and now uses bentonite instead in building new tubewells. The primary concern with using cow dung is not the fecal pathogens in the cow dung, because it was found that all the fecal coliform in the cow dung died out several days after living their host; hence, cow dung will not affect the microbial quality of the well water in the long term. However, the main problem is that cow dung is mainly organic matter, which will disintegrate over time. Those wells may have cracks and holes around the PVC pipe underneath the platform. These cracks and holes may create short circuits for the contaminated surface water. The space may also store dirty water, which in turn may seep into the tubewell or the aquifer, and causes microbial contamination.

Contamination may also be introduced by floodwaters during the monsoon, by priming of the well with dirty external water and by other unsanitary practices while using the well. Animals can walk around the wells freely, sometimes they could introduce bacteria into the well, too.

The problem in the Terai region is “water abundance”, not water scarcity. Tubewells are everywhere. Users do not care about one particular well– if one well is broken, they can always go to the next one, which is just 10 to 20 meters away, why bother to report it to the UC anyway or take good care of it? RWSSSP should re-evaluate the need for constructing new wells. Ironically, if it is too easy to get water, the users do not care to protect their water source.

Due to the above problems, measures need to be taken to eliminate and prevent the contamination of the tubewell. A maintenance program needs to be developed to ensure the proper operation of the tubewells. RWSSSP has a good tubewell program in principle and described in documents. This program includes the training of tubewell mechanics, a users’ committee system and encouragement of women’s participation. Although the ideal principles of this program are very good, in reality these principles are not enforced, and good ideas are ignored.

The suitability of shock chlorination was investigated in Nepal. The results indicate that shock chlorination is only effective in disinfecting the well at the time of the application, not in preventing future contamination. Nevertheless, shock chlorination is still a useful tool.

Based on the observations and fieldwork results in Nepal, the following actions are recommended to RWSSSP:

- Continue to monitor well water quality. The H_2S bacteria P/A test should be performed bi-annually to monitor water quality of the well.
- Evaluate the tubewell program yearly. The current practice is that once a tubewell is constructed, RWSSSP will step out of the picture. RWSSSP should perform yearly

evaluations of the system to ensure that the principles of the program, such as the function of the UC system and the proper use of the maintenance fund, are enforced. Re-evaluate the prioritizing criteria and the real need of constructing new wells.

- Make the work of a village maintenance worker (VMW) a paid job, so that VMWs will have more initiatives to perform their jobs and take more responsibilities. The users' committee should be paying the salary.
- Clean the platform and the drainage channel. Algae can grow on the platform. Trash can accumulate on the platform and the channel, therefore, cleaning the platform and the channel regularly is important to ensure that dirty water will not percolate into the well.
- Improve the health and hygiene education program. Education programs should be conducted in the rural areas to teach people about the importance of handling and storing water safely, and about personal hygiene. Health education motivators should be hired to inform people about the importance of sanitary practices and teach people how to handle water safely.
- Shock chlorinate the wells at least twice a year– one time in the beginning of the year and another time after the monsoon period. Shock chlorinate newly constructed wells, too.
- If possible, extend the water supply program to the use of household level water treatment such as household chlorination and biosand filtration, as has been successfully commenced at the IBS in Lumbini. Since shock chlorination is not effective in preventing contamination, incorporating household level water treatment seems to be a more reliable method to supply safe drinking water to the rural population in Nepal.

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