AN ABSTRACT OF THE DISSERTATION OF

Rochelle C. Rainey for the degree of Doctor of Philosophy in Public Health presented on April 15, 2003.

Title: Solar Disinfection of Drinking Water: Effectiveness in Peri-Urban Households in Siddhipur Village, Kathmandu Valley, Nepal.

Redacted for privacy

Abstract approved: ______________________________

Anna K. Harding

The study examined pH, turbidity, and fecal contamination of drinking water from household water storage containers, wells and taps, and the Godawari River, and tested the effectiveness of solar disinfection (SODIS) in reducing levels of fecal contamination from household containers. Second, the study investigated the relationship between use of SODIS and reported episodes of diarrheal illness in the participating households. Third, using the Health Belief Model as a framework, the study collected qualitative data about the acceptability of SODIS and about perceived susceptibility to diarrhea, and perceived benefits and barriers to adopting SODIS. Forty households from Siddhipur Village in the Kathmandu Valley participated in the study from March to July, 2002. The study included a baseline survey of health and water quality, training in how and why to use solar disinfection, and two follow-ups.

The results showed:

1. Water from all sources is contaminated with fecal coliform bacteria.
2. There is less contamination in water from the household containers than from wells and taps.
3. SODIS did significantly reduce the level of fecal contamination.
4. SODIS was not adopted by most households in this study. Due to the low level of adoption it was not possible to test for a reduction in episodes of diarrhea among households using SODIS.
5. The level of education and awareness about water and sanitation was low.

One recommendation is to examine the entire water distribution system for the village and identify specific points of potential contamination. The riparian zone upstream from the intake for the village reservoir and the areas around the taps and wells in the village should be protected from human and animal waste.

Education about water and sanitation should be provided to the primary food preparers, as well as information and training on other simple methods for household disinfection. A SODIS program integrated into the school curriculum would involve the children and relieve the women of this additional workload.

Additional research is needed to determine the effectiveness of SODIS in the shorter, colder winter days and at higher altitudes before final recommendations can be made for general use in Nepal.

Solar Disinfection of Drinking Water: Effectiveness in Peri-Urban Households in Siddhipur Village, Kathmandu Valley, Nepal

by
Rochelle C. Rainey

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

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Rochelle C. Rainey, Author

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SOLAR DISINFECTION OF DRINKING WATER: EFFECTIVENESS IN PERI-URBAN HOUSEHOLDS IN SIDDHIPUR VILLAGE, KATHMANDU VALLEY, NEPAL

CHAPTER 1. INTRODUCTION

Without water, there is no life on earth. Humans drink water, wash in water, and grow crops with it. As a development indicator, access to safe drinking water is one of four socio-economic criteria that the World Bank uses to assess the level of a country's development (World Bank, 2000), and the World Health Organization (WHO) has set guidelines for both the quantity and quality of water required for maintaining good health (WHO, 1993, 2002). Provision of an adequate supply of safe water was identified as one of eight key components of primary health care during the 1978 International Conference on Primary Health Care as part of a global effort to promote and protect the health of all the people of the world (WHO, 1978). But the Global Water Supply and Sanitation Assessment 2000 report notes that even after twenty years of concerted effort in this area, over one billion people still do not have access to safe drinking water for household consumption, and two-fifths of the world's population lack access to improved sanitation facilities (WHO/United Nations Children's Fund [UNICEF], 2000).

Globally, Asia has the lowest access to sanitation technologies, with only 50% of the population having access to some kind of "improved" sanitation, including connection to a public sewer or septic system, or a private pit latrine. In terms of drinking water, Asia is second lowest in access to improved drinking water with 81% of the population having access to some kind of protected water source or rainwater (WHO/UNICEF, 2000). Table 1.1 shows the water and sanitation technologies considered to be "improved" and "not improved" in the WHO/UNICEF study.

Table 1.1. Classification of water supply and sanitation technologies

Improved	
Water Supply	Sanitation
Household connection	Connection to public sewer
Public Standpipe	Connection to septic system
Borehole	Pour-flush latrine
Protected dug well	Simple pit latrine
Protected spring	Ventilated improved pit latrine
Rainwater collection	
Not Improved	
Water Supply	Sanitation
Unprotected well	Public latrines
Unprotected spring	Open latrines
Vendor-provided water	Service or bucket latrines
Bottled water	(manually cleaned)
Tanker-truck provision of water	

Note. From Global water supply and sanitation assessment 2000 report (p. 3) by World Health Organization and United Nations Children's Fund Joint Monitoring Programme for Water Supply and Sanitation, 2000. New York: Author. Copyright 2000 by World Health Organization and the United Nations Children's Fund. Reprinted by permission.

Both within the Asian region and at the level of countries in the region, the overall access statistics mask serious discrepancies in coverage between urban and rural areas. The worst levels of access to clean drinking water and sanitation are in rural areas. In Asia, rural access to sanitation is less than one-half that of urban areas (WHO/UNICEF, 2000).

Diseases related to polluted drinking water, improper excreta disposal, and unsanitary food preparation constitute a major burden on the health of people in the developing world. The report from the United Nations Conference on Environment and Development in 1992 estimated that 80% of all diseases and one-third of all deaths in developing countries are caused by the consumption of contaminated water (United Nations, 1992). In 1996, an analysis of the global burden of disease revealed that an estimated 20 to 25% of the total global disease and injury burden is related to exposures that underlie the major infections of young children, including malnutrition and poor water, sanitation and hygiene, making their control a priority for global public health (Murray & Lopez, 1996). Every year 4 billion cases of diarrhea cause 2.2 million deaths, mostly among children under five years old. Lack of access to safe drinking water increases the risk of contracting waterborne diseases including diarrhea, cholera, typhoid, hepatitis A, and amoebic dysentery (WHO/UNICEF, 2000). The World Bank (no date) notes that diarrhea is highly correlated with poverty, with diarrhea accounting for 53% of the deaths among the poorest 20%, and only 1% from among the riches 20% of the population.

Nepal is a small Asian country located along the Himalayan mountain range between India and China, as shown in Figure 1.1.

Figure 1.1. Map of Nepal

Note. From Maps.com. Retrieved February 23, 2003 from http://www.maps.com Copyright 1999 by Maps.com. Reprinted with permission.

Nepal has an area of 56,827 square miles, about the size of the state of Iowa. Nepal's population is 23.9 million people, with an average density of 420 people per square mile (Population Reference Bureau, 2002), compared to Iowa's 2.9 million people and average density of 52 people per square mile (US Census Bureau, 2002). It has an annual per capita income of US$250, one of the lowest in the world (World Bank, 2002). The Human Development Index rank of Nepal in 2002 was 142 out of 173 countries, indicating a low life expectancy at birth, low educational attainment and low income (United Nations Development Program [UNDP], 2002). Life expectancy at birth in Nepal is 58 years, compared to 77 years in the US. Infant mortality is estimated at 64 per 1000 live births, about 10 times the US rate of 6.6 per 1000 live births (Population Reference Bureau, 2002).

Many of Nepal's health problems, including high infant and child mortality and high incidence of fecal-orally transmitted disease, are related to contaminated water. (UNDP, 1995). The Asian Development Bank's 1998 Plan for Nepal stated that poor water supply and sanitation and unhygienic living conditions, especially in rural villages, remain among the major obstacles to improving health. The weak health infrastructure in rural areas contributes to high numbers of fatalities for many treatable illnesses, including dehydration due to diarrhea. In 1992 an estimated 45,000 deaths annually were due to contaminated drinking water in Nepal, mostly children under five years old (UNICEF, 1992).

Nepal has invested millions of dollars in water treatment plants and distribution systems in Kathmandu and other larger cities, but the rural populations are largely unserved. Eighty-five percent of urban populations have access to improved drinking water sources, and 75% have access to improved sanitation facilities as defined above in Table 1.1. For rural areas, 80% of the population has access to improved drinking water sources, and only 20% have access to improved sanitation facilities (WHO/UNICEF, 2000).

The current Melamchi Water Supply project, a $464 million, seven-year plan to provide water to the Kathmandu Valley urban area, suffers from budget crises and political instability due to the Maoist insurgency that has paralyzed the rural areas of Nepal (Sharma, 2002; Manandhar, 2002). Even the existing urban systems fail to provide safe drinking water due to lack of trained operators, a reliable supply of chemicals, inadequate maintenance and a mushrooming population in the service areas (Khayyat, 2000; Wolfe, 2000).

A joint study by the His Majesty's Government (HMG) of Nepal and UNICEF found that water treatment in the home reduced the risk of diarrhea in children by 1.5 times (HMG/UNICEF, 1997). They concluded that inexpensive effective methods of home water treatment are urgently needed as a short-term and even long-term solution to the lack of community-level water systems. There are many methods available for household-level disinfection of drinking water, including chlorination, iodine, filtering, and solar disinfection. Each of these methods or combinations of methods has tradeoffs in terms of effectiveness, convenience, and affordability.

One technique for solar disinfection (SODIS) was recommended during World Water Day 2001 as a method to improve drinking water quality at the household level (WHO, 2001b). It uses solar energy in the form of ultraviolet radiation and infrared heat to disinfect small quantities of contaminated water. The process has three main steps:

1. Collect clear, empty 1.5 or 2 liter PET plastic bottles (mineral water or soda pop bottles) with labels removed.
2. Rinse to clean inside and outside of bottles, then fill halfway with contaminated water. Close and shake the bottle vigorously for about five seconds to incorporate additional oxygen into the water, then fill to the top and close tightly.

3. Place bottles on their sides in full sun for at least four hours during the middle of the day when the solar radiation is most intense. Actual exposure time required depends on latitude, altitude, season, weather, and turbidity of the water (Swiss Federal Institute for Environmental Science and Technology/Department of Water and Sanitation in Developing countries (EAWAG/SANDEC), no date).

This technology has been tested under controlled conditions at a laboratory the Kathmandu Valley of Nepal, and has shown reductions of bacterial contamination in drinking water of over 90% (Environment and Public Health Organization (ENPHO), 2002). It has been tested in households in the *Terai,* or lower elevations of Nepal near the Indian border, and was shown to be effective both in disinfecting water and reducing diarrhea (Moulton, 1999). However, there has been no research on effectiveness under household conditions in the Kathmandu Valley, which differs in culture, ethnicity, and geography from the *Terai* region. Finally, there is very little information on the social and economic acceptability of this technology in Nepali culture.

Purpose Of Study

The purpose of this study was threefold. First, the study examined the drinking water quality from various sources, and the effectiveness of solar disinfection (SODIS) in eliminating microbial contamination of drinking water under household conditions in rural Nepal. Second, the study investigated the relationship between use of SODIS and diarrheal illness, measured by the reported number of episodes of diarrhea for household members before and after adoption. Third, the study collected qualitative information about the acceptability of SODIS as a water treatment method, and on the local understandings of links between water quality, sanitation, and health.

Significance of the Study

The results of this study will assist policy makers, Nepal's Office of Drinking Water, Sanitation and Sewerage under the Ministry of Local Development, non-governmental organizations and donors in designing effective interventions to improve drinking water quality and reduce water-borne disease in Nepal. This study shows that SODIS could provide low-income people in the Kathmandu Valley of Nepal with an inexpensive, simple and effective source of clean drinking water.

Research Questions

The research questions can be grouped by the three purposes of the study under the categories of water quality, diarrheal illness, and qualitative research. The following research questions guided this study:

1. Water Quality

1a. Does water quality as measured by pH, turbidity in FAU, and colony forming units (CFU) of fecal coliform bacteria differ by source of the water (river, taps, wells, or household water storage container (*gagri*)), when controlled for sampling round?

1b. Does water quality, as measured by CFU of fecal coliform bacteria, differ between the household storage container and the exposed SODIS bottle in that sampling round?

1c. Which, if any, of the following variables (age of household contact, education level of contact, size of household, presence of latrine/toilet in household) is a significant predictor of water quality, as measured by number of CFU of fecal coliform bacteria?

2. Diarrheal illness

2a. Does the reported number of episodes of diarrhea differ by the level of water contamination as measured by CFU of fecal coliform bacteria?

2b. Which, if any, of the following variables (age of household contact, education level of contact, size of household, presence of latrine/toilet in household, CFU of fecal coliform bacteria) is a significant predictor of reported number of episodes of diarrhea, controlling for sampling round?

3. Qualitative Research

This component of the study was open-ended, but used constructs from the Health Belief Model (Becker, Drachman & Kirscht, 1974) to identify local perceptions of risk of diarrhea, benefits and barriers to adopting SODIS through open-ended survey questions and interviews. Local understandings of water, sanitation and health issues were be explored through observation and semi-structured interviews.

Research Hypotheses

Hypothesis 1

$H1_0$: There is no significant difference in pH of untreated drinking water among the four different water sources (river, taps, wells, and households), controlling for sampling round.

Hypothesis 2

$H2_0$: There is no significant difference in turbidity of untreated drinking water, measured in formazin attenuation units (FAU), among untreated drinking water from the four different water sources (river, taps, wells, and households), controlling for sampling round.

Hypothesis 3

$H3_0$: There is no significant difference in fecal contamination of untreated drinking water, measured in CFU/100 ml, among the four different water sources (river, taps, wells, and households), controlling for sampling round.

Hypothesis 4

$H4_0$: The fecal contamination in CFU/100 ml of untreated water from the household storage container will be less than or equal to the fecal contamination of water that has been treated using SODIS. (one-tailed)

Hypothesis 5

$H5_0$: None of the following variables (age of household contact, education level of household contact in years, number of people in the household, and presence of latrine in household) is a significant predictor of water quality as measured by CFU of fecal coliform from the household water storage container, controlling for sampling round.

Hypothesis 6

$H6_0$: The number of reported episodes of diarrhea in control households will be less than or equal to the number of reported episodes of diarrhea in households adopting SODIS to treat their drinking water. (one-tailed)

Hypothesis 7

$H7_0$: None of the following variables (age of household contact, education level of household contact in years, number of people in household, presence of latrine in the household, and fecal contamination of water from the household water storage container in CFU/100 ml) is a significant predictor of number of reported episodes of diarrhea in that household, controlling for sampling round.

Limitations

The study period of this research was from March to July 2002. SODIS depends on ultraviolet radiation to disinfect pathogens, so these results can only be interpreted in the context of the weather and day length during the study period. Ultraviolet light also is a function of altitude, and Nepal has an enormous variation in topography. In addition to season and weather, the results only apply to areas of the same altitude as the study area.

The timing of the data collection was delayed several times due to strikes in the Kathmandu Valley, and a lack of timely follow-up may have affected the rate of adoption of the technology.

The surveys and interviews were conducted in Newari language, and translated into Nepali for the researcher, a native English speaker. These two levels of translation may affect the level of detail of the ethnographic data. Both for oral responses and for the observational data, there may be cultural factors that affect the responses or actions due to the presence of a foreign investigator.

Delimitations

The selection of the research site was not random, due to the political situation in Nepal during the research study. Rather, it was made on the basis of its location (5 kilometers outside the Ring Road circling Kathmandu) and because prior research by Environment and Public Health Organization (ENPHO) indicated a water quality problem in the village water sources. Thus, the results of this study are applicable only to villages with similar source water and storage patterns in the same elevation belt as the research site.

This study used episodes of diarrhea, as defined by CARE/Nepal (2000), as the dependent variable for health status. However, diarrhea may have other causes than contaminated drinking water, such as improperly prepared or stored food, or may be caused by consumption of contaminated water from outside the household. In addition, not all water-borne pathogens cause diarrhea as a symptom of infection. Similarly, colony forming units of fecal coliform bacteria are used as an indicator of fecal contamination, but these bacteria are not pathogenic themselves (WHO, 1997). Neither water nor stool samples were tested for the presence of any specific pathogen associated with any specific episode of diarrhea. The study gathers information on episodes of diarrhea in the past two weeks. Recall data is always subject to error, but Black (1984, as cited in VanDerslice & Briscoe, 1993) stated that periods up to two weeks provide information on morbidity with adequate accuracy.

Cultural understandings of diarrhea also varied, despite the use of a specific definition of diarrhea as three episodes of loose stools during the day or night, or five episodes in 24 hours for the purposes of the survey process. Thus the responses to the ethnographic component may not be describing the same construct as the survey responses.

The number of episodes of diarrheal illness for the entire household was reported by the contact in each household, who is the primary food preparer. There may be recall errors or insufficient information about other household members that affected the responses. Finally, the study design assumed adoption of the SODIS technology by all participating households as the basis for analysis of reduction in episodes of diarrhea. A low adoption rate meant that this analysis could not be performed because of sample size limitations.

Definition of Terms

For the purposes of this study, the following definitions of terms were used:

Cue to Action: A message, either written or oral, or other reminder for the household contact to use SODIS. A construct from the Health Belief Model (Becker, Drachman & Kirscht, 1974)

Coliform Bacteria: A type of bacteria widely distributed in nature, identified by gram-negative, aerobic or nonspore forming rod, used as a general indicator of water quality (WHO, 1997).

Colony-forming Unit (CFU): A blue spot of bacteria that appears on a membrane filter of contaminated water after incubation with fecal coliform media.

Contaminated Water: Water that produces one or more Colony Forming Units (CFU) of fecal coliform after being filtered through with 7micron filters and incubated at 44.5 degrees Celsius for 24 hours with Millipore Fecal Coliform media.

Enteric: Intestinal

Episode of Diarrhea: Three or more watery loose stools during the course of a single day or night, or five episodes or more in one 24-hour period for any member of the household, as reported by the household contact for this study.

Escherichia coli (E. coli): A subset of fecal coliform bacteria, found only in intestines of warm-blooded animals (USEPA, 2002). Also used as an indicator of fecal contamination.

Fecal coliform bacteria: A subset of coliform bacteria found only in intestines of warm-blooded animals. Its presence in drinking water indicates contamination by fecal matter and may also signal the presence of pathogens (USEPA, 2002).

Fluence: Amount of solar radiation reaching earth's surface over time, measured in watt-hours per square meter (Wh/m^2).

Household Contact: The primary food-preparer in the household.

Household Members: All members of a household who share the same cooking hearth.

Hygiene: Activities undertaken to avoid diseases related to poor sanitation, including handwashing, use of latrines, and laundry areas.

Improved Sanitation: A latrine or toilet connected to a public or private treatment system, septic system, or pit (see Table 1.1).

Improved Water Supply: Drinking water coming from a connection to a treated or protected source (see Table 1.1).

Latrine: A separate building, room, or private outdoor location specifically for excreta.

Maximum Contaminant Level: The maximum concentration of contaminants allowable in drinking water (USEPA, 2002).

Microbe: A microscopic organism.

Pathogen: A disease-causing organism.

Perceived Barrier: A factor that is likely to discourage an individual from taking preventive action to protect health, from the Health Belief Model (Becker, Drachman & Kirscht, 1974).

Perceived Benefit: A benefit expected by an individual as a result of taking a preventive action necessary to protect health, from the Health Belief Model (Becker, Drachman & Kirscht, 1974).

Perceived Seriousness: The importance an individual places on the severity of a potential problem with drinking water quality, from the Health Belief Model (Becker, Drachman & Kirscht, 1974).

Perceived Susceptibility: The individual's perception of personal vulnerability to health problems due to drinking water, from the Health Belief Model (Becker, Drachman & Kirscht, 1974).

Primary Household Water Source: The location where the household drinking water is usually procured, as reported by the household contact.

Sanitation: Facilities to reduce exposure to disease by safe excreta disposal, solid waste management, wastewater management, and hygiene facilities including latrines and laundry areas.

Safe Drinking Water: Water with no colonies of fecal coliform (CFU) after membrane filtration with 7micron filters and incubation at 44.5 degrees Celsius for 24 hours with Millipore Fecal Coliform media.

Solar Disinfection (SODIS): A technique using clear plastic or glass containers placed in the sunshine, using irradiation and thermal energy to kill water-borne pathogens in contaminated drinking water (WHO, 2001b; EAWAG/SANDEC, no date).

Turbidity: A measure of suspended solids, usually clay, silt, organic matter, or microorganisms in a solution (Hach, 1997). Visually, water that looks cloudy is called turbid.

Water-borne Diseases: Diseases transmitted by drinking water contaminated with pathogens (WHO/UNICEF, 2000).

Water-Washed Diseases: Diseases that occur when there is lack of sufficient water for washing and personal hygiene (WHO/UNICEF, 2000).

CHAPTER 2. LITERATURE REVIEW

This chapter reviews the literature related to water quality and health, guidelines for drinking water quality, water quality and health in Nepal, and solar disinfection as a household-level treatment for drinking water. The next section gives an overview of the status of women in Nepal, and then introduces the health belief model as a theoretical framework to explore the perceived risks of diarrheal disease, and the perceived benefits and barriers to adopting SODIS as a method of water treatment.

Water Quality and Global Burden of Disease

Water and sanitation have a major impact on health. Lack of clean water and sanitation together are the second most important risk factor for ill-health in terms of the global burden of disease, after malnutrition (Murray & Lopez, 1997). The lack of an improved household water supply leads to disease by two main routes; *waterborne* disease transmission occurs by drinking contaminated water, and *water-washed* disease occurs through lack of sufficient water for washing and hygiene (WHO/United Nations Children's Fund [UNICEF], 2000). Diarrhea is the most common public health problem affected by water and sanitation, and can be transmitted through both of these routes.

Examples of water-borne diseases include viral hepatitis, typhoid, cholera, dysentery and other diseases that cause diarrhea. The Global Water Supply and Sanitation Assessment report estimates that there are four billion cases of diarrhea annually, causing some 22 million deaths. Most of these deaths are children under five years old (WHO/UNICEF, 2000).

Diarrhea is a major cause of death in children, but also one of the most frequent childhood illnesses. In developing countries, the death rate from diarrhea is lower than a decade ago, but the frequency of diarrhea has not changed. This burden of diarrhea strains national health systems, households and communities, and the nutritional status of the individual children (Bateman & McGahey, 2001). Diarrhea, especially frequent and prolonged episodes, is an important contributor to malnutrition, and even mild malnutrition is associated with increased risk of death from a variety of childhood illnesses (Pelletier, Frongillo, Schroeder & Habicht, 1995).

Globally, interventions to improve water, sanitation and hygiene have been shown to reduce diarrheal disease by about one-third (WHO/UNICEF, 2000). However, changes in hygiene behaviors must accompany the infrastructure improvements like water supply systems and sanitation facilities. The behavior with greatest potential is hand washing with soap or ash after defecating and before preparing food, followed by safe disposal of feces in latrines, safe weaning food preparation, and safe water handling and storage (WHO/UNICEF, 2000). Two investigations into diarrheal prevention (Esrey, 1996; Huttly, Morris & Pisani, 1997) found that increased quality in drinking water improves health only when sanitation is also improved and when there is enough water for hygiene. Investments in water and sanitation not only reduce mortality from diarrheal disease, but also contribute to social and economic development. Women and girls, who bear the heaviest burden of water collection, spend less time collecting water and caring for ill family members when there is a dependable source of potable water close to the home (von Schirnding, 2002).

Strategies for developing safe water systems must include public health education in hygiene and water source protection and appropriate methods for regular water quality monitoring. There are three major elements involved in successful implementation of safe drinking-water and effective sanitation in developing countries. Protection of water resources, change in people's behavior in collecting and using water, and expanded use of latrines. Each of these calls for public health education, technical expertise, and also development of human resources and infrastructure (Kravitz, Nyaphisis, Mandel & Petersen, 1999).

Research into the predictors of water-borne disease have identified the positive correlation between maternal education and health of children (Halstead, Walsh & Warren (Eds.), 1985). In 1990, the Pan American Health Organization (PAHO, 1990) showed a clear link between level of maternal education and reduced infant mortality in their report on health conditions in the Americas. A study in Guinea-Bissau investigated risk factors for diarrhea. Among breastfed children, lack of maternal education was not associated with diarrhea. Among weaned children, an unprotected water supply, eating of cold leftovers, and lack of maternal education were associated with increased diarrhea, and for persistent diarrhea, major determinants included weaning, lack of maternal education, and having pigs in the home (Molbak, Jensen, Ingbolt & Aaby (1997). Omotade, Kayode, Adeyemo and Oladepo (1995) found that handwashing after defecation or after cleaning a child who had just defecated occurred more frequently in peri-urban areas than in urban villages, and speculated that the different may be due to higher education levels for peri-urban women.

Sandiford and Morales (1991) studied child mortality rates in Nicaragua over three decades from 1960 to 1986 and examined trends in income, nutrition, maternal education, immunizations, access to health services, and provision of water supplies and sanitation. They noted that it was difficult to separate the role of health and other social interventions from overall economic progress during the same time period, since changes often occur in parallel, although this was not the case during the period of a sharp drop in child mortality in Nicaragua. They suggest that the reduction in infectious illness was more important than improved nutrition for this drop. The turning point in child mortality in 1974 does not correspond to an increase in maternal literacy, but this may have contributed to subsequent reductions in child mortality as the level of child mortality continued to drop over the next 12 years. The availability of water supply and sanitation did not improve significantly over the period of 1974 to 1986. The authors propose that the most plausible explanation for the rapid decline in infant mortality beginning in 1974 was the political decision to shift in resources away from hospitals towards primary health care combined with rapid cultural changes in health seeking behavior.

Summers (1992), an economist at the World Bank, noted that investment in female education may be the most influential investment a country can make in development, resulting in social, economic, demographic, political and health benefits.

An educated mother can help break the cycle of illiteracy and bad health, because statistically her children will be fewer, healthier, and both daughters and sons will be educated.

Other researchers have investigated other variables associated with contaminated drinking water. Alberini, Eskeland, Krupnick and McGranahan (1996) found that absence of a hand washing basin in the latrine area, use of public toilets, flies in the toilet area and location of the residence were associated with contamination of water in the household. The United States Agency for International Development (USAID) Environmental Health Project (EHP) found that diarrheal disease in children was poorly correlated with water source or type of sanitation, but highly correlated with poor hygiene behaviors and lack of knowledge about the causes of diarrhea among mothers and caretakers (USAID, 1999).

Water Quality Guidelines

Water contains many naturally occurring substances, including salts and minerals from the soil and organic residues from vegetation and wildlife, as well as contaminants from human activities. Water contaminants fall into four general categories: microbial, chemical, physical, and radiological. Drinking water may reasonably be expected to contain small amounts of some contaminants, and this does not necessarily indicate that the water poses a health risk (De Zuane, 1997).

The World Health Organization has developed guidelines in these categories for drinking water quality in order to protect public health. The guidelines are not mandatory limits, but rather are meant to form the basis of national water quality standards, in the context of social, economic and cultural conditions at various levels within the countries using them. Setting guidelines that are unrealistic can be counterproductive to the overall goal of improving water quality. But the control of microbiological contamination is of paramount importance and must never be compromised (WHO, 1993).

In terms of water quality, pathogenic organisms remain the most important danger to drinking water in both developed and developing countries, although the importance of chemical contamination should not be underestimated (WHO, 1993). Unlike microbial contamination, chemical contamination does not usually cause acute health problems because the water is deemed undrinkable due to unacceptable taste, odor or appearance and is not ingested. The fact that chemical contaminants are not normally associated with acute effects places them in a lower priority category than microbial contaminants, the effects of which are usually acute and can be widespread. Physical and radiological contamination of drinking water are rare except in industrial accidents (WHO, 1993, 1996).

pH is a physical parameter representing the hydrogen ion activity in the water. It is a unitless value, defined as the base-10 logarithm of the inverse of the hydrogen ion activity. Values less than 7.0 are an indication of acidic reactions that may damage water pipes, and for effective disinfection with chlorine, the pH should be below 8, but there is no direct health effect in humans in the range expected in raw and treated drinking water (De Zuane, 1997). The World Health Organization does not have a health-based guideline for pH, although eye and skin irritation are associated with pH above 11 (WHO, 1993). The secondary standard for pH issued by the United States Environmental Protection Agency gives a range for pH in drinking water from 6.5 to 8.5 (USEPA, 2002). Secondary standards for the EPA mean that the guideline is non-enforceable because the contaminant has no health effects. The European Community guidelines give a recommended range of 6.5 to 8.5 for drinking water, but with a maximum level of 9.5 (De Zuane, 1997).

Turbidity is a physical parameter characterizing the optical properties of liquids by measuring the amount of light scattered by any suspended particles. It is measured in standard units called Nephelometric Turbidity Units (NTU), or their equivalent, Formazin Attenuation Units (FAU) (Hach, 1997). It can also be considered a microbiological parameter because the suspended particles that cause turbidity can also harbor pathogens and reduce the effectiveness of disinfection. In general, a low level of turbidity can be correlated with a low level of bacterial contaminants (De Zuane, 1997). The USEPA regulates turbidity under the primary drinking water regulations, with legally enforceable standards for public water systems to protect public health. The EPA has set the maximum contaminant level (MCL) of turbidity in drinking water at 1 NTU, and it must not exceed 0.3 NTU in 95% of daily samples in any month (USEPA, 2002). The WHO guidelines for routine monitoring are that the median level of turbidity should be less than or equal to 1 NTU, with a maximum of 5 NTU for any single sample (WHO, 1993).

There are three main types of pathogenic microbial contaminants: bacteria, viruses, and protozoa and helminths. However, guidelines for safe drinking water do not set acceptable levels of these pathogens. This is because, from a public health standpoint, water with any detectable pathogenic organisms cannot be considered safe for drinking. Also, only certain waterborne pathogens can be detected reliably and easily in water samples, and some are detectable only during irregular intervals. Therefore, most drinking water guidelines and standards use an indicator for the possible presence of pathogens, and require routine testing for the presence of this indicator organism (WHO, 1993, 2001). The indicator chosen for monitoring of microbial contamination should be easy to detect, present in contaminated water but not naturally present in uncontaminated water, and respond in a similar manner to pathogens with respect to persistence in water and response to water treatment methods. The coliform group of bacteria, a broad class of bacteria that live in digestive tracts of warm-blooded animals, meets these criteria (NAS, 1977; WHO, 1997). Table 2.1 below shows that comparative die-off rates in water of fecal indicator bacteria and some enteric pathogens.

Table 2.1. Comparative die-off rates in water of indicator bacteria and enteric pathogens

Type of bacteria	Half-time (hours)*	Number of strains
Indicator		
Coliform (average)	17.0-17.5	29
Enterococci (average)	22.0	20
Streptococci (from sewer)	19.5	-
S. equines	10.0	1
S. bovis	4.3	1
Pathogen		
Shigella dysenteriae	22.4	1
S. sonnei	24.5	1
S. flexneri	26.8	1

Table 2.1. (continued)

Pathogen	Half-time (hours)*	Number of strains
S. enteritidis, paratyphi A&D	16.0-19.2	2
S. enteritidis, typhimurium	16.0	1
S. typhi	6.0	2
Vibrio cholerae	7.2	3
S. enteritidis, paratyphi B	2.4	1

* Time required for 50% reduction in the population at 9-12.5°C.
Note. From Drinking Water and Health, Vol. 1, National Academies Press, Washington, DC. Copyright 1977 by National Academy of Sciences. Reprinted by permission from National Academies Press.

In the United States, the Environmental Protection Agency (USEPA) has set drinking water quality standards for microorganisms under the Total Coliform Rule (USEPA, 2001). The rule sets both health goals and legal limits for total coliform levels in drinking water. The health goal for total coliforms during routine sampling at drinking water treatment plants is zero, and legally no more than five percent of samples may contain coliform bacteria. If any coliform bacteria are found, indicating a possible problem in the water treatment process, the water treatment plant must collect a repeat set of samples within 24 hours, and this time test for fecal coliforms and *Escherichia coli (E. coli)*, coliform bacteria that are directly associated with fresh fecal contamination. Depending on the level of contamination, the state and the public must be notified within a certain time limit.

The WHO does not have the mandate or the authority to set regulations for drinking water quality, but the WHO guideline for microorganisms in drinking water is that fecal coliform bacteria, or *E. coli* bacteria, must not be detectable in any 100 ml sample. Recognizing that fecal contamination is widespread in the great majority of rural water supplies in developing countries, it is recommended that national surveillance agencies in these countries set interim targets for progressive improvement in water supplies over several years or national planning cycles (WHO, 1993). Because the infective dose of bacterial pathogens is in part a function of the level of contamination in the water, WHO has developed a risk classification system for drinking water based on the number of colony forming units (CFU) of fecal coliform bacteria, shown below in Table 2.2.

Table 2.2. Classification of water quality by magnitude of contamination

CFU/100 ml sample	Classification
0	Conforms to WHO guidelines
1-10	Low risk
11-100	Intermediate risk
101-1000	High risk
above 1000	Very high risk

Note. From World Health Organization Guidelines for Drinking Water Quality Vol. 2, 2nd ed, (p. 78), 1998, Health Criteria and other supporting information. Geneva: World Health Organization. Copyright 1998 by World Health Organization. Reprinted with permission.

Ideally, drinking water should not contain any microorganisms known to be pathogenic or any bacteria indicative of fecal pollution in order to reduce the risk of waterborne disease. In practice, the CFU count of the water is combined with an evaluation of the community or household water supply to assess the overall risk of waterborne disease (WHO, 1993). Specific points of possible contamination from the water source to point of consumption are identified and quantified to select priority areas for action. All water sources should be protected from contamination by human and animal waste, which can contain a variety of bacterial, viral and protozoan pathogens and helminth parasites, as shown in Table 2.3.

Table 2.3. Infectious agents potentially present in raw domestic wastewater

Organism	Disease	Symptoms, Remarks
Bacteria		
Escherichia coli	Gastroenteritis	Diarrhea
Francisella tualrensis	Tularemia	
Legionella pneumophila	Legionellosis	Acute respiratory illness
Leptospira species	Leptospirosis	Jaundice, fever
Salmonella typhi	Typhoid fever	High fever, Diarrhea, ulceration
Salmonella paratyphi-A	Paratyphoid fever	
Salmonella other species	Salmonellosis (Food poisoning), enteric fever	Vomiting, diarrhea
Shigella dysenteriae, S. Flexneri, S. Sonnei	Bacillary dysentery	
Vibrio cholerae	Cholera	Extremely heavy diarrhea, dehydration
Yersinia enterolitica	Yersinosis, gastroenteritis	Diarrhea
Other genera of Enterobacteriaceae: *Edwardiella, Proteus, Serratia,* and *Bacillus*	Gastroenteritis	
Viruses		
Adenovirus (31 types)	Respiratory disease	
Enteroviruses (67 types)	Gastroenteritis, heart anomalies, meningitis	
Hepatitis A	Infectious hepatitis	Jaundice, fever
Norwalk agent	Gastroenteritis	Vomiting
Reovirus	Gastroenteritis	
Rotavirus	Gastroenteritis	
Protozoa and Helminthes		
Balantidium coli	Balanticliasis	Diarrhea, dysentery
Cryptosporidium	Cryptosporidiosis	Diarrhea
Entamoeba histolytica	Amebiasis (amoebic dysentery)	Prolonged diarrhea with bleeding, abscesses of the liver and small intestine
Giardia lamblia	Giardiasis	Mild to severe diarrhea, nausea, indigestion
Ascaris lumbricoides	Ascariasis	Roundworm infestation

Note. From Wastewater Engineering: Treatment and Reuse, 4th ed. (p. 110), by Metcalf and Eddy, Inc., 2003, Boston, McGraw-Hill. Copyright 2003 by The McGraw Hill Companies. Reprinted with permission.

The presence of pathogens in water presents only a potential threat to human health. For an active threat to health, a dose of the excreted pathogen that is high enough to cause infection must be ingested. It is difficult to determine the number of viable pathogenic cells necessary to produce infections in humans due to insufficient epidemiological evidence of mode of transmission, and the number of variables involved (WHO, 1997). Transmission is affected by host characteristics and behavior, including immunity from previous exposure, nutritional status, health status, age, sex, personal hygiene, and food hygiene. The survival of the organism in water, the water temperature, and presence of colloidal matter in water are also significant influencing factors (WHO, 1997; De Zuane, 1997). Colloidal particles in the water can provide habitat to microorganisms and increase their survival.

VanDerslice and Briscoe (1995) and Jensen et al. (2002) discuss the interactions of different environmental interventions to improve water quality. In the Philippines, VanDerslice and Briscoe found that the effects of water quality, household sanitation and community sanitation on reducing diarrhea are all strong and statistically significant. However, they found that improving drinking water quality in neighborhoods with poor environmental sanitation would have no effect on diarrhea. They suggest that improvements in both water supply and sanitation are necessary to improve infant health in developing countries. Jensen et al., in Pakistan, looked at the effect of interventions to prevent in-house contamination at different levels of contamination of source water. They found that in-house contamination is important only when the source water is relatively clean. If the source water is contaminated at a level of greater than 100 CFU/100 ml, then interventions to reduce in-house contamination will have a minor impact on improving drinking water quality.

Ehiri and Prowse (1999) note that childhood diarrhea has a complex epidemiology, with sanitation, poverty and education confounding results of research in this area. The tendency to include only a few variables in the analysis may cause those variables to receive undue weight. Even for variables such as maternal literacy that have been shown to be associated with reductions in childhood diarrhea there is still little understanding of the pathways by which it affects health.

Generally, the greatest microbial risks in drinking water are associated with ingestion of water that is contaminated with human and animal excreta, because these sources of contamination can also contain pathogens. Microbial risk can never be entirely eliminated, because diseases that are waterborne also have other modes of transmission, including person to person and food borne, but provision of a safe water supply will reduce the chances of transmission by these other routes (WHO, 1993).

Immunity may play a role in reduced incidence of diarrheal disease. Studies of the incidence of travelers' diarrhea compared to the incidence of diarrhea in the local populations in areas with contaminated drinking water seem to support the hypothesis that local people do build up immunity to the pathogens in their normal drinking water. In the local populations, exposure to diarrheal pathogens is far more common than observable disease. However, there is a substantially higher incidence of illness in young children in developing countries where the drinking water than in developed countries. This high incidence of gastrointestinal disease in children is one of the reasons behind the high childhood mortality in developing countries, so this immunity comes at a high price (WHO, 2001a).

Storing drinking water in the home is common in the developing world. Several studies have documented increased concentration of fecal coliforms during household storage (Blum et al., 1990; Pinfold, as cited in VanDerslice & Briscoe, 1993). These studies promoted the belief that in-house water contamination is an important transmission route for enteric pathogens, and that the benefits of improving water source quality will be lost if water is recontaminated in the home.

Black and his colleagues (1989, as cited in VanDerslice & Briscoe, 1993) found that previous exposure to a particular enteric pathogen does appear to reduce the risk of diarrhea during subsequent infections, and these asymptomatic infections are common in developing countries. VanDerslice and Briscoe (1993) noted that these aggregate measures of level of contamination of water at the source and in the household conceal household level changes. They created a model to estimate the additional contamination contributed in the household and the additional cases of diarrhea in the household. They found that contamination of stored drinking water did not increase the family's risk of diarrheal disease, because pathogens contaminating drinking water during storage are most likely internal pathogens originating from the family members' own feces. A contaminated water source, however, may contain pathogens from other people's feces which are new to the household environment. It is these external pathogens that may initiate new infections. The authors propose that providing a high quality water supply would eliminate this source of external pathogens and reduce the risk of a family's diarrhea, regardless of the risk of in-house contamination.

Epidemiologists agree about the importance of improvements in hygiene behaviors for health protection, but it is not well understood. Promoting the behavioral changes necessary to benefit from water and sanitation interventions requires skills that are different from those needed to develop and manage a water supply system or build latrines. Water supply, sanitation and hygiene are not collective goods, but affect each person as an individual, so progress in this sector requires a focus on the household level (WHO/UNICEF, 2000).

Household Approaches to Water Treatment

Most of the population in developing regions of the world lives in rural and suburban areas where conventionally treated drinking water is generally unavailable. Urban residents in these regions are also becoming aware of the dangers of contaminated water, whether from inadequate treatment or compromised distribution lines that introduce contaminants to treated water. Population growth and migration are straining the capacity of existing water and sanitary infrastructures and complicate the planning and construction of new ones (Mintz, Bartram, Lochery &Wegelin, 2001).

Providing safe water for all is a long-term goal (WHO/UNICEF, 2000). However, relying on time and resource-intensive solutions like systems of piped treated water will leave hundreds of millions of people without safe water far into the future. Traditional drinking water departments have a poor record of supporting alternative technologies, but there is an immediate need for self-sustaining, decentralized approaches to make drinking water safe. Where centralized water treatment systems are absent or inadequate, responsibility for making drinking water safe falls to community residents by default (Gupta & Chaudhuri, 1992; Mintz et al., 2001).

Household-level treatment is not widely practiced, but it does have advantages in fewer capital costs, no pipes or distribution systems, and only water to be used for drinking needs to be treated. It is clear who is responsible for the use, operation and maintenance of the system. If the system breaks down, only that household will be affected, and adoption of treatment is according to that household's willingness and ability to pay (Jackson, 2000). Expansion of improved water supply systems is important, but it will not address the immediate needs of the most disadvantaged people who are currently unserved by safe water systems. Decentralized technologies have a role to play in improving drinking water quality in the short-term, and may become a permanent feature of water and sanitation services in the long run.

There is a renewed interest in assessing traditional domestic water purification methods and popular devices as well as developing and testing simple low-cost devices. When comparing options for treatment, both technical and social perspectives must be considered. Technical issues include the water quality, quantity, safety in operating the method, and the environmental impacts of implementing the technology. Social issues include the cost of the treatment, convenience, gender roles in the household and community, and acceptability (Jackson, 2000).

There are physical, chemical, and biological methods for disinfecting drinking water. Each has strengths and weaknesses, and often multiple methods are used to ensure complete removal of possible pathogens. Physical methods include straining through fine cloth or filter, settling, boiling, and exposing to ultraviolet light. Chemical methods include coagulation to remove particles, and adding chlorine or iodine to kill pathogens. Biological treatment occurs with the use of slow sand filters that decompose the bacteria. All of these options offer timely solutions to the people most affected by contaminated drinking water, and thus merit much greater attention and priority for rapid implementation (Jackson, 2000; WHO, 2001a).

Colwell et al. (2003) demonstrated that filtering water through four layers of fabric removed particles greater than 20 μm, and use of this filtering technique reduced the incidence of cholera in a Bangladeshi village by 48% over the 34 months of the study. Domestic candle filters are used as a point-of-use treatment device in many developing countries (Gupta & Chaudhuri, 1992). Data on the removal of coliforms by candle filters indicates considerable improvement of the bacteriological quality of artificially contaminated well water, but the quality is still unsatisfactory for drinking. Use of chlorine along with the filters was advocated. A sand-charcoal-sand filter performed moderately well in removing turbidity and fecal coliform. However, a relatively long maturation period was required and short life before filtrate quality deteriorated. With the addition of a polishing sand filter it improved the performance and the longevity (Gupta & Chaudhuri, 1992).

Boiling drinking water is economically and environmentally unsustainable in many developing countries where the primary cooking fuel is firewood, but it is very effective at inactivating pathogens. There is no residual protection from boiling, so it does carry the risk of recontamination during transfer to a storage container (Jackson, 2000; WHO, 2001). Chemical disinfectants such as iodine and chlorine are options, but have safety and economic drawbacks even in areas where they are readily available. Sodium hypochlorite, the active ingredient in laundry bleach, is the most widely used, easily used, and most affordable chemical disinfectant for point-of-use treatment (WHO, 2002; Mintz et al., 2001). It is not as effective against parasites and viruses as boiling but it leaves a residual to protect against post-disinfection bacterial contamination.

The United States Centers for Disease Control (USCDC) has developed a Safe Water System for populations at risk of disease from contaminated water that combines treatment and storage. Liquid sodium hypochlorite is used to disinfect the water in a narrow-mouthed container that prevents recontamination during storage. This system has been used and shown to be effective in improving drinking water quality and reducing diarrhea in Bolivia, Zambia and Pakistan (Macy & Quick, 2002), Kenya (Makutsa et al., 2001) and Guinea-Bissau (Daniels et al., 1999).

Bleach affects the taste and odor of water, and thus its use may be unacceptable to populations used to drinking untreated water. Another disadvantage is that the effectiveness of chemical disinfectants is reduced when used in water containing large amounts of organic material (Mintz et al., 2001).

The World Health Organization proposes another low-cost alternative for disinfection of drinking water by using the bactericidal properties of sunlight to disinfect drinking water (WHO, 2001b).

Solar Disinfection (SODIS)

The sun continuously radiates out enormous amounts of energy across a wide range of wavelengths, called the electromagnetic spectrum. The wavelengths range from the gamma-rays, the shortest at less than 10^{-19}m, through the x-ray, ultraviolet, visible light, infrared and microwave spectrums, to radio rays with the longest wavelengths, up to 20 meters in length (United States National Aeronautics and Space Administration, 2002). The earth's atmosphere blocks almost all of the radiation in certain bandwidths. Visible light and a small amount of the ultraviolet and infrared radiation can pass through our atmosphere, as do radiowaves and microwaves. The amount of energy from solar radiation is measured in watts per square meter. Over time, the energy from solar radiation reaching the earth is called fluence, and is measured in watt-hours per square meter (Wh/m^2) (EAWAG/SANDEC, no date).

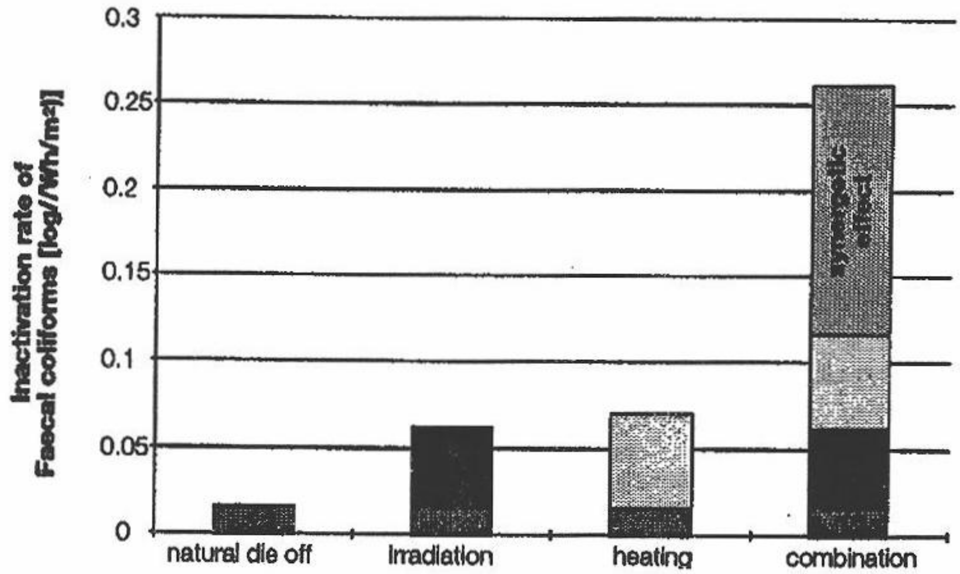
Solar Disinfection (SODIS) is a technique that uses solar energy in the form of ultraviolet radiation and infrared heat to disinfect contaminated drinking water. Water to be treated for drinking is placed horizontally in transparent glass or plastic containers and exposed to full sunlight for about six hours (depending on latitude, altitude, season and cloud cover). Solar radiation, along with thermal energy, inactivates and destroys pathogenic microorganisms in the water. The effective component of solar radiation involved in microbial destruction seems to be the near ultraviolet A band from 320-400 nm, and to a lesser extent the visible band of violet and blue light, from 400-490 nm; Acra, Raffoul, & Karahagopian, 1984; Acra, Jurdi, Mu'allem, Karahagopian, & Raffoul, 1990; Wegelin et al., 1994).

SODIS was recommended during World Water Day 2001 (WHO, 2001b) as a simple, low-cost method for water purification at the household level. Some of the first research on disinfecting drinking water through ultraviolet exposure by sunlight was done in Lebanon by Dr. Acra and his colleagues (1984, 1990). More recently, EAWAG/SANDEC has undertaken and sponsored research on the technology in a variety of settings.

Sunlight has a direct impact on microorganisms. There are two processes that use solar energy to improve microbiological water quality. The first process is exposure to sunlight's UV-A radiation. This causes molecular damage to the DNA, nucleic acids and enzymes of pathogens. In the presence of oxygen, sunlight also produces highly reactive forms of oxygen like oxygen free radicals and hydrogen peroxides, which in term kill microorganisms. These reactive forms are temporary by-products of the action of sunlight on microbes in oxygenated water, with no significant residual effect once the sample is removed from the sunlight (EAWAG/SANDEC, no date; Reed, 1997). The second process uses infrared radiation to raise the water temperature to over 65°C, pasteurizing the water. Neither of these processes sterilizes the water, but any pathogens in the water are deactivated making it safe to drink (EAWAG/SANDEC, no date).

The combination of ultraviolet and infrared energy has synergistic effects which enhance the efficiency of disinfection. The die rates of fecal coliforms exposed to irradiation and heating increases substantially when both stress factors occur, as shown below in figure 2.1.

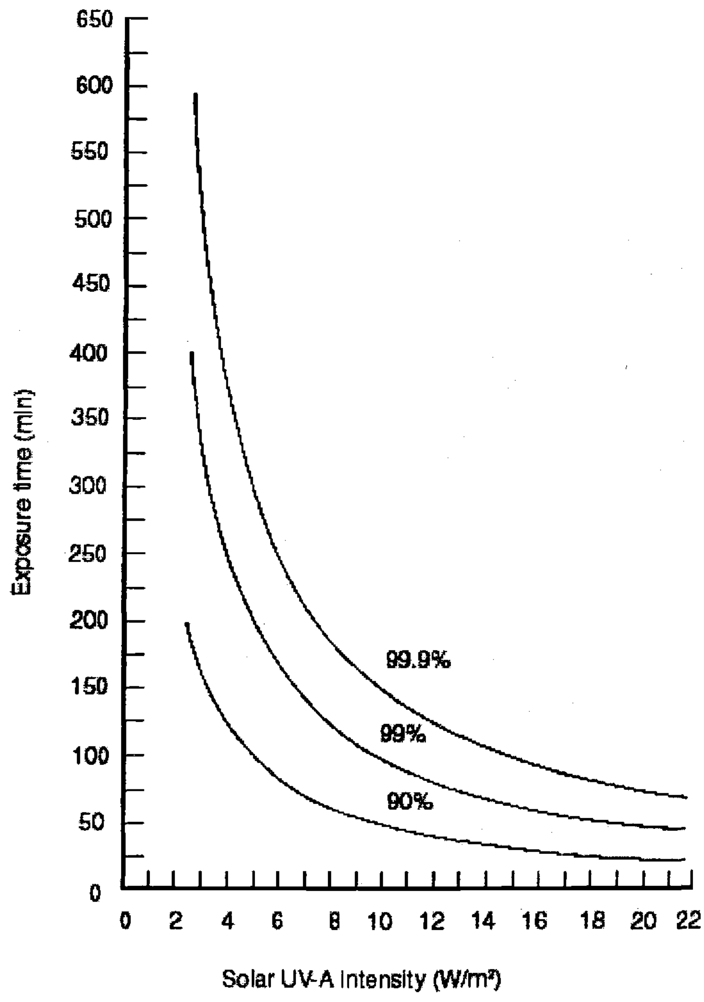
Figure 2.1. Effect of UV radiation and temperature on fecal coliforms in raw water



Note. From "SODIS Technical Note #9, " by M. Wegelin, no date, Online: www.sodis.ch/files/notes.pdf. Available 23 March 2003. Copyright by EAWAG/SANDEC. Reprinted with permission.

Using SODIS, survival decreases with exposure following an exponential decline curve typical of bacterial destruction by chemical disinfectants like chlorine and iodine, as shown below in Figure 2.2.

Figure 2.2. Time Required to Inactivate Coliforms in Contaminated Water as a Function of Solar UV-A Intensity



Note. From "Water Disinfection by Solar Radiation: Assessment and Application", by A. Acra, M. Jurdi, H. Mu'allem, Y. Karahagopian, and Z. Raffoul, 1990, Ottawa: IDRC. Copyright 1990 by IDRC. Reprinted with permission of Canada's International Development Research Center.

Acra and his colleagues also found that fecal indicator bacteria are slightly more resistant to the lethal effects of sunlight than enteric pathogens (Acra et al., 1990), making them a good choice for testing effectiveness of SODIS, as shown below in Table 2.4.

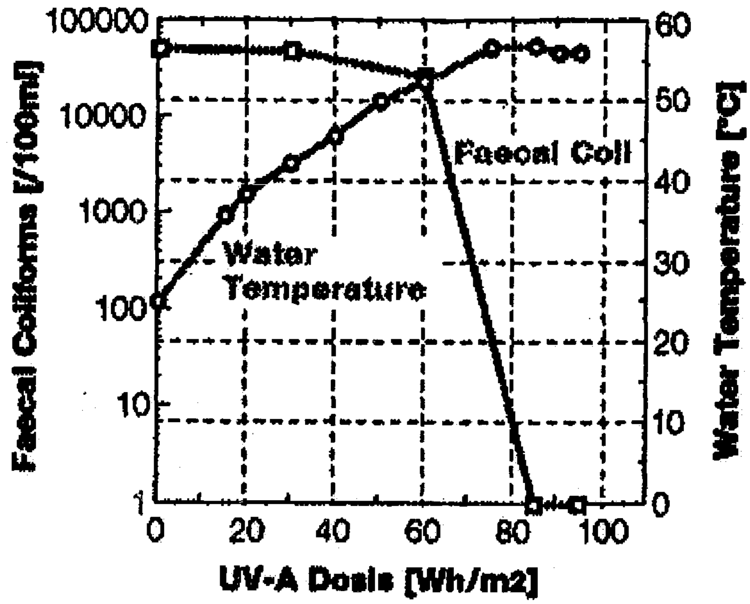
Table 2.4. UV-A resistance of some microorganisms

Test organism	Fluence ($W-h/m^2$) required to inactivate		
	90%	99%	99.9%
Streptococcus faecalis	8.90	17.80	26.72
Coliforms	8.24	16.59	24.74
Escherichia coli	6.36	12.72	19.08

Note. From "Water Disinfection by Solar Radiation: Assessment and Application", by A. Acra, M. Jurdi, H. Mu'allem, Y. Karahagopian, and Z. Raffoul, 1990, Ottowa: IDRC. Copyright 1990 by IDRC. Reprinted with permission of Canada's International Development Research Center.

Wegelin et al. (1994) found that solar water disinfection in the laboratory is effective after the equivalent of 5 hours of mid-day mid-latitude summer sunshine if the water is contaminated with less than 1000 colony-forming units of *E. coli* bacteria per 100 ml of sample. This dose inactivates *E. coli*, the bacteriophage f2 and rotavirus, although a picornavirus required twice this dose. They also found that thermal inactivation for bacteria has a threshold of 50°C, while the inactivation rate of viruses increases steadily with temperatures in the range of 20°C to 50°C. Inactivation of protozoa is dependent on water temperature. Cao and Metcalf (2000) found that rotavirus, a major cause of diarrhea in developing countries, is not inactivated by direct sunshine alone but is inactivated at temperatures above 60°C. Figure 2.3 below shows the rate of inactivation of fecal coliforms using SODIS bottles that are painted black on the bottom half.

Figure 2.3. Inactivation of fecal coliforms with half-colored PET bottle.



Note. From "SODIS Technical Note #1, " by EAWAG/SANDEC, no date, Online: www.sodis.ch/files/notes.pdf. Available 23 March 2003. Copyright by EAWAG/SANDEC. Reprinted with permission.

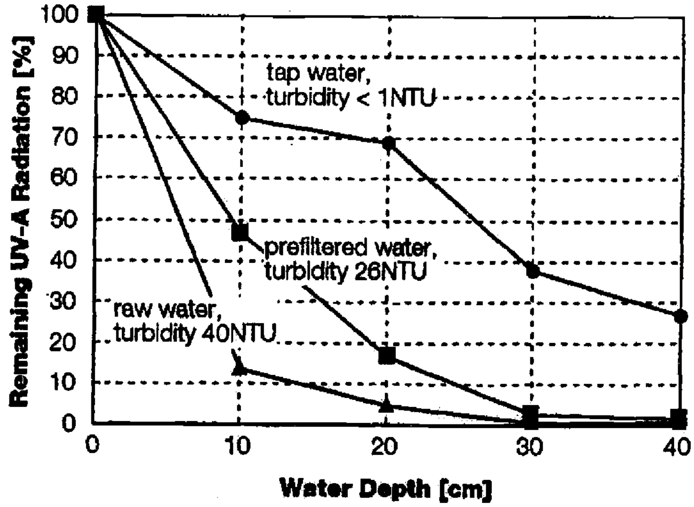
Sommer et al. (1997) measured reduction of fecal coliforms and *Vibrio cholerae* from SODIS and found that it is a reliable and effective inactivation method if water temperatures of 50°C are combined with UV-A radiation. Joyce, McGuigan, Elmore-Meegan and Conroy (1996) found that the heating effect of Kenyan sunlight could produce complete inactivation of high populations of fecal indicators *E. coli* even in highly turbid water (approximately 200 NTU) within 7 hours if the temperature reaches at least 55°C.

There are several ways to increase the efficiency of SODIS. Thermal activation becomes significant only at water temperatures above 45°C. To increase the temperature of water in SODIS bottles, one-half of the bottle (top to bottom, as they are exposed on their side, not upright) may be painted black, or clear bottles can be laid on a black or reflective surface to increase the thermal effects (EAWAG/SANDEC, no date). Inactivation of fecal bacteria is strongly dependent on the amount of oxygen in the water. Oxygen increases the photooxidization of microbes through formation of free radicals. Water can be aerated by vigorous shaking before exposure to solar radiation to take advantage of increased bactericidal effects that occur in the presence of oxygen (Reed, 1997).

Limitations of SODIS

SODIS is simple, inexpensive, and provides good quality water, but like all water treatment options, it has some limitations. Radiation intensity is reduced by increasing water depth and turbidity, as shown in Figure 2.4. High turbidity reduces the light penetration in water and thus disinfection efficiency. To ensure safe water disinfection, the raw water should have turbidity less than 30 NTU. Although water with turbidity over 30 NTU absorbs more infrared radiation, increased temperature alone is not as efficient as the combination of UV-A and infrared. Water with turbidity above 30 NTU looks visibly dirty in a clear container and may be rejected by consumers on the basis of this, regardless of the bacteriological quality. Water with a turbidity of over 30 NTU can be filtered, or settled and poured off the top to increase clarity before exposing.

Figure 2.4. Reduction of UV-A radiation as a function of water depth and turbidity



Note. From "SODIS Technical Note #10, " by EAWAG/SANDEC, (no date), Online: www.sodis.ch/files/notes.pdf. Available 23 March 2003. Copyright by EAWAG/SANDEC. Reprinted with permission.

McGuigan and his colleagues (1998) characterized the bacterial inactivation process with solar disinfection. They simulated conditions of optical irradiance, water turbidity and temperature in Kenya. Inactivation was observed even in highly turbid water (200 NTU), and at low irradiances of only 10 mW cm^2. Thermal inactivation was found to be important only at water temperatures above 45C, at which point strong synergy between optical and thermal inactivation occurs. They concluded that where strong sunshine is available, solar disinfection of drinking water is an effective low cost method for improving water quality.

SODIS is not useful for treating large volumes of water, because the UV-A light does not penetrate past 10 cm in a clear container. SODIS does not remove chemical contaminants in drinking water, if any exist. It does not change the taste or the odor of source water, and if these innate qualities in the source water are unacceptable to the consumer it will still be undesirable after SODIS exposure. Finally, SODIS needs plastic 1.5 or 2 liter bottles (at least 1 bottle per person per day), adequate sunlight, and some time to fill and set out and collect the bottles (EAWAG/SANDEC, no date).

SODIS Containers

Acra et al. (1984) examined the suitability of different containers used for solar disinfection. The container must be transparent to sunlight, but both glass and plastic were shown to be effective. Glass transmits light more readily, but the thinness of plastic bottles compensates for plastic's greater absorption of UV light.

There has been concern about the health effects of drinking water from plastic exposed to sunlight, and this was investigated by Wegelin et al. (2000). Plastic bottles are usually made of either polyethylene terephthalate (PET), or polyvinyl chloride (PVC). Both types of plastic contain additives to increase their stability or to protect them and their contents from oxidization and UV radiation. In the course of the plastic polymer's life, the additives will be depleted from the host material by photochemical reaction or diffusion. Sunlight not only destroys disease-causing microorganisms found in the water, but also transforms the plastic material into photoproducts. PVC contains some additives that could diffuse into the water and pose a health risk. Laboratory and field tests on PET plastic revealed that these photoproducts are generated at the outer surface of the bottles, with no indication of migration into the contents of the bottles. PET bottles are inert and therefore recommended for SODIS.

Aging of the bottles does lead to a reduction in UV transmittance, which causes less efficient inactivation of microorganisms. Smooth and careful cleaning and handling during exposure are necessary to avoid scratches in the outside of the bottles (EAWAG/SANDEC, no date).

An important benefit of the PET plastic bottles is the narrow mouth. SODIS disinfection takes place in a closed bottle, eliminating secondary contamination by consumers. The USCDC's work to develop the Safe Water System (Macy & Quick, 2002) shows that disease may be spread within the household by peoples' hands contaminating wide mouthed containers when collecting water. Narrow-mouthed containers are recommended for use in societies where waterborne diseases are endemic, which is the case in Nepal.

SODIS Field Tests

Field investigations of the effectiveness of SODIS have been carried out by EAWAG/SANDEC in Columbia, Costa Rica, Jordan, and Thailand (EAWAG/SANDEC, no date), and by others in Kenya (Conroy, Elmore-Meegan, Joyce, McGuigan, & Barnes, 1996, 1999), and Nepal (Environment and Public Health Organization (ENPHO), 2002; Moulton, 1999; Pandit, 2002, Mallick, 2000; Karki, 2001 & Saladin, 2002a). The different geographical locations allowed assessment of inactivation rates under different climatic, physical, chemical, and microbiological conditions. They found that bacteria were consistently destroyed upon exposure to sunlight for an adequate amount of time. The duration of exposure required was found to depend on the intensity of sunlight (which in turn depends on latitude, season, and time of day, and cloud and/or pollution cover), the type of bacteria, the characteristics of the container (color, size, shape, thickness, transparency to sunlight, and orientation to sun), and depth and clarity of the water.

Conroy et al. (1999) in an extension of their work in Kenya in 1996, showed a modest reduction of the prevalence of diarrheal disease in children under 5, from 58.1% in controls to 48.8% in the test group. This reduction was sustained for more than one year in the field, confirming solar disinfection's ability to make a positive contribution to improved health despite the behavioral changes necessary to adopt it.

EAWAG/SANDEC (no date) conducted a review of multiple field trials of SODIS to examine the social acceptability of the technology. Overall, 84% of users in field trials said they would certainly continue to use SODIS after the conclusion of the project, and 13% would consider using it. Only 3% said SODIS was not necessary as they had no adverse health effects from their untreated drinking water. But in China, around half the people interviewed said they still drink untreated water even though they are aware that the quality is poor. Table 2.5 summarizes the reasons for using and for not using SODIS.

Table 2.5. Reasons for using and for not using SODIS

Reasons for using SODIS	Reasons for not using SODIS
Easy and practical	Don't trust it
Provides good and clean drinking water	Takes too long, no patience for it
Less working time and burden	Unpleasant taste and smell of water
No pathogens	No bottles available
No stomachaches	
Less sickness, diarrhea	
Saves costs	
Saves time	
Increased social status from use	
Improves quality of life	

Note. From "SODIS Technical Note #15, " by EAWAG/SANDEC, (no date), Online: www.sodis.ch/files/notes.pdf. Available 23 March 2003. Copyright by EAWAG/SANDEC. Reprinted with permission.

SODIS in Nepal

Acra et al. (1984) determined the most favorable belt for solar energy applications as the areas between 15° and 35°, both north and south of the equator. In these semi-arid belts, more than 90% of the total solar radiation is direct radiation because of the limited cloud coverage. Nepal lies in this belt, at approximately 23° north of the equator. Solar disinfection (SODIS) is a low-cost technology that has been shown to have potential to improve drinking water quality in Nepal (ENPHO, 2002; Moulton, 1999; Saladin, 2002a, 2002b; Pandit, 2002; Mallick, 2000 & Karki, 2001), although Khayyat (2000) identified possible limitations to its use in Kathmandu Valley.

Moulton (1999) confirmed the effectiveness of solar disinfection in the Terai region, with full disinfection within 1 to 8 hours depending on the treatment tested.

Disinfection occurred in 5 to 6 hours of peak sunlight during April and May. However, season and altitude differences created wide variations in the results. There was no detectable difference in the effectiveness of new vs. old bottles, but bottles placed on a black rack needed 3-4 hours, and with a foil solar reflector total disinfection was accomplished in 1 hour.

The International Buddhist Society has been implementing a SODIS program in 9 villages in the Terai since 1998 (Mallick, 2000) with the use of health motivators and the village health coordination committees. They found that cases of diarrhea, abdominal pain and amoebiasis had decreased. Prevalence of diarrhea went from 1067 cases before the introduction of SODIS to 203 cases after three months of use, an 81% decrease, with biweekly visits from health motivators in the community to provide encouragement and answer questions about the technique.

The Environment and Public Health Organization (ENPHO) (2002) conducted full-scale tests of SODIS in Kathmandu on the roof of their office building from January to July 2001 covering winter, spring and early summer/monsoon conditions. Out of 33 tests conducted over the six months with varying temperature and weather, the average reduction in fecal coliform after exposure was 89.5%.

Khayyat (2000) tested SODIS in January in the Kathmandu valley, a season where there is often morning fog. He found that complete removal of *E coli* was not achieved in these tests, although there was a reduction. He suggested that chlorine is more effective and comprehensive than solar disinfection, but in areas where it is unavailable or infeasible, solar disinfection can be substituted as an interim solution.

However, Karki (2001), also tested the effectiveness of SODIS in plastic bottles in Kathmandu during the winter, and found that all community water samples with coliform contamination were completely disinfected by solar radiation after four hours of exposure to sunlight. Water that was heavily contaminated with lab strains of *E. coli* and *S. typhi* was completely disinfected within five hours of exposure to sunlight.

Pandit (2002) conducted a study using SODIS in Chunganarayan, a small town in the Kathmandu Valley. He found that 90% of the source water samples were contaminated with fecal bacteria, and 95% of the samples from the household storage containers were contaminated. Forty percent of the 35 exposed SODIS bottles tested negative for fecal bacteria, and the remainder of the water samples showed significant reduction in numbers of colony-forming units of fecal bacteria. The time period of data collection was not specified in the report.

Saladin (2002a) tested water at various altitudes and under various types of bottle treatments during April to August 2002. He found that the overall removal rate of fecal coliform was 94% during the study. Clear bottles yielded the highest average removal rate, at 99.2%, and the lowest removal rate was 91.5% with bottles that were painted black on one side. He notes that more data are needed for all altitudes during the cold winter season and during cloudy weather. Saladin found that two-day tests were more effective than one-day exposures. However, the increased efforts in time, materials (three sets of bottles would be needed) and management must be considered when formulating guidelines on how to use SODIS, and the extra reduction in pathogens may not warrant a recommendation for two-day exposure. He noted that a single day of exposure can be considered sufficient in most locations and under most weather conditions (Saladin, 2002a).

Saladin also investigated the social acceptability of the technology (Saladin, 2002b). He found that SODIS was well received in two communities in Nepal. In spite of the low level of awareness of links between water quality and health, the participants were willing to participate in the training and try the technology. However, he notes that it is still a long way until the users are convinced that the technology is improving their water quality and their health, and sustaining use of the technology.

Water Quality and Health in Nepal

A study of water quality conducted by Wolfe (2000) found that 100% of surface water sources and 80% of water samples from water distribution points in the Kathmandu Valley tested positive for fecal indicators. Rijal, Fujioka and Ziel (1998) tested drinking water in Kathmandu and found that water from consumer sources (household taps, public taps, and water stored in household containers) contained unacceptable concentrations of fecal coliform and other fecal microorganisms and this water is a likely source of transmission of waterborne disease. They also found that household water containers have much higher concentrations of fecal contamination than piped water. There are many opportunities for contamination in the household, including contact with contaminated hands or dippers, wiping babies, or multiplication of existing bacteria during storage in the household container.

The monsoon season leads to increased run-off and deterioration in the water quality, both at the sources and in the distribution systems. Wolfe's metaanalysis of previous studies of water quality in Kathmandu Valley (2000) found a pattern of more microbial contamination in late spring/early summer than in the dry winter season. Along with increases in contamination of water, Shrestha and Sharma (1995) found an increase in water-borne diseases during the rainy season. They also found a strong correlation between levels of contamination in the drinking water system and incidence of disease.

Often drinking water is stored in copper or brass containers in the household. Kuhn (1983) investigated bacterial growth on metal by inoculating strips of brass, copper, stainless steel, and aluminum with broths of *E. coli, S. aureus*, *Streptococcus*, and *Pseudomonas* species and incubating them on blood agar. The copper and brass strips showed little or no growth, while the aluminum and stainless steel produced a heavy growth of all microbes. Brass was disinfected within seven hours, depending on the state of the surface of the metal, with freshly scoured brass disinfected in one hour. Copper was disinfected of some microbes within 15 minutes, indicating its high level of toxicity to bacteria.

WHO notes that copper and some other chemical agents have been proposed and are sometimes used to inactivate waterborne pathogens, but they are not considered suitable for long-term use. Copper is difficult to deliver to water and is primarily bacteriostatic, meaning that bacteria are inactivated but not killed by exposure to copper (2002).

In humans, copper is a micronutrient but also a toxin. It is considered a drinking water contaminant regulated under the USEPA's secondary standards, with a non-enforceable guideline of 1.0 mg/L (USEPA, 2002). Short-term effects of too much copper in drinking water are stomach and intestinal problems including nausea, vomiting, cramps and diarrhea, while long-term exposure to excess copper can lead to liver and kidney damage (USEPA, 2003).

In the past six years, His Majesty's Government (HMG) of Nepal has undertaken two studies examining the situation of women, children and households throughout the kingdom (HMG/UNICEF, 2001; HMG/UNICEF, 1997). Both of these studies contained information disaggregated by ecological region, geographic region, and in urban and rural settings, on issues related to water, health and sanitation. Some of the results of these studies are presented below.

Drinking Water Source

Households in Nepal get drinking water from a variety of sources, and in some areas the use of some sources is seasonal. For example, in the dry season, tap water from the river may be used for drinking. During the rainy season when this water is cloudy from sediment, well water may be preferred. HMG/UNICEF (2001) found that 83% of residents in the Kathmandu Valley used piped water, but only 46% of rural communities. The remaining 17% in Kathmandu Valley used a well or spring, but in rural areas 50% used wells or springs and 4% used some other type of drinking water source.

In a study in Eastern Nepal, public water was available to 33% of the population, 48% used a natural spring and 19% used a shallow well. In this study there was no association between the type of water source used and the level of gastroenteritis reported (Rai, Hirai, Ohno & Matsumura, 1997). Well water has a degree of natural protection from contamination compared to surface water because of the filtering action of the soil and sediment through which the water passes before reaching the well (Robertson & Edberg, 1997; Entry & Farmer, 2001), but Rai et al. (1997) did not measure levels of fecal coliform in this study.

The 1997 report defined "safe" water as water from a tap, pipe, handpump, borehole, or spring. The results of the study show that a child in a house with an unsafe water supply has nearly 50% more diarrhea risk than does a child with safe water. This gap is not explained by sanitation or hygiene practices. However, universal provision of safe water as defined in this study could be expected to reduce the two-week incidence of diarrhea in children from 20% to 16%, a risk difference of only 4%. This modest potential effect raises questions about the quality of water from these supposedly safe sources, and indicates that even "safe" water is contaminated. Some taps are fed from surface water sources (HMG/UNICEF, 1997).

Culture may also affect the perceptions of water quality. Nepal is a Hindu kingdom, and Hindus regard all water as sacred (Murray, 1994). Many beliefs are based on the concepts of purity and pollution. Purity is increased by coming into contact or associating with things assigned pure status, and water is the most common form of purification. It is considered to have intrinsic purity and the capacity to absorb pollution and carry it away (Babb, as cited in Murray, 1994). The 1997 study found that people judge water quality mainly on the basis of taste, smell and color, while water that is heavily contaminated with pathogens may be perfectly acceptable. There was no association between perceived quality of water from any source and the occurrence of diarrhea (HMG/UNICEF, 1997).

Water Treatment

The 2001 report included methods of water treatment used in Nepal. They found that 35% of households in the Kathmandu Valley filter their water, but only 1% of households in rural areas. Likewise, 29% of Kathmandu Valley households boil water but only 4% of rural households. Two percent of Kathmandu Valley households reported using purifying tablets, but no rural households reported using this type of treatment (HMG/UNICEF, 2001). These results are consistent the previous study that reported 94% of households do not treat their water in any way (HMG/UNICEF, 1997).

Water treatment is not common in Nepal, especially in the rural areas, but it does reduce the risk of diarrhea. Although the number of households that treat water is low, the 1997 report noted that treatment did lower the risk of diarrhea. Among those households that reported diarrhea in the last two weeks, 17% of those who did not treat their water had diarrhea, while 13% of those who did treat their water had diarrhea. The authors conclude that the methods of treatment include simple filtration, and the reduction in diarrhea would likely be larger if methods that are more effective were used. They note that inexpensive, effective methods of home water treatment are needed (HMG/UNICEF, 1997).

Water Supply and Sanitation

Data from the Global Sanitation Report (WHO/UNICEF, 2000) indicate that 85% of urban and 80% of rural residents in Nepal have access to some type of improved water supply. The figures for sanitation are lower, and show a marked difference between urban and rural situations, with 75% of the urban population having access to improved sanitation facilities, while only 20% of the rural population is served.

The 1997 report included information from 17,227 households on perceived problems with local water supplies. They found that 41% of households reported no problems with their water supply. The top two problems reported were both related to water quantity. Twenty-eight percent said there was not enough water, and 27% said the water source was too far away. Nineteen percent said that the water source was dirty. Other problems reported by less than 10% of the study population include crowds and arguments at the source (9%), bad taste or odor of the water (6%), problems with the journey (5%), and poor maintenance of the water source (2%) (HMG/UNICEF, 1997).

Distance from household to a water source is sometimes used an indicator of development, and the HMG survey collected this information from respondents in their 2001 study. The results are shown below in Table 2.6.

Table 2.6. Distance in minutes from household to drinking water source

Number of minutes	Kathmandu Valley	Rural Communities
0 minutes	68%	29%
1-4 minutes	8%	9%
5-10 minutes	22%	37%
11-29 minutes	2%	12%
30 minutes or greater	-	13%

Note. From Report on the Situation of Women, Children and Households, (p. 36). His Majesty's Government/Nepal National Planning Secretariat Central Bureau of Statistics, 2001.

The 2001 report also included information on the quantity of water available households in the study, which may affect levels of water-washed diseases. The question asked if the respondent had a sufficient amount of drinking water for household drinking and daily cleaning needs, but the actual amount was assessed subjectively by the respondents as to what was adequate for her or him. Twenty-six percent of the respondents in the Kathmandu Valley said they did not have sufficient water, while 8% of answered this way (HMG/UNICEF, 2001).

Along with disease and death, there are other hardships associated with lack of access to water. The time burden of fetching water falls primarily on girls and women at the expense of their schooling and on women's health and other tasks. In the central hills of Nepal, the average time to fetch water is 16 minutes. With an average of 3.9 trips per day for water, an average of 62 minutes per day is taken up by collecting drinking water. In the rural areas of Nepal, the average time is 11 minutes, with 4.3

trips per day on average, or 47 minutes of every day spent on this activity (HMG/UNICEF, 2001).

In the Kathmandu Valley 100% of households had a latrine within 50 feet, but only 71% of the rural communities had latrines within this distance. Twenty-three percent of rural communities had latrines between 50 and 100 feet from the household, and 6% were more than 100 feet (HMG/UNICEF, 2001).

The presence of latrines has not been found to be an effective method for reducing childhood diarrhea (HMG/UNICEF, 1997) or worms (Rai et al., 1997). The 1997 study found that the risk of childhood diarrhea in this sample is not affected by presence of a latrine. They note that presence of a latrine is different than using a latrine, or using it properly. Among children of literate mothers, there is slightly lower risk of diarrhea if the house has a latrine, and a child in a house where adults use the latrine has only half the diarrhea risk of a child from a house where they do not. Programs of latrine provision need to emphasize education about proper use. Many households perceive latrines as irrelevant or even harmful by contaminating the environment and concentrating the infection risk, with 67% of people reporting no need for sanitation facilities (HMG/UNICEF, 1997). Boya Village in Eastern Nepal was studied during 1996 and 1997. There the researchers found that the number of households having a latrine increased significantly during the study period, but with no significant reduction in the number of cases of helminth infection (Rai et al., 1997).

In the 2001 report, 16% of the respondents in the hill region of Nepal reported diarrhea in their communities in the past month, and 7% reported dysentery. Two percent reported typhoid, and 1% reported presence of cholera in their community in the last month (HMG/UNICEF, 2001). A CARE/Nepal study from 2000 reported that 28% of children had diarrhea in the past month (CARE, 2000), while the earlier HMG/UNICEF study found an incidence of 18% in children under five in the past two weeks. They found that children from seven to 18 months had the highest proportion of diarrhea, and that the incidence of diarrhea in children varied between urban and rural sites. Overall in Nepal 58% of episodes of diarrhea last more than 3 days (HMG/UNICEF, 1997). The 1997 study examined the beliefs about causes of diarrhea in children. The results are summarized below in Table 2.7. The same study also used focus groups to examine issues of water, health and sanitation in more detail. They found that in focus groups, the most common cause cited for childhood diarrhea was mother not having time to care for their children properly or attend to sanitation, cited by 18% of focus groups.

Table 2.7. Household views of cause of most recent episode of diarrhea

Cause	% of respondents
Hot or cold weather	39%
Excess food	14%
Don't know	13%
Leftover or dirty food	12%
Teething	10%
Specific foods (not itemized)	8%
Infections	6%
Evil spirits	3%
Dirty environment	3%
Too busy to care for child	1%

Note. From Diarrhoea, Water and Sanitation: Final Report (p.7) His Majesty's Government/Nepal National Planning Commission Secretariat, Kathmandu, Nepal, 1997.

The 1997 study found that 90% of households throw away any remaining water and wash the container before refilling it each time water is collected. However, there was a wide variety of materials used for washing, like ash, dirt, straw, rags, and water only, and they varied based on availability. Because of the large number of variables, it was not possible to analyze the effect of different washing materials. Similarly, it was not possible to analyze effect of type of water container used because of the large number of options and use of multiple types of containers within households, including brass, aluminum and copper metal containers, ceramic jugs and plastic buckets (HMG/UNICEF, 1997).

Reddy, Bodhankar, and Sinha (1997) investigated the prevalence of specific pathogens in patients with acute diarrhea in Nepal. They found the most common pathogens are *Giardia*, various worms, and amoeba.

Women's Status in Nepal

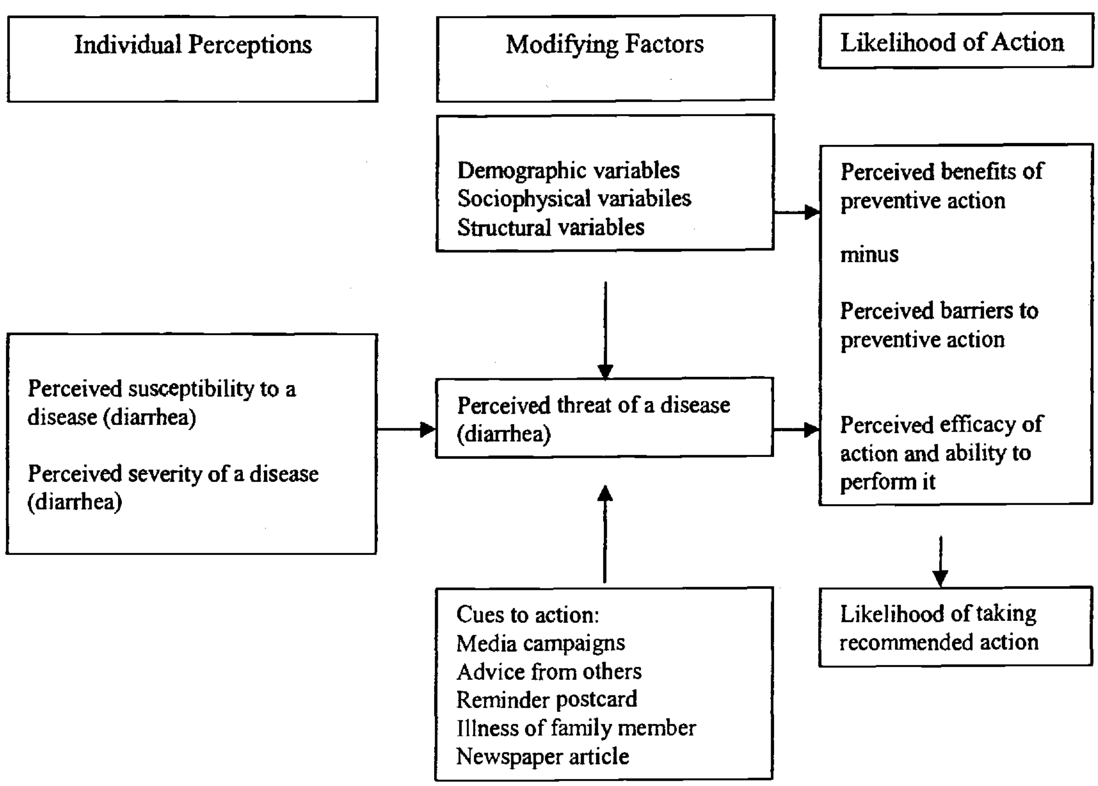
Women in Nepal are disadvantaged compared to men in almost every aspect of society: access to property, credit, health, education, skills development, technology and legal status (Asian Development Bank, 1999). Nepal ranked 142 out of 173 countries in the United Nation Development Program's (UNDP) 2002 Gender-Related Development Index, which disaggregates life expectancy, literacy, and income by gender, indicating that the existing human development gap has substantial gender inequities (UNDP, 2002).

The rugged topography makes provision of services in remote areas difficult, and the low productivity agriculture practiced in Nepal increases the burden on poor people as they must work long hours in the fields just to meet subsistence needs. Women carry the double burden of responsibilities for both family and farming. In most of Nepal, women gather firewood or fuel for cooking, prepare the meals, feed the children, and wash dishes and clothing in addition to their agricultural work. Increased population and a high dependency on natural resources base has led to ecological degradation of forests, soils and water sources. These in turn have increased women's workload as they have to travel further to find the resources they need (United Nations Food and Agriculture Organization, no date).

Theoretical Frameworks and Behavior Change

Stanton, Black, Engle and Pelto (1992) note that almost all public health activities aimed at reducing the incidence or severity of diarrheal diseases require some behavioral change, whether it is in learning to use latrines, preparing oral rehydration fluids, food handling and storage practices, hand washing practices, or treating water. Therefore, a strong theoretical base for interventions can increase the effectiveness and sustainability, as well as contribute to the body of knowledge about behavior change interventions. The ethnographic component of this study was theory-based, with support from the Health Belief Model (HBM), shown below in Figure 2.5 (Becker, Drachman & Kirscht, 1974).

Figure 2.5. Health Belief Model



Note. From "A new approach to explaining sick-role behavior in low-income populations" by M. Becker, R. Drachman, and J. Kirscht, 1974, American Journal of Public Health. 64 p. 206. Copyright 1974 by American Public Health Association. Adapted with permission.

The study uses the constructs from the HBM in an exploratory fashion as a framework for qualitative data collection. The HBM was developed as a systematic approach to explaining and predicting preventive health behavior, and can also be applied to beliefs about another's susceptibility, such as a mother's belief about her children's vulnerability to contagious disease (Stanton et al., 1992).

Under the HBM, the likelihood that someone will adopt or continue a health protective behavior is a function of two factors. First, the person must personally feel threatened by the disease – that is, the person perceives that he or she personally is vulnerable and that the disease is serious. Second, the person must believe that the benefits of the preventive action outweigh the barriers to taking that action. It incorporates the idea of self-efficacy, both of the action (Does it work?) and the individual (Can I do it correctly?). The model also shows the importance of "cues to action" for bringing about behavior change.

Several studies indicate that HBM is an appropriate choice as a framework for this research. Nepalese people do not necessarily think that diarrhea is a problem, or see a relationship between diarrhea and water (HMG/UNICEF, 1997). A study of malnutrition in Nepal showed that chronic malnutrition is considered a normal state (Kolsteren and Lerude, 1997), and anecdotal experience indicates this may be the case for diarrheal disease as well. Stapleton (1989) found that many people in Nepal believe infant diarrhea is caused by teething, so they are less likely to treat water, change handwashing behavior, or adopt latrines to prevent it. Stapleton also found that mothers with infants are more likely to see a doctor when there is severe diarrhea rather than mild, so perceived severity is a factor in changing health behavior (1989).

The importance of cultural values and beliefs in determining health behavior has been studied in Asia. Quah (1993) explored the effects of ethnicity and social class on preventive health practices in Singapore, and found significant differences in health behaviors and health outcomes. The etiology of disease in other cultures differs from the western paradigm. Sometimes causes are attributed to natural, supernatural, or social sources. Indigenous beliefs for causes of sickness, the mind-body relationship, and culturally appropriate methods for health interventions can generate resistance to western forms of health prevention and health care (J. Subedi, 1989), underscoring a need to understand local knowledge and beliefs about water quality. These studies indicate that understanding the context of water and water purity in Nepalese villages can assist in identifying culturally appropriate interventions to improve the quality of drinking water and health.

M. Subedi (2001) notes that a belief in supernatural causes of illness is strong among the Newar in Kathmandu Valley. He identifies three levels of spirits: gods and goddesses, ghosts, and witches. The villagers offer regular rituals or worship to the deities, who are protective forces recognized by that place and people. These deities may send an illness or fail to protect an individual being attacked by evil forces if the proper rituals have not been observed. Gods and goddesses are worshiped to ask for their protection. Ghosts are associated with the spirits of the dead that have not achieved the proper passage to reincarnation. Usually ghosts are considered harmless, but there are evil ghosts that may enter and consume a live person from the inside, causing them to lose weight and become ill. This requires a special service to exorcise the ghost. Witches, almost always female, are thought to be the chief supernatural cause of any kind of affliction. They can be encountered in the abstract through stories about witches, or an actual woman, usually elderly and a widow, can be named a witch. In the case of a death, illness or other misfortune blamed on a witch, a traditional healer is used to identify the witch, and she is punished through beating, humiliation, and often death.

CHAPTER 3. RESEARCH DESIGN AND METHODS

This chapter describes the research site and sample selection procedures for the water quality and health survey components, the preparation and testing of the survey instruments, and methods of data collection and analysis.

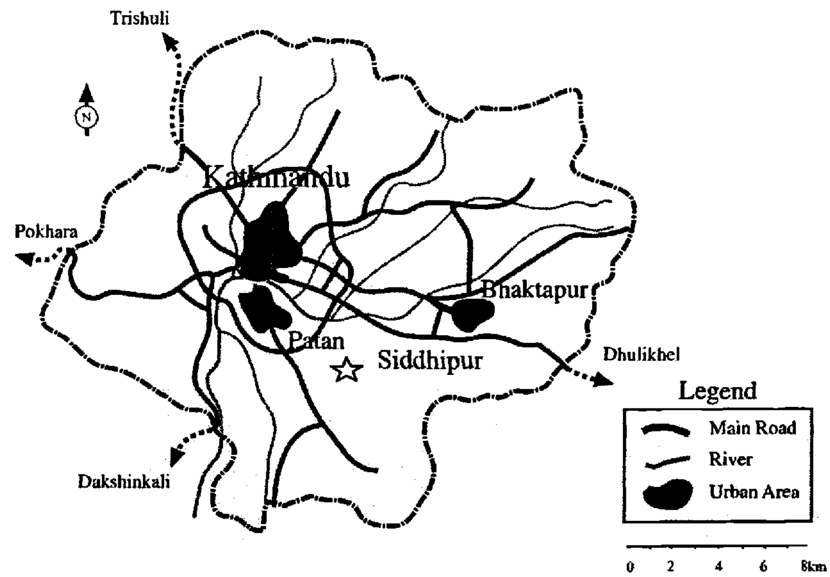
Research Setting

The study was conducted in Nepal from February to July 2002. Dunche Bazaar, the original study site, was randomly selected from a set of all villages in Rasuwa District within 2 hours walk from the road. Research was begun in November 2001, but was abandoned at that site in January 2002 because of the unstable security situation in rural areas caused by a political movement to overthrow the current government.

The study was restarted in February Siddhipur village, located about ten kilometers southeast of the capital city of Kathmandu. Siddhipur was selected due to its proximity to Kathmandu (within the travel restrictions placed on the researcher by the granting agency), previous research by a local consulting firm that indicated contamination of the drinking water sources in this village, and a supportive village council who was interested in improving the water quality situation.

There are 950 households in Siddhipur, with a population of 5685 people. Figure 3.1 shows the location of the research site in relation to Kathmandu and other urban areas in the Kathmandu Valley.

Figure 3.1. Map of Kathmandu Valley



Note. Map by J. Buckley, Oregon State University. (2002). Used by permission.

The area around Siddhipur is undergoing rapid urbanization, but is still predominantly agricultural, with rice and wheat fields surrounding the village as shown in Figure 3.2. During the dry season many fields in this part of the Kathmandu Valley are used to make bricks. Many of the kilns use obsolete and operate without permits, but the unstable political situation in the rural areas has created a strong demand for housing in Kathmandu and other urban areas.

Figure 3.2. Landuse patterns around Siddhipur Village

Photo: R. Rainey

Siddhipur's population is ethnically Newar, the indigenous people of the Kathmandu Valley. Newars have a complex system of social stratification and their own written and spoken language. The level of education in Siddhipur is low. Only 33% of men over 15 years old are literate, and 14% of the women over 15 years are literate (Siddhipur Village Profile, 2001). Much of the business at the city offices and in homes is conducted in Newari language. Due to the low level of education for women and the cultural obstacles in terms of early marriage and heavy household workload, few women spoke Nepali language, the national language of Nepal. The primary occupation and source of income for the residents of Siddhipur is agriculture. Most of the agricultural work is done by hand or with animal traction. Men do the plowing and assist in harvesting, but women do most of the planting, cultivating, and threshing of the grain crops. In addition, the women in Siddhipur are known for their fine straw mats, and when not occupied in other tasks they sit in the courtyards hand weaving thick straw mats that are used in traditional Nepali homes as floor coverings. These are usually sold to a broker to market in Kathmandu.

There is a paved road along one edge of the village, and several unpaved roads provide access to neighborhoods within the center of the village. However, most of the village is accessible only by narrow footpaths, sometimes paved with stones or bricks. Most households in Siddhipur are connected to the electrical grid, and the electricity is very reliable. Electricity is mainly used in the households for lighting and cooking.

There is no municipal system to deliver piped water to households in Siddhipur. Most of the households get their drinking water from 27 public wells and numerous private wells. Wells are also used by households when tap water is not available. The public wells are not covered, but all the private wells, which were smaller, were covered with a metal hinged lid. Well water must be pulled up manually in buckets but is available 24 hours a day. The Environment and Public Health Organization (ENPHO) first identified the problem of fecal contamination in drinking water in Siddhipur in the early 1990s. At that time, they identified wells that should never be used for drinking water, and this is still observed in the village. They also provided training in adding bleach to the reservoir and wells, but that has not been maintained.

The remaining households get their drinking water from a system of 54 taps that are fed from a central 50,000 liter reservoir just outside the village. The reservoir in turn is fed directly from the Godawari River. The river is diverted into a pipe about 5 kilometers upriver from Siddhipur. Twice daily, in the morning and evening for several hours, the water is turned on from the central reservoir to feed the system of village taps. Some days no water comes from the taps, either because no one turned the main tap on at the reservoir or because the reservoir is empty. This may be due to a broken pipe above the reservoir, or the tap may have been left open and drained the reservoir.

Bathing and washing dishes and laundry also take place around the taps and wells. Currently there is no shortage of water at any time of year in Siddhipur, although this is a problem in nearby urban areas.

Each time water is collected, first the container is scrubbed with ash and mud and rinsed thoroughly, shown below in Figure 3.3. Then the container is filled, either from the tap or buckets of water drawn up from the well. Usually one container of water was sufficient per day, but in several cases water is usually fetched twice or more a day, and in one case, of a single widow living alone, one container of water lasted 2-3 days.

Figure 3.3. Washing the household water container

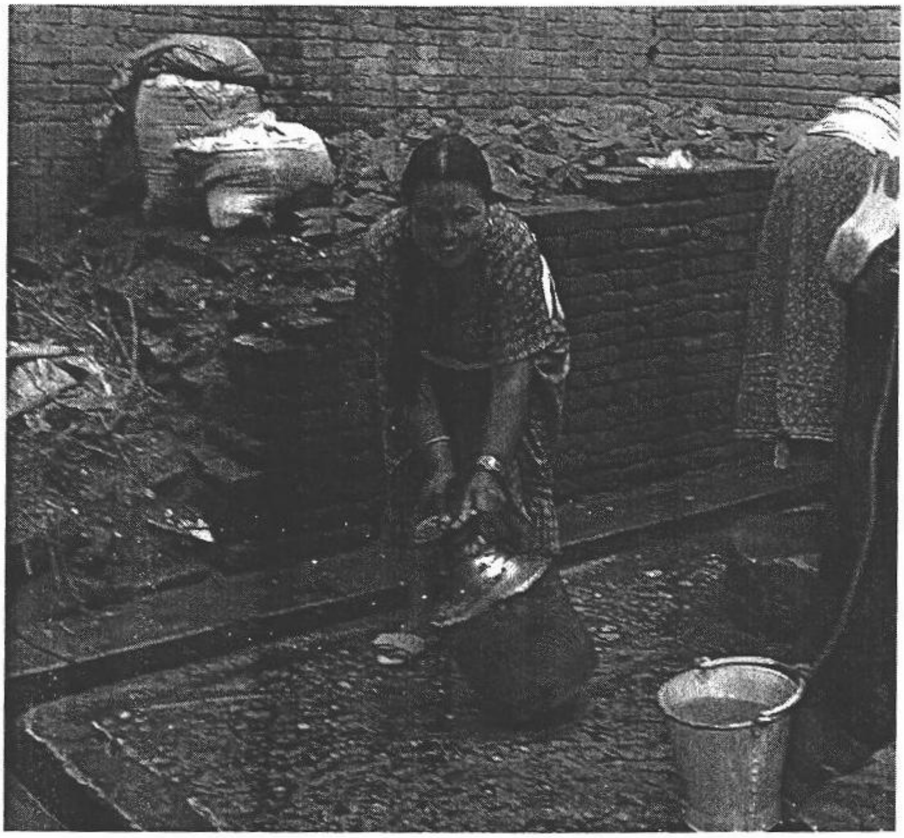


Photo: R. Rainey

Two hundred sixty-six of the 950 households in Siddhipur have latrines, or about 28% of the village. These are usually a lined cement pit that is cleaned out once every few years and the composted matter spread on the agricultural fields. There are five outdoor public toilets for use by women and children. Along the paths in the village and in the fields surrounding the village there is ample evidence of human excrement.

One infant died in the year prior to the data collection for the village profile. There was no information on death rate for the village, but a list of important diseases included pneumonia, whooping cough, diarrheal diseases, measles, stomach aches and skin diseases (Siddhipur Village Profile, 2001).

Sample Size

The sample size was calculated to estimate the number of households required to test for a statistically significant reduction in contamination after implementing SODIS. Assistance was provided by Oregon State University's Statistics Department. The sample size was obtained by using the formula for sample size using proportion estimation (Lohr, 1999). From the literature of SODIS field tests, solar disinfection eliminates over 90% of bacterial contamination, so this was used as the proportion of reduction in the equation. Alpha was set at 0.05, two-tailed, and the margin of error at 0.10.

<u>Parameters for Proportion Sample Size calculation</u>

0.9 P = reduction in contamination as measured in CFU as seen in previous studies

0.1 (1-P) = proportion still contaminated

0.1 D = margin of error

0.05 α = Alpha (two-tailed)

1.96 Z score for 0.05/2

<u>Proportion Sample Size Calculation</u>

N $= (Z \text{ for } \alpha/2)^2(P)(1-P)/D^2$

N $=(1.96)^2(.9)(.1)/.1^2$

N =34.57, or a minimum of 35 households

A total of 42 households were enrolled in the study, although two later dropped out of the study. Six of the 42 served as controls, and received no training or materials on SODIS until the completion of the study in July 2002.

Subject Selection

The households were selected using a stratified random sampling technique with village wards (administrative units roughly corresponding to neighborhoods) as the strata (Levy & Lemeshow, 1999). Three of the nine wards in Siddhipur were randomly selected. Then, from the village census which lists all of the households in the village by ward, 14 households were randomly selected from each of the three wards for a total of 42 households in the study. Two households in each ward served as the controls, and the other 12 households were in the treatment group for testing SODIS. Two treatment households dropped out of the study after the baseline information had been collected. Information from these households was not included in the analysis.

Each household was visited by the researcher and the interpreter. The study was explained to the primary food-preparer in each household, known in this study as the contact, before she was asked to participate. If she agreed, the voluntary consent form was filled out at that time. If the contact was not available, the researcher returned again later.

Each member of the 42 participating households was included in the health component of the study, for a total of 213 individuals. The two households that dropped out of the study had a total of seven individuals, so the final study population was 206 individuals.

Survey Instruments

Water Quality Component

For water quality data, a laboratory notebook was prepared for recording field and analysis notes. Data were collected on three water quality parameters associated with water borne disease, microbial contamination and solar disinfection: pH, turbidity, and colony-forming units of fecal coliform bacteria, as well as weather and other notes that might affect sampling results. Data were entered into an Excel spreadsheet daily.

Health Survey Component

Several existing survey instruments were modified and combined for use in this part of the study. Assistance from the OSU Survey Research Center was valuable in both content and format of the health questionnaires. The primary source was the survey form used in the Nepal Multiple Indicator Surveillance study for the His Majesty's Government (HMG) Diarrhea, Water and Sanitation final report (HMG/UNICEF, 1997). This instrument contains questions on literacy of the mother, age and sex of household members, questions about incidence and severity of diarrhea for each member, and questions about the source of water and sanitation practices in the household. There was no information on reliability or validity provided for this instrument, but it formed the basis of another government survey, the Report on the Situation of Women, Children and Households, undertaken in 2000 (HMG/UNICEF, 2001). Additional questions relating to acceptability of SODIS were added to the followup surveys based on prior research by EAWAG/SANDEC (no date).

The three survey forms (one baseline and two follow-ups) were validated for content and appropriateness on arrival in Nepal by a panel of three Nepali professionals with expertise in water quality and social sciences. Mr. Rabinlal Chitrakar, Director of Environmental Health Section, Dr. Roshan Shrestha, Executive Director of Nepal Environment and Health Organization, and Ms. Kalawati Pokharel, Project Director for Rural Water and Sanitation Project, are all active in water and health projects in Nepal. Their comments were incorporated into the survey forms, and the surveys were translated into Nepali language for use in the original research site. The researcher is fluent in Nepali language. When Siddhipur was selected as the final research site, the survey forms were pilot tested with an interpreter who translated the questions from Nepali into Newari and the responses from Newari into Nepali.

After pilot testing, minor changes were made and the survey instruments were finalized and administered to the study participants with the assistance of an interpreter. The questions were asked by the researcher in Nepali, then orally translated into Newari by the interpreter. The responses were likewise orally translated from Newari into Nepali and then the researcher wrote the responses on the survey form. The interpreter for the study was Maiya Maharjan, a woman health volunteer from the village of Siddhipur who speaks both Newari and Nepali languages. The baseline survey took approximately 25 minutes to administer. Subsequent interviews took about 15 minutes each, to gather information on diarrheal illness in the household and on the acceptability of SODIS. The data from the health surveys were entered into an Excel spreadsheet daily.

Several questions eliciting the same information were included in the surveys, and these were manually checked for reliability. Yes/no questions about importance of treating drinking water, necessity of treating drinking water, and acceptability of SODIS treated water were asked twice, once in a positive way and once in a negative way. Regarding the importance of treating drinking water, 25 of the 28 respondents, or 89%, answered the two "yes/no" questions different ways, indicating a high level of reliability. For the necessity of treating drinking water, 25 of 29 respondents or 86% answered the two "yes/no" questions different ways. For the acceptability of SODIS water, 25 of 31, or 81% of the respondents answered the two questions different ways. Additional information on acceptability was gathered from the qualitative component to clarify differences in responses.

Qualitative Component

The qualitative research component consisted of open-ended questions on the survey forms, observation by the researcher around the village water sources and in households, and also included semi-structured interviews with the contacts. The aim was to provide additional information on acceptability of SODIS in terms of the constructs of the Health Belief Model: perceived risk, benefits and barriers to adopting this new health behavior. Local understandings of health and drinking water quality were also explored. See Appendix 1 for an illustrative list of questions and observations used to inform the qualitative component.

Institutional Review

This research was approved by Oregon State University's Institutional Review Board for the Protection of Human Subjects. Participants were read the voluntary consent form in their native language (Appendix 2), and then signed or affixed a thumbprint to the form, written in Nepali script, to indicate their willingness to participate. A copy of the completed voluntary consent form was given to each participant. The originals will be kept in the researcher's files for three years and then destroyed. The research also had the support of His Majesty's Government of Nepal's Drinking Water and Sanitation Section under the Ministry of Local Development, and of the Mayor of Siddhipur. The mayor gave his full approval and support for the research. One of his staff was assigned as a translator and facilitator.

Data collection

The following table (Table 3.1) shows the timeline for data collection for the three components of the research (health data, water quality data, and qualitative data). The process for data collection for each component is described below in more detail.

Table 3.1. Timeline of data collection.

	February 2002	March 2002	April 2002	May 2002	June 2002	July 2002	August 2002
Approvals							
Informed consent							
Baseline health survey							
Baseline water sampling							
SODIS Training							
Qualitative data collection							
First followup health							
First followup water sampling							
Final followup health							
Final followup water sampling							
Present preliminary results							

Water Sampling

Water sampling was performed during the period of March to July 2002. In March, baseline samples were taken from the household water storage container (*gagri*) in each household, and from each water source used by the participating households. Households generally used the closest tap or well to the house, although some households preferentially used one type or the other despite a slightly longer walk to reach the water source. Two follow-up sampling rounds occurred, the first in June and the second in July. For these sampling rounds, in addition to the household containers and the household water sources, water was sampled directly from a solar disinfection bottle, if one was used in that household. pH and turbidity measurements were taken on site in the field. For testing fecal contamination, samples were collected in Hach Whirl-pak microbiological bags and held in a cooler on ice during transport back to the laboratory facility at the researcher's apartment.

pH Testing

pH, a measure of the concentration of hydrogen ions, was measured and recorded in the field with a Hach Pocket Pal pH tester. The pH meter was calibrated with standard solutions at the Environment and Public Health Organization (ENPHO) laboratory before data collection. Raw water for use as drinking water usually has a pH in the range of 5.5 and 8.6, and in this range there is no immediate health effect in humans (DeZuane, 1997). pH can, however, affect the rate of leaching of metals or minerals into water and the growth of microorganisms.

Turbidity Testing

Turbidity is a measure of suspended solids -- usually clay, silt, organic matter, or microorganisms - in a solution (Hach, 1997). Turbidity was measured and recorded in the field using a HACH DR/820 portable spectrophotometer. The units are in Formazin Attenuation Units (FAU), equivalent to Nephelometric Turbidity Units (NTU) (Hach, 1997). The EPA has set the maximum contaminant level (MCL) of turbidity in drinking water at 1 NTU, and it must not exceed 0.3 NTU in 95% of daily samples in any month (USEPA, 2002). The WHO guidelines for routine monitoring are that the median level of turbidity should be less than or equal to 1 NTU, with a maximum of 5 NTU for any single sample (WHO, 1993).

Bacteriological Testing

Fecal coliform bacteria was used as an indicator of fecal contamination. The use of normal intestinal bacteria as indicators of fecal pollution is acceptable for monitoring and assessing the microbial quality of water supplies (WHO, 1993).

Samples were collected directly from the taps and household containers into 120 ml Whirl-pak bags. Well water samples were collected by rinsing the researcher's bucket in the well to be sampled, then collecting a bucketful for sampling. Water was poured directly from the bucket into the Whirlpak bag. Samples were transported on ice in a cooler back to the laboratory for processing. Processing occurred less than eight hours after collection in accordance with handling times and temperatures for microbiological samples (Hach, 1997).

The water samples were tested for fecal contamination using membrane filtration and incubation. The samples were processed using a Del Aqua membrane filtration kit and incubator loaned by the government's Drinking Water and Sanitation office. The samples were filtered through Millipore 0.7 micron membrane filters with grids. The Millipore M-FC fecal coliform media was prepared in small batches of 100 or 200 ml, on an "as needed" basis, by the lab staff at Nepal Environment and Public Health Organization (ENPHO) laboratory facilities to ensure sterile conditions. The media was packaged in 24 ml sterilized glass tubes with lids, enough media for about seven samples. Any partially used tubes of media were discarded. After completing filtration of the day's samples, a blank sample with boiled water and then a spike with water known to be contaminated with fecal material were run to test for reliability and incubated along with the other samples.

Quality Control/Quality Assurance

The lab procedures were carried out using quality control measures as specified by Hach for bacteriological testing, disinfection of the area, and disposal of completed tests (Hach, 1997). See Appendix 3 for the lab procedures for bacteriological analysis.

Health Data

After receiving informed consent from each participating household, the pilot-tested and validated baseline survey was administered by the principal investigator with the help of a translator in February 2002, using the survey form titled "Baseline Health and Demographics Survey – Nepal" (See Appendix 4). The contact in each household that provided the data was the primary food-preparer in that household. Next, all contacts attended a three-hour training session during March 2002. Two sessions were held, on March 24 and March 25 in order to ensure full participation by the contacts. Some contacts attended both sessions. The training was presented in both Nepali and Newari languages. Two of the contacts did not attend the training, and so these households were dropped from the study at this point.

The training included information and discussion about the ways water can become contaminated, the health effects of drinking or consuming contaminated water, and instructions on how to implement the SODIS method of solar disinfection of drinking water. A volunteer from each session demonstrated the technique with feedback from the other participants. See Figure 3.4 for a picture of the training. Each of the two sessions finished with a discussion of the next steps of the study and how the results would be used.

Figure 3.4. Volunteer demonstrating SODIS during training in Siddhipur, Nepal

Photo: C. Otte

After the training, all participating households were provided with two 1.5 liter clear PET bottles for each person in the household. Half of the set of bottles were to be exposed one day, and the second set exposed the following day. On the second day the first set of bottles (that had been exposed the day before) were to be used for consumption as drinking water. This cycle was to be continued so as one set was being exposed to sun, the second set that was irradiated the day before was ready for consumption.

The first follow-up for health data collection occurred in the first week of June 2002, approximately six weeks after the SODIS training. This followup coincided with the wheat harvest, and the women were very busy. The researcher had only about a two-hour window between 6:30 and 8:30 a.m. to catch the contacts at home before they had to go out to work in the fields. Each contact was surveyed about episodes of diarrhea among the household members, and the acceptability of the SODIS technology, using the survey titled "First Follow-up Health Survey and SODIS Acceptability - Nepal" (see Appendix 5).

A second, and final, follow-up occurred the first week of July, 2002, using the survey form titled "Final Follow-up Health Survey and SODIS Acceptability - Nepal" (see Appendix 6). This round of data collection fell during the rice planting season. Rice is the staple food of Nepal, and many families live on the rice they grow on their own land, so again agricultural fieldwork was a priority for the contacts.

The six households that served as controls did not receive the education and equipment package in March, but were interviewed for baseline and followup health surveys (leaving out questions about SODIS) along with the SODIS households. The control households received training and bottles for SODIS at the completion of the study in July 2002.

Qualitative Data Component

Open-ended questions from the surveys, semi-structured interviews and observations (Kelleher, 1993) were used throughout the research period to gather qualitative data related to use of SODIS, other aspects of water use, and sanitation practices. Interview and observational data collected by the researcher were written into the field notebook and transcribed into a wordprocessing file on return to the office.

Data Analysis

The quantitative data from water testing and from the health surveys were entered into Excel 2000 spreadsheets. The data were checked for input errors before importing into statistical software packages for analysis. Water samples with CFU recorded as TNTC (too numerous to count) in the data log were replaced with 1000 CFU per 100 ml for the purposes of analysis, a slightly larger value than the highest numeric count in the data.

The frequencies and percentages in the descriptive data were generated using JMP IN version 4.05 statistical package (SAS Institute, 2001). The statistical analyses were carried out both in JMP IN version 4.05 and in S+ statistical package (Insightful Corp, 2001). Variables and residual plots were examined for assumptions of the statistical tests. Natural logarithm transformations were done on CFU and FAU variables in order for them to meet the assumptions of the parametric analyses. Interpretation of the log-transformed data was done using the guidelines in Ramsey and Schafer (1997).

Hypotheses 1, 2, and 3, examining various parameters of water quality among the four different sources of drinking water, were tested with a two-way analysis of variance (ANOVA) test, controlling for the effects of sampling round, using S+. Tukey HSD post-hoc tests were used to determine which sources were different when the ANOVA was significant.

Hypothesis 4, a paired analysis of before and after water samples, was tested using a Wilcoxon Signed Rank test because of the small sample size, in JMP IN. Hypothesis 5 was tested in S+ using multiple regression to examine predictors of water quality. Hypothesis 6 was initially planned to be tested using a t-test comparing episodes of diarrhea in controls and treatment households, but this analysis could not be performed due to inadequate sample size. Hypothesis 7, to identify predictors of diarrhea, was tested using a Log-Linear Poisson regression in S+ because of the distribution of episodes of diarrhea.

The qualitative data were grouped and examined for themes that might support or explain the health behavior of the participants (Ely, 1991), based on constructs from the theoretical framework, the Health Belief Model (Becker, Brachman & Kirscht, 1974).

CHAPTER 4. RESULTS

The results of the study are presented in this chapter. First, the demographic characteristics of the study sample are given. This is followed by descriptive data gathered from the baseline, first, and final follow-up health surveys (three rounds of data collection). Next is the descriptive data from the water sampling component (three rounds of water sampling). This is followed by the results of the hypothesis testing. The chapter ends with a presentation of the analysis of the qualitative research results.

Demographic Characteristics

In this study, the contact person for each of the selected households was the primary food preparer for the household. All of the contacts in the study were women. Contacts at 42 households were interviewed for baseline data during February and March, 2002. Thirty-six households were in the experimental group to pilot test SODIS, and six households served as controls. The controls did not attend the SODIS training or receive any materials to do SODIS until the end of the study in July, but participated in the health interviews and water sampling during both the June and July follow-ups. After the baseline data were collected, two of the households in the experimental group dropped out, leaving a total of 40 households. The households that dropped out were excluded from all analyses.

Age of contacts

The average age of the 40 household contacts was 39.7 years, with a range of 21 to 74 years. The mode was 30 years old, with five contacts reporting this age. The age distribution of the contacts is shown below in Table 4.1.

Table 4.1. Age distribution of household contacts

Age range	Number of contacts n	(%)
21-29	9	22
30-39	16	40
40-49	5	13
50-59	4	10
60-69	4	10
70-74	2	5
Total	40	100

Age of Study Population

The study population included all members of the selected households. The final study population was 206, with 96 men and 110 women in the health component of the study investigating episodes of diarrhea. The ages of the men in the study ranged from newborn to 82 years, with a mean of 28 years (SD 18) and a median age of 25 years. The ages of the women in the study ranged from 6 months to 77 years, with an average of 28 years (SD 18) , and a median of 24 years. The age breakdown of study participants is shown below in Table 4.2.

Table 4.2. Study population age breakdown for study population (N=206)

Age in years	Men		Women		Total	
	n	(%)	n	(%)	n	(%)
0-5y	7	(3)	7	(3)	14	(7)
6-15	20	(9)	18	(9)	38	(18)
16+	69	(34)	85	(41)	165	(75)
Total	96	(46)	110	(54)	206	(100)

Most of the households in the study were multigenerational, with women marrying into the husband's family and living with his parents. The average size of treatment households was 5.2 people, and ranged in size from 1 to 10 people, as shown below in Table 4.3.

Table 4.3. Size of households by number of members (N=40)

Number of members in household	Count of households	
	n	(%)
1	1	(2.5)
2	2	(5.0)
3	5	(12.5)
4	9	(22.5)
5	7	(17.5)
6	8	(20.0)
7	2	(5.0)
8	2	(5.0)
9	3	(7.5)
10	1	(2.5)
Total	40	(100)

Years of Education of Contacts

Overall, the number of years of education for the contacts ranged from 0 to 10 years, and 29 of the 40 women had never attended school. The overall distribution of years of education for all contacts is given below in Table 4.4.

Table 4.4. Number of years of education of contacts

Number of years in school	Number of contacts n	(%)
Never attended	29	(72.5)
Up to 1 year	3	(7.5)
1 to 2 years	2	(5.0)
4 years	1	(2.5)
9 years	2	(5.0)
10 years	3	(7.5)
Total	40	(100.0)

Baseline Survey Information

Water Source

Contacts were asked to list all of the sources they use for drinking water. For this question, 37 (88%) of the contacts said they get drinking water from public wells in the village. Thirty-two (76%) of the contacts said they use the public taps for drinking water, no one uses the irrigation channels, and one contact (2%) uses a neighbor's private well to get drinking water. Next, contacts were asked to identify their primary source of drinking water. Twenty-four of the households reported using wells as their primary source for drinking water, and 16 households used taps. The 40 households used a total of 13 different sources of drinking water, with water from 8 different taps in the village, 4 public wells, and 1 private well. See Table 4.5. for a summary of these results.

Table 4.5. Sources of drinking water used (N=40)

All sources of drinking water used by household*	Number of households n	(%)
Public well	36	(90)
Tap	31	(78)
Private well	1	(2)
Irrigation channel	0	(0)
Household's primary source of drinking water	**Number of households n**	**(%)**
Public well	24	(60)
Tap	16	(40)
Total	40	(100)
Use of different drinking water sources (N=13 sources reported)	**Number of sources of this type n**	**(%)**
Taps	8	(62)
Public wells	4	(31)
Private wells	1	(7)
Total	13	(100)

* more than one answer possible

All contacts reported that more than one person fetched water for their household, including the one contact who lived alone. Thirty-seven out of the 40 contacts reported collecting water for their household. By definition for this study, the contact is also the primary food-preparer in the household. Nineteen of the contacts reported their daughters collected water, and eleven households had a daughter-in-law or sister-in-law who collected drinking water. Two contacts reported that their mother-in-laws fetched water. No households had a worker who collected water for the household, but in one household the contact reported that her son fetched water.

The distance from participating households to their primary drinking source was measured on a scale map of the village. The mean distance was 40 meters (SD 34), with a range from 3 meters to 150 meters. The mean number of households reported to be using the different drinking water sources named in the study was 36 households per source (SD 25), with a range from 7 households to 80 households.

Water Storage in Household

All of the households used a large narrow-mouthed container (approximately 20 liters) to store drinking and cooking water in the household, since there was no running water in the houses. Thirty-eight of the forty households (95%) reported using a brass container to store the drinking water, and two households reported using ceramic containers for drinking water. All households reported covering their water container, although observationally sometimes the containers were not covered. Water is poured into a smaller brass container with a spout for drinking. The smaller container is lifted above the head and tilted so water comes out of the spout and pours into the mouth without touching lips to the container, since contact would make the container ritually unclean for other drinkers. When plastic bottles are used for drinking water, they are used the same way so there is no contamination from saliva. Types of covers used for the containers are shown in Table 4.6 as are behaviors associated with cleaning of containers.

Table 4.6. Behaviors associated with sanitation of water containers (N=40)

Behavior	Number of households n	(%)
Cover container	40	(100.0)
With a dish	37	(92.5)
With fabric	2	(5.0)
With both dish and fabric	1	(2.5)
Throw away remaining water before refilling water container	38	(95.0)
Cleaning water container	40	(100.0)
Clean water container each time refilled	37	(92.5)
Clean water container once daily	3	(7.5)

Water treatment and Sewage Disposal Practices

The most common form of water treatment was to filter the water from the tap or out of a bucket of well water through a piece of fabric. Thirty-six of 40 households (90%) reported using this technique. Thirty-four households reported boiling water for use by member of the household when they were suffering from diarrheal illness or a cold, but did not boil routinely. One contact began boiling water during the final round of data collection because her daughter-in-law became pregnant. No households reported using chlorine or iodine to treat their drinking water. One contact reported that she boiled water for her husband, but the rest of the family did not like the taste, so they drank untreated water. These results are summarized below in Table 4.7.

Table 4.7. Type of drinking water treatment used in the household (N=40)

Type of treatment used	Number of households reporting this type n	(%)
Fabric filter	36	(90.0)
Boil for ill household member	34	(85.0)
Chlorine or iodine	0	(0.0)
Copper or brass container	38	(95.0)
Ceramic container	5	(12.5)
Cover with cloth or dish	40	(100.0)
Boil water for husband	1	(2.5)

Note: Percentages do not add up to 100% because some contacts reported more than one type of treatment

Fifteen out of 40 households have their own latrine either inside the house or within the walled housing compound. Twenty-three contacts reported using one of the six public toilets in the village. During the next round of data collection, the researcher learned that these public toilets are for women's use only. There is no data on what facilities the rest of the household uses for those households where the contact uses the public toilet. One contact reported using the fields outside the village, and one contact reported using the latrine at a relative's house nearby.

Excluding the households that have a latrine, the mean number of meters from household to a latrine is 112 meters, (SD 191, N=25). The range is from 5 meters to 1000 meters. One contact reports using the outlying fields for excreta disposal, a distance of 1000 meters from the house. If this household is excluded as an outlier, the mean distance for the households with no latrine is 75 meters (SD 47, N=24), with a range of 5 meters to 160 meters.

Fifteen of the 40 households have latrine facilities that one or two households use on a daily basis. Five contacts reported using a public latrine that is used by an estimated 100 households on a daily basis, and 18 contacts reported using a public latrine that is used by an estimated 300 households on a daily basis. Later in the study, the researcher was told that the public latrines are for use by women and children only. By that time in the study it was not possible to collect information from participants on behavior of other household members with respect to disposal of excreta, but it is assumed that these members use the surrounding fields. One contact reported that the household used the fields around the village for a latrine. An estimated 500 households in the community of Siddhipur dispose of urine and excreta in this manner. These data are summarized below in Table 4.8.

Table 4.8. Latrine use by households (N=40)

	Number of households	
Location of latrine	**n**	**(%)**
In house	15	(36)
Use public latrine	23	(60)
Use relative's house	1	(2)
Use fields outside village	1	(2)
Total	40	(100)
Distance to Latrine	Number of households	
	n	(%)
0 (in-house)	15	(37.5)
1-20 meters	2	(5.0)
21-50 meters	10	(25.0)
60-100	4	(10.0)
110-160 meters	8	(20.0)
1000 meters	1	(2.5)
Total	40	(100.0)
Number of Households using Types of Latrines		
Type of facility	Number of households	
	n	(%)
1 or 2 households – private latrine	16	(40.0)
Public toilets, used by an estimated 100 households*	5	(12.5)
Public toilets, used by an estimated 300 households*	18	(45.0)
Fields, used by an estimated 500 households	1	(2.5)
Total	40	(100.0)

* public toilets are for women and children's use only

Diarrhea in Study Population

In the baseline survey, 35 of 40 (87.5%) contacts reported stomach problems and/or diarrhea in their household at some time. Twenty-seven of the contacts (67.5%) considered diarrhea to be a problem in their household. Table 4.9 shows the distribution of episodes of diarrhea in the households.

Table 4.9. Diarrhea in household members (N=40)

	Number of households that reported n	(%)
Do you or anyone in your household ever have diarrhea?		
	Yes = 35	(87.5)
	No = 5	(12.5)
Total	40	(100)
Do you consider this to be a problem for your household?		
	Yes = 27	(67.5)
	No = 13	(32.5)
Total	40	(100)
Has anyone in your household had diarrhea in the past two weeks?	Yes = 7	(17.5)
	No = 33	(82.5)
Total	40	(100)

Ten of the 206 subjects (4.8%) in seven households (17.5%) had diarrhea in the last two weeks (defined as 3 loose stools during either the day or night, or 5 loose stools in 24 hours) in the baseline study. Four households had one reported episode of diarrhea, and three households had two reported episodes each during the previous two weeks. Cases were evenly distributed among age groups and sexes.

Twenty-six of 40 (65%) contacts felt that diarrheal problems were seasonal. Three of them reported higher incidence of diarrheal problems in the winter dry season (December/January), four contacts cited the March/April season of snowmelt, and 19 mentioned the monsoon season of July/August as being a season with more diarrhea. This is summarized in the Table 4.10 below.

Table 4.10. Seasonality of diarrheal problems (N=40)

	Number of contacts	
	n	(%)
Do you think diarrhea is a	Yes = 25	(65)
seasonal problem?	No= 15	(35)
Total	40	(100)
If yes, what season has more diarrhea problems? (N=25)		
Monsoon (July/Aug)	19	(76)
Snowmelt (March/April)	3	(12)
Dry season (December/Jan)	3	(12)
Total	25	(100)

First Follow-up on Health and SODIS Acceptability

The first follow-up occurred during the wheat harvest of June 2002. All the harvesting and threshing is done by hand, and the contacts were very busy. Interviews were held between 6:30 a.m. and 8:00 a.m. before the contacts went out to work in the fields. In this round of surveying, one household with three members was not available during the sampling period, with three members in the household. Only households in the treatment group were asked about SODIS use, so the total households for questions relating to SODIS use and acceptability are 33 for this survey round.

Diarrhea in Study Population

Seven households out of 39 in this round of sampling reported episodes of diarrhea in the past two weeks. This resulted in a total of 9 household members out of 203 people. Five households each had one episode, and two households had two episodes. There were 4 cases in women from 24 to 38 years old, and 5 cases in men from 3 to 65 years old.

SODIS Use and Acceptability

Thirteen out of 33 households reported using SODIS regularly after the training until the start of the wheat harvest, but only 3 households did not miss any days. Twenty-two of 33 contacts reported that they were satisfied with SODIS in the first follow-up interview. Seven said they were not satisfied, 3 did not know, and one contact did not give a response to this question.

Thirteen (39%) of households reported using SODIS regularly since the training 75 days before, but 30 (91%) reported missing at least one day of SODIS. The average number of days missed was 42 days out of 75 (56% of the time), with a standard error of 5 days. The range of days missed was 0 to 75 days.

Contacts were asked a series of questions about why they did not adopt SODIS. The answers to the survey format are presented below in Table 4.11. In addition, the contacts were asked open-ended questions to further explore the reasons for non-adoption of SODIS, and these answers are presented in the ethnographic section at end of this chapter.

Table 4.11. Summary of responses for why SODIS not used (N=30)

Reason for not using SODIS	YES n	YES (%)	NO n	NO (%)	DON'T KNOW n	DON'T KNOW (%)	Total n	Total (%)
Too slow	3	(10)	27	(90)	0	(0)	30	(100)
Bad taste	12	(40	18	(60)	0	(0)	30	(100)
Too much work	18	(60	12	(40)	0	(0)	30	(100)
Too complicated to understand	0	(0)	30	(100)	0	(0)	30	(100)
Don't have access to bottles	0	(0)	30	(100)	0	(0)	30	(100)
Don't believe it is necessary	5	(17)	23	(77)	2	(7)	30	(100)
Don't believe it works	2	(7)	25	(83)	3	(10)	30	(100)
Cost	0	(0)	30	(100)	0	(0)	30	(100)
Forgot	7	(23)	23	(77)	0	(0)	30	(100)
Neighbors stopped using it	0	(0)	30	(100)	0	(0)	30	(100)

Three contacts (9%) felt that using SODIS had led to an improvement in their health, while 28 (85%) felt there was no improvement. Two respondents (6%) did not answer this question. The three contacts mentioned "no diarrhea now," "fewer stomach aches," and "no stomach rumbling or diarrhea" as the improvements in their health.

Six contacts (18%) felt that using SODIS had led to an improvement in their household's health, 25 (76%) did not think there was any improvement, and two (6%) had no answer to this question. Five of the contacts said there were fewer stomach aches, and one contact said "my daughter doesn't get sick when she drinks SODIS water, but she does when she drinks other water."

Thirteen (39%) of the contacts reported that they would get bottles for SODIS on their own, while 14 (42%) said they would not get bottles on their own. Six respondents (19%) did not answer this question. Table 4.12. below shows the responses when the contacts were asked where they could get more PET plastic bottles for SODIS.

Table 4.12. Where contacts would get additional bottles for SODIS (N=33)

Source of bottles	Number of contacts n	(%)
Don't know	14	(42)
Can use empty soda pop bottles	9	(28)
Husband can get from Kathmandu	2	(6)
Can use empty oil bottles	1	(3)
Buy a bottle of water and reuse bottle	1	(3)
From health worker	1	(3)
No answer	5	(15)
Total	33	(100)

Twenty of 33 respondents said it was important to use SODIS, while 11 said it was not important, and two did not know. The contacts were asked a series of questions about the acceptability of SODIS treated water, and the answers are presented below in Table 4.3.1. The responses to the open-ended question about why SODIS is important are presented in the ethnographic section at the end of this chapter, in Table 4.13.

Table 4.13. Responses to criteria for acceptability of SODIS (N=33)

Criteria for acceptability of SODIS	YES		NO		DON'T KNOW		NO RESPONSE		TOTAL	
	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)
All day is too long to wait for water	4	(12)	27	(82)	1	(3)	1	(3)	33	(100)
SODIS gives good tasting water	18	(55)	13	(39)	1	(3)	1	(3)	33	(100)
SODIS is necessary	24	(73)	5	(15)	3	(9)	1	(3)	33	(100)
It is time-consuming to prepare bottles	13	(39)	16	(49)	1	(3)	3	(9)	33	(100)
SODIS is easy	27	(82)	2	(6)	1	(3)	3	(9)	33	(100)
Kills germs in the water	23	(70)	1	(3)	7	(21)	2	(6)	33	(100)
SODIS costs too much money	0	(0)	31	(94)	0	(0)	2	(6)	33	(100)
SODIS adds too much extra work	17	(52)	12	(36)	1	(3)	3	(9)	33	(100)
SODIS is unimportant	5	(15)	24	(73)	2	(6)	2	(6)	33	(100)
It is hard to get new bottles	14	(42)	14	(42)	2	(7)	3	(9)	33	(100)

Twenty-one (64%) of the 33 contacts said they thought they would continue to use SODIS. Nine (27%) said they would not use it in the future, two (6%) did not know, and one contact (3%) did not answer this question.

The final question on the first follow-up survey form was "What would you tell your neighbors or relatives about SODIS?" The answers to this question are incorporated into the qualitative analysis presented at the end of this chapter.

Final Follow-up Health Survey and SODIS Acceptability

Thirty-four treatment households and six control households participated in the final round of data collection in July 2002. This round of data collection came during rice planting season, the busiest time of the year in the fields.

Diarrhea in Study Population

Ten (25%) of the 40 contacts in this round of sampling reported episodes of diarrhea during this round, for a total of 12 household members out of 206 people in the study. Eight households each had one episode, and two households had two episodes. There was no pattern with respect to age or sex of the cases of diarrhea.

Seven (20%) of the contacts felt that water treatment had improved their health in the past month, but 8 (24%) did not think that their health had been improved. One respondent (3%) did not know if there was any change, and 18 (53%) contacts had no response to this question. Those who did not use SODIS had no response to the question.

Five of the seven contacts mentioned "fewer stomach problems" in the past month, one mentioned both cough and stomach problems were fewer while she was drinking SODIS water, and one said her whole body felt better when she drank SODIS water.

Five (15%) contacts also said that using SODIS had led to an improvement in their families' health, all of them mentioning fewer stomach problems. Nine contacts (26%) said there was no difference, one respondent (3%) did not know if there was any change, and 19 (56%) had no response to this question.

SODIS Use and Acceptability

Eleven (32%) of the 34 contacts in the treatment group reported that they had used SODIS regularly in the past month (since the first follow-up in June 2002). Twenty-one (62%) reported that they had not used it regularly, and two (6%) reported intermittent use as the demand for their labor permitted. Thirty contacts reported missing at least one day of using SODIS in the past month. The mean number of days missed was 20, with a standard error of 2 days. The range was 3 days to 30 days, with a mode of 30 days missed.

The 30 contacts who reported skipping treatment were asked a series of questions about reasons for skipping treatment, and the responses are summarized in Table 4.14. An open-ended question about why treatment was skipped is reported at the end of this chapter with the ethnographic data. Important, however, is that the final followup was done during rice planting. Almost all agricultural work is done manually in Nepal, including rice planting. Rice is the staple food of Nepalese, so this work is high priority.

Table 4.14. Reasons for skipping SODIS treatment (N=30)

Reason for not using SODIS	YES		NO		DON'T KNOW		NO ANSWER		TOTAL	
	n	(%)	n	%	n	%	n	(%)	n	(%)
SODIS water is too warm	6	(20)	24	(80)	0	(0)	0	(0)	30	(100)
SODIS water has a bad taste	5	(17)	25	(83)	0	(0)	0	(0)	30	(100)
SODIS is too much work	25	(83)	5	(17)	0	(0)	0	(0)	30	(100)
SODIS is too complicated to understand	0	(0)	30	(100)	0	(0)	0	(0)	30	(100)
I don't believe SODIS is necessary	10	(34)	19	(64)	0	(0)	1	(3)	30	(100)
I don't believe SODIS works	1	(3)	18	(60)	10	(34)	1	(3)	30	(100)
Forgot to do it	1	(3)	29	(97)	0	(0)	0	(0)	30	(100)
Not enough sunshine	5	(17)	25	(83)	0	(0)	0	(0)	30	(100)

Twenty (59%) of the contacts reported they were satisfied with SODIS, five (15%) were not satisfied, and 9 contacts (26%) had no response to this question. The contacts' comments about SODIS are incorporated into the qualitative analysis presented at the end of this chapter.

Water Quality Results

Water samples were tested from 4 different sources. The sources included the Godawari River at the intake for the Siddhipur reservoir that feeds the village taps, the taps used by the households in the study, the wells used by households in the study, and the water containers from each household. For households that had SODIS bottles that had been exposed the day before, this water was also sampled. Some samples had no result for bacterial contamination due to pads drying out during incubation. All missing values were excluded from the analyses.

A summary of the water quality results follows. The means and standard deviations of the parameters measured in the households, from the SODIS containers, and from wells, taps and the river are shown in Table 4.15.

Table 4.15. Means and standard deviations (SD) for all water quality parameters, all drinking water sources

Water Source	Sampling round 1 March 2002	Sampling round 2 June 2002	Sampling round 3 July 2002	Overall
HOUSEHOLD Untreated	Count Mean (SD) Range	Count Mean (SD) Range	Count Mean (SD) Range	Count Mean (SD) Range
pH	n=40 7.8 (0.6) 6.9 to 8.9	n=38 7.8 (0.6) 7.2 to 8.9	n=38 7.8 (0.5) 7.1 to 9.4	N=116 7.8 (0.6) 6.9 to 9.4
Turbidity[1]	n=40 10.1 (15.0) 0.0 to 61.0	n=38 7.3 (6.7) 0.0 to 29.0	n=38 7.3 (8.5) 0.0 to 41.0	N=116 8.2 (10.7) 0.0 to 61.0
Fecal contamination[2]	n=40 67 (77) 0 to 348	n=34 262 (272) 0 to TNTC[4]	n=37 112 (136) 0 to 608	N=111 140 (193) 0 to TNTC[4]
SODIS treated				
pH	-	n=5 8.0 (2.5) 7.5 to 8.8	n=8 8.4 (0.5) 7.5 to 8.8	N=13 8.2 (0.5) 7.5 to 8.8
Turbidity[1]	-	n=5 1.4 (1.7) 0.0 to 4.0	n=8 3.3 (4.0) 0.0 to 11.0	N=13 2.5 (3.4) 0.0 to 11.0
Fecal contamination[2]	-	n=5 0 (0) 0	n=7 24 (63) 0 to 168	N=12 14 (48) 0 to 168
Wells				
pH	n=8 7.2 (0.1) 7.1 to 7.5	n=8 7.2 (0.1) 7.1 to 7.5	n=8 7.3 (0.2) 6.9 to 7.5	N=24 7.2 (0.1) 6.9 to 7.5
Turbidity[1]	n=8 30.6 (27.2) 0.0 to 73.0	n=8 17.6 (22.3) 0.0 to 73.0	n=9 13.8 (21.4) 0.0 to 56.0	N=25 20.4 (25.3) 0.0 to 73.0
Fecal contamination[2]	n=8 124 (118) 6 to 380	n=8 401 (308) 8 to TNTC[4]	n=9 357 (191) 47 to 592	N=25 297 (255) 6 to TNTC[4]
Taps	Sampling round 1	Sampling round 2	Sampling round 3	Overall
. pH	n=1 7.7	n=9 8.4 (0.0) 8.4 to 8.5	n=9 8.3 (0.1) 8.1 to 8.6	N=19 8.3 (0.2) 8.1 to 8.6
. Turbidity[1]	n=10 11.4 (5.9) 2 to 19	n=9 16.9 (6.9) 1 to 24	n=9 51.8 (9.4) 36 to 64	N=28 26.1 (19.5) 1 to 64
Fecal contamination[2]	n=10 238 (279) 36 to TNTC[4]	n=9 488 (108) 356 to 660	n=8 598 (172) 232 to 760	N=27 428 (250) 36 to TNTC[4]

Table 4.15. Water Quality results (continued)

River	Sampling round 1	Sampling round 2	Sampling round 3	Overall
. pH	n=1	-	n=2	N=3
	8.9		8.8 (0.0)	8.8 (0.1)
. Turbidity[1]	n=1	-	n=2	N=3
	7.0		36.5	26.7 (23.7)
	7		20 to 53	7 to 53
Fecal	n=1	-	n=2	N=3
contamination[2]	TNTC[4]		TNTC[4]	TNTC[4]

[1] In Formazin Attenuation Units (FAU)
[2] In fecal coliform colony forming units (CFU) of fecal coliform bacteria per 100 ml sample
[3] In degrees Celsius
[4] Too numerous to count (TNTC), replaced with 1000 CFU for analyses, a value slightly larger than the highest count of CFU in the study

Hypothesis Testing

Hypotheses 1, 2 and 3 deal with different parameters of water quality among the four drinking water sources. A summary of results of the statistical analyses is shown below in Table 4.16.

Table 4.16. Summary of results of ANOVA tests for all different water sources and parameters

Water Quality Parameter	Household water storage containers	Wells	Taps	River	F test (degrees of freedom)	P value
pH	7.8	7.2	8.3	8.9	13.45 (5,157)	<0.0001
Turbidity[1,2]	5.6	8.4	20.1	20.8	6.57 (5, 168)	0.00001
Fecal contamination[2,3]	27.9	82.8	169.1	607.1[4]	14.98 (5, 161)	<0.0001

[1] In Formazin Attenuation Units (FAU)
[2] Data transformed using natural logarithm
[3] In fecal coliform colony forming units (CFU) of fecal coliform bacteria per 100 ml sample

Hypothesis 1

$H1_0$: There is no significant difference in pH of untreated drinking water among the four different water sources (river, taps, wells, and households), controlling for sampling round.

The data and residuals were examined and met the assumptions for normality and equal variances. A two-way analysis of variance (ANOVA) compared the mean differences in pH in untreated water samples from the Godawari River, taps, wells, and from household gagris, or storage containers, controlling for sampling round. Missing values were excluded from the analysis. An alpha of 0.05 was used in this analysis.

The test was found to be statistically significant, $F(5,157) = 13.45$, $p<0.0001$, so the null hypothesis of no difference is rejected, and the alternative hypothesis, that there is a difference in the mean pHs among the four sources, is accepted. There was no significant effect from sampling round. The adjusted means and standard errors are presented in Table 4.17.

Table 4.17. pH means and standard errors for all water sources

Water source	N	Mean pH	Std Error (SE)
Well	24	7.25	0.11
Household	117	7.81	0.07
Taps	19	8.34	0.12
River	3	8.85	0.29

A Tukey Honest Significant Difference (HSD) multiple comparison test was used post-hoc to determine which means were different among the four sources. The results are shown below in Table 4.18. The mean pH from the wells (7.25, SE 0.11) was significantly different than households, (7.81, SE 0.07; $p<0.001$), taps (8.34, SE 0.12; $p<0.0001$), and the river (8.85, SE 0.29; $p<0.001$). The mean pH of samples from households is also different than taps ($p<0.001$) and the river ($p<0.001$). The mean pH between taps and rivers was not significantly different.

Table 4.18. Difference in pH between water sources: Tukey HSD

	Wells	Households	Taps
Wells			
Households	P<0.001		
Taps	P<0.001	P<0.001	
River	P<0.001	P<0.001	Not significant

The mean difference in pH between wells and households was 0.56, with a 95% Confidence Interval (CI) of 0.28 and 0.84. Mean differences and confidence intervals for the other pairs of sources are shown below in Table 4.19. The mean difference in pH between taps and the river was not significantly different, but the confidence interval is from –0.27 to 1.31, which is a large difference in pH's, because of the logarithmic scale.

Table 4.19. pH mean difference and 95% confidence intervals between water sources

Water Sources	Lower Limit 95% CI	Mean difference in pH	Upper limit 95% CI
Wells-Households*	0.28	0.56	0.84
Wells-Taps*	0.70	1.09	1.49
Wells-River*	0.84	1.61	2.39
Households-Taps*	0.21	0.53	0.85
Households-River*	0.31	1.05	1.79
Taps-River	-0.27	0.52	1.31

* significant difference at alpha=0.5

Hypothesis 2

$H2_0$: There is no significant difference in turbidity of untreated drinking water, measured in formazin attenuation units (FAU), among untreated drinking water from the four different water sources (river, taps, wells, and households), controlling for sampling round.

Because the turbidity data was positively skewed, a natural log transformation was performed on the turbidity data to ensure that it met the assumptions of normality and homoscedasticity. Then a two-way analysis of variance (ANOVA) compared the mean differences in the natural log of turbidity in water samples from the Godawari River, taps, wells, and from household storage containers, controlling for sampling round. Samples with missing data were excluded from the analysis. An alpha of 0.05 was used in this analysis.

The test was found to be statistically significant, $F(5,168) = 6.568$, $p<0.001$, so the null hypothesis was rejected, and the alternative, that there is a difference somewhere among the four sources, is accepted. The means and standard errors of the different sources are shown below in Table 4.3.7. With log transformed data, the anti-log of the transformed mean is the geometric mean of the data in the original scale. The geometric mean turbidity of households is $e^{1.73}$, or 5.6 FAU. This is an estimate of the median of the data in the original scale. The geometric mean and standard error are also shown in Table 4.20.

Table 4.20. Turbidity means and standard errors (SE) by water source

Water Source	N	Mean (SE) of Natural Logarithm of Turbidity in FAU	Geometric Mean (SE) of Turbidity in FAU*
Household	118	1.73 (0.15)	5.6 (1.2)
Well	24	2.13 (0.25)	8.4 (1.3)
Taps	28	3.00 (0.24)	20.1 (1.3)
River	3	3.03 (0.66)	20.8 (1.9)

* antilog of mean of transformed data

A Tukey HSD multiple comparison test was used post-hoc on the transformed data to determine which groups were different among the four water sources, shown below in Table 4.21. There was no significant effect from sampling round. The mean turbidity of households (1.73 (0.2))is not significantly different from the mean turbidity of wells (2.13 (0.2)), but it does differ significantly from the mean turbidity of taps (3.00 (0.2), $p<0.001$), and of the river (3.03 (0.7), $p=0.048$). The mean turbidity from well samples is significantly different only from taps ($p=0.005$). The mean turbidity from taps differs from both wells and from households, and the mean difference in turbidity from the rivers is significantly different only from household samples.

Table 4.21. Difference in turbidity between water sources: Tukey HSD

	Households	Wells	Taps
Households			
Wells	Not significant		
Taps	P<0.001	P=0.005	
River	P=0.048	Not significant	Not significant

In the natural log scale, the mean difference in turbidity between wells and households is 0.41. With log-transformed data, in the original scale, the best estimate of the ratio of the difference in turbidity is $e^{0.41}$, or 1.5 times as much turbidity in wells compared to households. In the natural log scale, the 95% CI for the population mean difference in turbidity between households and wells is –0.22 to 1.04, so in the original scale the geometric mean of well water is 1.5 times as turbid as water from household storage containers (95% CI: 0.80 to 2.82 times as much). The best estimate of the population mean differences in turbidity, expressed as a ratio between the two sources in the original scale of FAU, and the 95% Confidence Intervals are shown below in Table 4.22.

Table 4.22. Ratios of mean differences and 95% confidence intervals (CI) for Turbidity

Water Sources	Mean Difference in natural log-transformed data	Lower Limit 95% CI	Ratio of Mean Difference in Turbidity in original scale	Upper limit 95% CI
Households-Wells	0.41	0.80	1.50	2.82
Households-Taps*	1.28	1.96	3.59	6.53
Households-River*	1.31	0.69	3.69	19.85
Wells-Taps*	0.87	1.08	2.38	5.24
Wells-River	0.90	0.42	2.46	14.23
Taps-River	0.03	0.18	1.03	5.92

* significant at p=0.05

Hypothesis 3

$H3_0$: There is no significant difference in fecal contamination of untreated drinking water, measured in CFU/100 ml, among the four different water sources (river, taps, wells, and households), controlling for sampling round.

Too numerous to count (TNTC) data points were replaced with 1000 for this analysis. A natural log transformation was performed on the fecal contamination data so that it met the assumptions of normality and equal variance. Then a two-way analysis of variance (ANOVA) compared the mean differences in CFU of fecal coliform in water samples from the Godawari River, taps, wells, and from household storage containers, controlling for sampling round. Missing values were excluded from the analysis. An alpha of 0.05 was used in this analysis.

The test was found to be statistically significant, $F(5,161) = 14.98$, $p<0.001$, indicating a difference in fecal contamination among the four sources, so the null hypothesis was rejected, and the alternative, that there is a difference somewhere among the four sources of water, is accepted. The means and standard errors are shown below in Table 4.23. With log-transformed data, the anti-log of the transformed mean is the geometric mean of the data in the original scale. The geometric mean level of fecal contamination of in household water storage containers is $e^{3.33}$, or 28 CFU/100 ml sample. This is an estimate of the median of the data in the original scale. The geometric mean and standard error are also shown in Table 4.23.

Table 4.23. Fecal contamination means and standard errors (SE) by source

Source	N	Mean (SE) Natural Log CFU/100 ml	Geometric Mean (SE) CFU/100 ml
Household	112	3.33 (0.20)	28 (1.2)
Well	25	4.42 (0.40)	83 (1.4)
Taps	27	5.13 (0.31)	169 (1.4)
River	3	6.41 (0.85)	607 (2.3)

A Tukey HSD multiple comparison test was used post-hoc to determine which groups were different among the four water sources after controlling for sampling round, shown below in Table 4.24. The mean natural log of CFU of the household samples (3.33 (0.2)) is significantly different than all other sources: wells (4.42 (0.4), $p<0.001$), taps (5.13 (0.3), $p<0.001$) and the river (6.41 (0.8), $p<0.001$). Fecal contamination in wells was also significantly different than rivers ($p=0.025$).

Table 4.24. Differences in fecal contamination between water sources: Tukey HSD

	Households	Wells	Taps
Households			
Wells	P<0.001		
Taps	P<0.001	Not significant	
River	P<0.001	P=0.025	Not significant

In the natural log scale, the mean difference in fecal contamination between wells and households is 1.09. With log-transformed data, in the original scale, the best estimate of the ratio of the difference in fecal contamination is $e^{1.09}$, or 2.97 times as much fecal contamination in wells compared to households. In the natural log scale, the 95% CI for the population mean difference in fecal contamination between wells and households is 1.31 to 6.71, so in the original scale the geometric mean of well water is 2.97 times as contaminated as water from household storage containers (95% CI: 1.31 to 6.71 times as much). The best estimate of the population mean differences in fecal contamination, expressed as a ratio between the two sources in the original scale of CFU/100 ml, and the 95% Confidence Interval limits are shown below in Table 4.25.

Table 4.25. Ratio of mean differences and 95% confidence intervals (CI) for fecal contamination

Water Sources	Mean Difference in Log-Transformed Data, CFU/100 ml	Lower Limit 95% CI	Ratio of Mean Difference in Fecal Contamination, CFU/100 ml	Upper Limit 95% CI
Households-Wells*	1.09	1.31	2.97	6.71
Households-Taps*	1.80	2.75	6.06	13.35
Households-River*	3.08	2.49	21.75	190.18
Wells-Taps	0.71	0.73	2.04	5.69
Wells-River*	1.99	0.76	7.33	70.49
Taps-River	1.28	0.38	3.59	34.31

* statistically significant at p=0.05

Hypothesis 4

$H4_0$: The fecal contamination in CFU/100 ml of untreated water from the household storage container will be less than or equal to the fecal contamination of water that has been treated using SODIS.

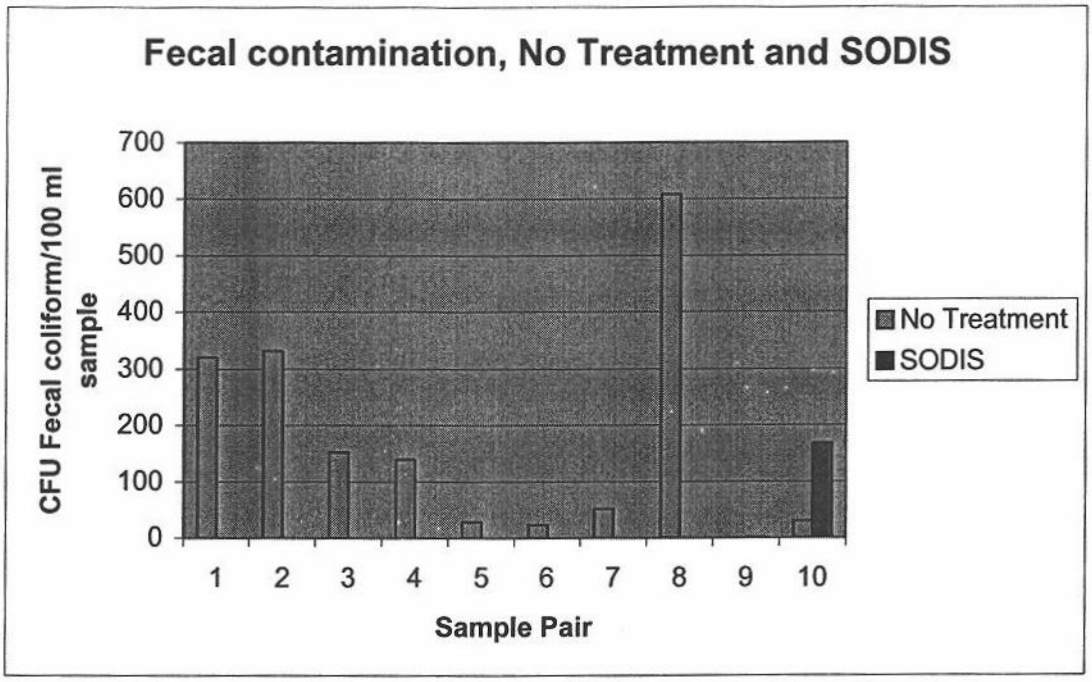
The data for this analysis is shown below in Table 4.4.2. A Shapiro-Wilkes test for normality of the data was significant, indicating that the assumption of normality is violated with this data. The sample size of 10 pairs of data was small so the t-test, normally robust to violations of this assumption, could not be used.

A one-sided paired samples Wilcoxon Signed-Rank test was performed, comparing the average difference in level of contamination (as measured in CFU) in each pair of samples before and after SODIS exposure (μ=152 CFU, SE=68), to a hypothesized mean of 0. An alpha of 0.05 was used in this analysis. The Signed-Rank statistic with 9 degrees of freedom is 21.5, and the probability of getting a larger test statistic is 0.014 so the null hypothesis is rejected. The data supports the alternate hypothesis that there is a reduction in fecal contamination after using SODIS. The reduction in fecal contamination is shown below in Table 4.26 and a graph illustrating the reduction is below in Figure 4.1.

Table 4.26. Fecal contamination of household water before and after SODIS

Sample Pair	Sample Date	Sample ID	CFU/100 ml	Treatment
1	4 June 2002	6-69	320	None
		6-69S	0	SODIS
2	4 June 2002	6-71	332	None
		6-71S	0	SODIS
3	9 June 2002	3-43	152	None
		3-43S	0	SODIS
4	9 June 2002	3-64	140	None
		3-64S	0	SODIS
5	4 July 2002	3-43	29	None
		3-43S	0	SODIS
6	5 July 2002	3-55	23	None
		3-55S	0	SODIS
7	5 July 2002	6-71	52	None
		6-71S	0	SODIS
8	6 July 2002	6-69	608	None
		6-69S	0	SODIS
9	7 July 2002	3-66	0	None
		3-66S	1	SODIS
10	9 July 2002	3-57	30	None
		3-57S	168	SODIS

Figure 4.1. Reduction in fecal contamination after SODIS



Hypothesis 5

$H5_0$: None of the following variables (age of household contact, education level of household contact in years, number of people in the household, and presence of latrine in household) is a significant predictor of water quality as measured by CFU of fecal coliform from the household water storage container, controlling for sampling round.

A log transformation was performed on the fecal contamination data so that it met the assumptions of normality and equal variance. Records with missing data were excluded from the analysis, and an alpha of 0.05 was used. A multiple regression was performed on the transformed data. None of the variables (age of household contact, education of household contact, number of people in the household, or presence of latrine in the household) was a significant predictor of the level of contamination in CFU of fecal coliform in the household water container, after controlling for sampling round. The results of the regression are presented below in Table 4.27. The coefficient for presence of latrine is negative, indicating a reduction in contamination associated with this variable, but the value was not statistically significant. All other variables had positive coefficients, indicating an increase in contamination, but not statistically significant.

Table 4.27. Results of regression analysis on predictors of fecal contamination

	Coefficient value	Standard error	t score (105 df)	Probability
Intercept	2.42	0.94	2.56	
Age of contact	0.02	0.01	1.95	0.05
Years of education of contact	0.07	0.05	1.33	0.19
Number of household members	0.09	0.75	1.24	0.22
Presence of latrine	-0.33	0.33	-1.01	0.31

Hypothesis 6

$H6_0$: The number of reported episodes of diarrhea in control households will be less than or equal to the number of reported episodes of diarrhea in households adopting SODIS to treat their drinking water.

This t-test analysis could not be performed due to the differing rates of adoption of the SODIS technology within the treatment group. Only three households reported using SODIS every day, a sample to small to use for statistical analysis. The range for the remaining households was from almost always to only one day. The frequency of use was collected in the survey, but not the distribution of days, so households that used it once per week for a total of four days could not be distinguished from households that used it for four days and then ceased use of SODIS.

Hypothesis 7

$H7_0$: None of the following variables (age of household contact, education level of household contact in years, number of people in household, presence of latrine in the household, and fecal contamination of water from the household water storage container in CFU/100 ml) is a significant predictor of number of reported episodes of diarrhea in that household, controlling for sampling round.

Due to the distribution of the number of episodes of diarrhea in the sample (0, 1 or 2), a Log-Linear Poisson regression was performed on this data with an alpha of 0.05. Records with missing data were excluded from the analysis. Sampling round was not found to be a significant predictor so it was excluded from the final analysis. Age of contact was the only significant predictor of diarrhea in this model. The results are shown below in Table 4.28.

Table 4.28. Results of Log-Linear Poisson regression on predictors of diarrhea

	Coefficient value	Standard error	t score (69 df)	Probability
Intercept	0.98	2.12	0.46	
Age of contact	-0.11	0.04	-2.47	0.02*
Years of education of contact	-0.19	0.10	-1.90	0.06
Number of household members	0.14	0.17	0.82	0.41
Presence of latrine	-0.71	0.57	-1.25	0.22
Natural log CFU/100 ml	0.47	0.24	1.98	0.05

* significant at alpha=0.05

Qualitative Research

This component of the research was not designed to test hypotheses, but was exploratory in nature, using constructs from the Health Belief Model about perceived risk of diarrheal illness, and perceived barriers and benefits of different water treatment methods to gain an understanding of the context of water treatment in the participants' daily lives. This component of the research included survey questions, semi-structured interviews, and observation. The themes that emerge from the qualitative analysis include lack of awareness of fecal-oral route of diarrheal disease, lack of time, and issues about acceptability of and social constraints to improving sanitation in the village.

Perceived Risk

Perceived risk combines the constructs of perceived susceptibility and perceived severity of the health problem. A person must believe that he or she may get the disease, and that the consequences are negative, in order to perceive a health risk related to the disease, according the Health Belief Model (Becker, Drachman & Kirscht, 1974). The level of perceived risk of diarrheal illness did not seem to be high among the contacts.

Lack of knowledge about the sources of water contamination and the mechanisms of transmission of water-borne disease is a component of perceived susceptibility. The level of education of the contacts was low. During this research period, the researcher interviewed about 20 Nepalese in professional positions in Kathmandu about their drinking water behavior. All of them treat their water while in Kathmandu, and they all cited education as the main reason they began to treat their drinking water, so lack of knowledge could lead to a low perceived susceptibility to water-borne disease in Siddhipur. In this study, diarrhea was seen more as a random, but common occurrence than one traceable to a particular cause. Forty percent of the contacts answered "I don't know" in response to an open-ended question about the causes of diarrhea, and one contact said "If you think eating something will make you sick, then it does, but if you don't think it will, it doesn't." This was also illustrated by a comment "When your stomach hurts it hurts, and when it doesn't hurt it doesn't hurt." Spicy food was the second most common response, with 25% of the contacts giving this response. This may indicate confusion about diarrhea caused by water-borne pathogens versus indigestion. One contact said diarrhea happens "when you eat too much or too spicy food. Some people say water causes diarrhea, but I don't believe it," while another said "Diarrhea comes from indigestion, but I don't know where that comes from." Infants and children who have not been toilet trained often use the floor of the house to defecate or urinate. The mother usually wipes this up with a rag, which is then rinsed or washed out along with other dirty laundry at the tap, where drinking water is also collected.

None of the households had a separate place to wash hands in the kitchen, and few of those observed had any soap visible. Often the same towels that were used for wiping dishes were used for drying hands and faces.

Bad water, along with bad food, was the third most common reason given for diarrhea. Food and water were presented as one category by the contacts giving this response. In Nepal, leftover food is considered ritually unclean, or *bashi,* and this was mentioned by several of the respondents as a cause of diarrhea. In a country where refrigerators are not common, leftovers could well be a cause of diarrheal disease, and a taboo on eating them could be adaptive. No one mentioned fecal contamination of water as a cause of diarrhea, even though the riverbanks are commonly used for defecation. One contact said "I don't know if SODIS really works or not, because I can't see bacteria," and many contacts indicated that their definition of dirty water meant visible turbidity, not any bacteriological parameter. One contact commented that "If you haven't done the proper rituals, it [diarrhea] can happen" but this was an isolated comment and did not seem to be a major belief among the contacts in this study.

The lack of need to treat drinking water came up as a theme in perceived risk. One of the oldest contacts in the study said in a joking way "I got to be this old without treating my drinking water. If I start treating it maybe I will die!" and another contact, after telling her neighbors about SODIS, said one replied "We are fine drinking this water, why go to any more trouble?" Another contact, asked if she believed it was important to use SODIS, said "I don't know if it is really important or not." The summary of the open-ended question about causes of diarrhea is presented below in Table 4.29.

Table 4.29. Causes of diarrhea (N=40)

Cause of diarrhea	Number of contacts who gave this reason	
	n	(%)
Don't know	16	(40.0)
Spicy food	10	(25.0)
Bad water or food (including leftover food)	9	(22.5)
Eating too much	3	(7.5)
Indigestion/gastritis	3	(7.5)
Eating meat	3	(7.5)
Not eating regularly	2	(5.0)
Menses	2	(5.0)
Greasy food	2	(5.0)
Worms	1	(2.5)
Haven't done proper rituals	1	(2.5)
Eating foods you don't like	1	(2.5)

Note: more than one response possible

Contacts in this study mentioned three main health problems with approximately the same frequency; headaches, diarrhea, and cold/cough/fever. Diarrhea was ranked second, after headaches, for the most frequent health problem in the household, indicating a perception of lower susceptibility to diarrhea. The third main group of health problems was cough/cold/fever. The summary of responses to this question are shown below in Table 4.30.

Table 4.30. Summary of responses to most common health problems in household (N=40)

Health Problem	Number of contacts who mentioned this problem	
	n	(%)
Headache	11	(27.5)
Diarrhea and stomach ache	10	(25.0)
Cold/cough/fever	9	(22.5)
No health problems	8	(20.0)
Sore feet	4	(10.0)
Sore back	4	(10.0)
Asthma	2	(5.0)
Gastric	1	(2.5)
Gallstone	1	(2.5)
Don't know	1	(2.5)
Sore legs	1	(2.5)
Toothache	1	(2.5)

Note: more than one response possible

One family began boiling water during the study because the daughter in law became pregnant. This may reflect an awareness that untreated water itself can cause disease, or it may be that pregnancy is treated like a common illness. In Siddhipur, 85% of the contacts reported boiling water for a household member who was ill. This could be a topic for future research.

Perceived Barriers

Both follow-up surveys included an open-ended question asking participants who did not use SODIS why they did not use the technique, indicating perceived barriers. These answers were grouped to summarize the responses, using qualitative research techniques to search for themes (Ely, 1991). Most of them said they were too busy to use SODIS, even though they may think their water is dirty. As one contact said, "The tap water is dirty, so I should do it, but I am too busy now," while another said "Using SODIS takes planning, but it is not a problem unless we are too busy in the fields," and another "Doing SODIS is not as important as working in the fields." A third mentioned transporting the bottles as a related problem "I am too busy in the fields, and can't carry the bottles as well as the hoes for planting." One contact told her neighbors about SODIS, but her neighbors said "We are too busy to do that."

The main theme that emerged from examination of perceived barriers was that water treatment is a small part of the women's concerns, although fetching water is a constant part of their daily life. When asked why they did not use SODIS to treat their drinking water, the most common answer was that they were too busy. Observation of the women revealed that they are responsible for the cooking, dish washing, clothes washing, and childcare as well as the most of the cultivation and processing of agricultural crops. Women do not plough, but they plant, weed and harvest the grain crops, as well as weaving mats for sale in Kathmandu.

Four contacts said they did not have a good place to expose the bottles all day long. Most houses in Siddhipur had an open porch area on the top floor, but some houses had steep roofs with tiles that were not suitable for exposing SODIS bottles and, for participants living in this type of house, finding a good location for SODIS was a problem. One contact said her new roof was too steep, and others said they did not have a secure place to expose the bottles. In the words of one contact, "I am afraid someone will steal my bottles when I put them out in the sun." Three contacts said they did not use SODIS because of the weather, because the training session covered lack of full sunshine as a limitation of the method.

Another barrier is the acceptability of the water after exposure. Several contacts mentioned that the water tasted different, or did not taste good, or was too warm after exposure. One contact said because it gave water a bad taste "I tried it and didn't like the taste of the water after it sat out in the sun" while another told her neighbors that SODIS water is good, but they responded "Cold water is good. SODIS makes the water warm, and it is not tasty then." Another contact mentioned the hard work in the fields and said "In the hot weather we want cold water to drink."

A cultural factor that was mentioned several times was that water that is exposed using SODIS can be perceived as leftover, or *bashi*, and considered impure. Another cultural factor may be Nepal's use of hot and cold to characterize foods and diseases. One contact did not use SODIS because "It is not good to mix drinking water, you get a cold if you do, and when working in fields you have to drink other water, so I haven't used SODIS."

Finally, a barrier is that there are currently no other viable options for drinking water in Siddhipur. "The drinking water is dirty here, but we need to drink something." One contact's mother said it would be easier to add medicine (bleach) to the public wells than to treat it in the household, but other contacts mentioned the unpleasant taste of bleach, indicating a possible problems with bleach as an option for treatment.

Perceived Benefits

Answers to questions about the importance of SODIS revealed some of the perceived benefits ascribed to this method of water treatment. Contacts were asked if they thought using SODIS was important. For those who answered yes (n=20), an open question addressed why they thought it was important. All of the responses were some variation of "for health" or "for fewer stomach problems." The training session for SODIS included an introduction to water-borne disease so the contacts may have learned about the links between water and diarrhea there. Comments by contacts include "I am too busy now, but the water is dirty and we should do it for our stomachs," and "Things we can't see are in the water, so we need to treat it." There was a perception that tap water was dirtier than well water, because the tap water was more turbid than well water following rain. One contact noted "Water from the tap is dirty, but we don't need to treat the water from the well."

Contacts who used SODIS were asked if they noticed a change in their own or their households' health. Five of the seven contacts mentioned "fewer stomach problems" in the past month, one mentioned both cough and stomach problems were fewer while she was drinking SODIS water, and one said her whole body felt better when she drank SODIS water. Five (15%) contacts also said that using SODIS had led to an improvement in their families' health, all of them mentioning fewer stomach problems. Nine contacts (26%) said there was no difference, one respondent (3%) did not know if there was any change.

Cues to action

Cues to action are things that stimulate a person's behavior. Although the original plan was for the researcher to live at the research site, due to security and logistical issues, the researcher lived in Patan, and visited the research site by bicycle for data collection. During the study Kathmandu Valley was often shut down due to general strikes called by the rebels, and the mayor suggested that the researcher should stay at home during the strikes. The presence of the researcher herself would be a cue to action during the period of data collection. Other cues to action might be the sight of the multiple activities at the tap, or the sight of excrement along the trails in the village.

Self-efficacy

Another theme that emerged from the qualitative analysis of water and sanitation is the difficulty in working together for public goods like sanitation. There was a general agreement that it would not be possible to set aside certain taps and wells just for collecting drinking water and others for bathing and dishwashing, although the village was working on covering the open drains in the inner part of the village. Several contacts had made suggestions to improve the sanitation of the village, especially around the taps and wells. One said "I told people not to let their dirty rope go into the well and they yelled at me," and another one commented that "People hold each other back, even when one person knows to change, it is impossible to implement improvements in sanitation." Another comment was "The water is not good. We need to clean but it is hard to get everyone to do it. The neighbor still throws water (gray water, that has been used for washing) out into the public courtyard." The researcher observed the courtyard was used for many activities that might affect the quality of the nearby wells, such as feeding the poultry, washing dishes, and several times defecation of small children. One contact said "We should clean up ourselves but people don't do it. They just clean their own front porch and say things are clean, they have no idea of community cleanliness," and several specifically mentioned the toilets "It is dirty, we need more sanitation and more toilets, and "Clean drinking water is not available for the people of Siddhipur, but our biggest problem is public toilets, they are very dirty."

CHAPTER 5. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to examine water quality, diarrheal illness, and to explore local beliefs about water quality and illness. This chapter provides a discussion of the results, conclusions and recommendations based on the research findings presented in Chapter Four. The characteristics of the study sample are presented first, with respect to other similar studies in Nepal. This is followed by a discussion of the research questions. The chapter ends with conclusions and recommendations.

Characteristics of Study Sample

Education of Contacts

In terms of level of education, this sample seems similar to the national results reported in 2001 (HMG/UNICEF, 2001). That study reported that 18% of adult women in Nepal are literate, while 15% of the women in this study had four years or more of education, indicating some level of basic literacy. However, 72% of the women in this study have never attended school at all. This has implications for any educational program that attempts to raise awareness of water quality and health.

Women's education was first identified as a condition associated with reductions in infant mortality using case studies from India, Sri Lanka, Costa Rica, and China (Halstead, Walsh & Warren (Eds.), 1985). Sandiford and Morales (1991) examined the association between maternal literacy and infant mortality in Nicaragua. They found that the initial decrease in mortality beginning in 1974 was not accompanied by a large increase in literacy, although they speculate that subsequent decreases may have been supported by the large increase in literacy that occurred in the next ten years. In a study in Guinea-Bissau, lack of maternal education was a risk factor identified for diarrheal disease for weaned children, along with unprotected water supply, and eating of cold leftovers (Molbak, Jensen, Ingholt & Aaby, 1997). In Nigeria, handwashing by women after defecating or cleaning a child who had just defecated was associated with a higher level of education (Omotade, Kayode, Adeyemo & Oladepo, 1995), and this hygiene behavior is also related to reduced diarrheal disease (WHO, 2001). Despite the inverse association found between maternal education and child health, there is little research into the mechanism by which education acts to reduce childhood disease (Ehiri & Prowse, 1999).

Primary Source of Drinking Water

In this study, contacts were asked to identify their primary source of drinking water. The characteristics of the study sample differed with respect to the source of drinking water compared to other recent studies (HMG/UNICEF, 2001; HMG/UNICEF, 1997). More households use wells in Siddhipur, 60% compared to 17% of Kathmandu Valley households in HMG's 2001 study and 14% nationwide in the 1996 study (HMG/UNICEF, 1997). Some contacts in the study preferred the taste and temperature of well water, especially during the rainy season when water from the taps is visibly turbid. Alternatively, Siddhipur's population has outgrown the capacity of the tap distribution system, and people have compensated by using wells more often for their drinking water. However, this growth is probably similar to that experienced in the rest of the Kathmandu Valley and so may not account for the difference in source of drinking water. Perhaps the difference in source of drinking water is due to the prevalence of wells in the flat lands like the *Terai*, along the border with India, and in Kathmandu Valley. Wells are rare in the mid-hills and higher elevations.

Latrine Coverage

Strategies for developing safe water systems must include public health education in hygiene and water source protection and appropriate methods for regular water quality monitoring. Kravitz, Nyaphisis, Mandel & Peterson (1999) noted that there are three major elements involved in successful implementation of safe drinking-water and effective sanitation in developing countries: protection of existing water resources, changes in people's behavior in collecting and using water, and expanded use of latrines. Each of these elements calls for public health education, technical expertise, and also development of human resources and infrastructure.

The latrine coverage for Siddhipur, in the Kathmandu Valley, is considerably lower than the HMG's study (HMG/UNICEF, 2001) found for the Kathmandu Valley as a whole. They report 96% of households in Kathmandu Valley have a latrine in the house or immediate vicinity, and the remaining 4% of households have a latrine less than 15 meters away. In Siddhipur, only 37% of households in this study have a latrine within 20 meters. This is more similar to the nationwide statistics reported in the HMG study, where 34% of households had facilities in the immediate vicinity, than it is to the Kathmandu Valley statistic. The HMG study may have focused on the more densely populated urban areas that have better latrine coverage than peri-urban agricultural areas such as Siddhipur in the Valley.

However, latrines have not been found to be an effective method for reducing childhood diarrhea (HMG/UNICEF, 1997) or worms (Rai et al., 1997) in Nepal. The HMG/UNICEF study (1997) found that risk of childhood diarrhea was not reduced by the presence of a latrine in the household. The study attempted to classify latrines according to cleanliness, but the multiple descriptions used by the enumerators made any analysis of this variable impossible. However, the study suggests that the local perception of latrines as unsanitary may contain some truth, and that the unsanitary conditions in some latrines could obscure the positive effects of latrines overall. They did find that a child from a household where the adults used an existing latrine had only half the risk of diarrhea than a child from a household where the adults do not use an existing latrine. They hypothesize that proper use of a latrine is more important than the presence of the latrine itself.

The 2001 study also investigated the association between childhood diarrhea and distance to the nearest latrine. About two-thirds of the households in the national study were farther than 100 steps from the nearest latrine (HMG, 2001). However, they did not find any association between these two factors in their analysis, and this question was not addressed specifically in the current study.

Household Water Treatment

There were higher rates of household water purification methods reported in the government study than were found in Siddhipur (HMG/UNICEF, 2001). Twenty-nine percent of households boil water in the Kathmandu Valley, 35% use a filter and 70% covered the water storage vessel. Observationally, the level of water treatment in Kathmandu is much higher among the educated elite in professional positions than among those who recently arrived in Kathmandu from villages. In Siddhipur, the most common method was to use a piece of fabric to filter the water as it poured into the storage container, a method which was not mentioned in the HMG study, but that has found to be effective in filtering out more than 99% of the bacteria that causes cholera, and in reducing cholera by 48% in Bangladesh (Colwell et al., 2003). It was less common to see well water filtered through fabric as it was poured into the storage container, but well water is less turbid, while tap water was often visibly turbid. Boiling of drinking water was not routinely done in Siddhipur, except for a member of the household who was already ill, which may act like a cue to action. When asked why they do not boil water, contacts reported the unacceptable taste of boiled water rather than economic concerns, although this is not the case in other areas of Nepal where there is no electricity and where firewood is scarce. There was little perception of a need for water treatment, or it was a lower priority than other demands on the contacts' time.

Drinking water concerns

Participants were asked to identify drinking water concerns. The concerns about water are somewhat different than those cited in the nationwide study conducted in 1996 (HMG/UNICEF, 1997). In that study, water quantity was cited most often as the biggest problem with water with 28% of the study reporting this complaint. Water quantity was not reported as a problem in Siddhipur, either from survey responses or observationally, although it is a serious problem in agricultural villages close by, and also in Kathmandu itself, 6 km away. The second most common complaint in the nationwide survey is related to water quantity as well. It was that the water source was too far away with 27% mentioning this problem (HMG/UNICEF, 1997) but again this was not mentioned by any of the respondents in the Siddhipur study. The layout of Siddhipur, a traditional Newari village, ensures that each household is close to a tap or well. This is not always the case with other ethnic groups and in areas with fewer water resources and this may account for the difference.

Nineteen percent of the nationwide study respondents said their water was dirty (HMG/UNICEF, 1997). This was not a specific question in the present study, but in the open-ended question about drinking water and sanitation, six contacts (15%) mentioned that the water was dirty, similar to the earlier study.

Container sanitation

In Siddhipur typically the water containers are washed with a handful of sand and straw gathered from around the base of the tap or well before the containers are filled. The 1997 HMG/UNICEF study noted the wide variety of materials used for washing water containers and dishes, including ash, dirt, straw, rags and only water, with use varying based on availability. They noted that these may also have an effect on water quality, but the lack of consistent use of any of one material makes it difficult to determine its contribution to water contamination, if any. Macy and Quick (2002) noted the potential for contamination of water during the filling and storage in the household.

Research Questions

Water Quality

The study examined untreated water quality from households, wells, taps, and the river for three parameters: pH, turbidity, and level of fecal contamination. There were significant differences among the four sources for all three parameters tested.

pH

The lowest mean pH was found in the wells, followed by household samples, taps, and then the water directly from the Godawari River. Wells, with a mean pH of 7.2 (SE 0.1), were significantly different from all other sources, as were households, with a mean of 7.8 (SE 0.1). Taps (mean 8.3, SE 0.1) and the Godawari river (mean 8.7, SE 0.3) were not significantly different from each other. The mean pH from each sources was under the WHO guideline of 11.0 (WHO, 1993). The mean pH from the river is higher than the 8.5 maximum in the EPA standards (USEPA, 2002), but lower than the maximum limit of 9.5 for the European guidelines (De Zuane, 1997). No one in Siddhipur drinks directly from the river, although the river is the source of the water that is distributed through the system of taps in the village, so there is probably no, or very little, exposure to drinking water with pH levels above 8.5. Lower pH may not be desirable because water is stored in brass water containers, and acidity can cause copper to leach out of the brass container. Copper is regulated under a secondary standard by the EPA as a drinking water contaminant, and high levels may cause adverse health effects including stomach, liver and kidney problems (USEPA, 2002, 2003).

Turbidity

EAWAG/SANDEC recommends that turbidity of less than 30 NTU for effective solar disinfection using SODIS (EAWAG/SANDEC, no date). The overall mean turbidity from all four water sources was less than 30 FAU. However, examining the water sources by sampling round, several means are above 30 FAU. Wells were just over this limit, with a mean of 30.6 FAU (SD 27.2) in the first round of sampling. Means for tap water and the river in the third round were also over 30 FAU. In this round, eight of the nine individual taps sampled were over 30, and the mean for that sampling round was 51.8 FAU (SD 9.4). The mean turbidity in the river for the third sampling round was 36.5 with no variability between the two samples. The regression analysis controlled for effect of sampling round on turbidity, and found that it was not statistically significant. However, the third round of sampling took place in July 2002, about a month after the start of the monsoon rains. The contacts noted that in their village after heavy rain the water from the taps is dirty.

The high levels of turbidity in the taps during the rainy season indicate that perhaps tap water is not appropriate to use for SODIS without first using some method of reducing turbidity during this time. Settling in the household storage container, filtration, or some method of coagulation and flocculation could be used to reduce turbidity. Since the household samples were all under 30 FAU, filling the SODIS bottles from the gagri rather than directly from the tap may be sufficient to lower the turbidity enough to use SODIS. Water with turbidity of 30 FAU is visibly discolored, so it does not take any special equipment to test whether settling is required. Examining the water after filling the SODIS bottles for cloudiness can tell the user right away if the turbidity is too high or if the water should be settled or treated first. Future research might be useful in this area.

Turbidity levels were not significantly different between the means of wells and households, but the 95% Confidence Interval (CI) for the ratio of the difference in means was between 0.8 and 2.82 times as much turbidity in wells compared to households, still a sizeable difference. The 95% CI for the ratio of mean difference between wells and taps was from 1.08 to 5.24, indicating that taps can be quite a bit more turbid than wells.

Fecal contamination

Siddhipur's drinking water from all sources: households, taps, wells and the Godawari river, had levels of fecal coliform in excess of the World Health Organization's recommended guidelines of 0 CFU/100 ml (1998). The mean household contamination was 140 CFU (SD 193), and wells had a mean of 297 CFU/100 ml (SD 255). Taps had a mean of 428 CFU/100 ml (SD 250), and the river, which is the source of the tap water, had a level of contamination that was too numerous to count in a 100 ml undiluted sample, but was higher than 960 CFU/100 ml, the highest number of colonies counted during the water testing. Ideally there should be 0 CFU/100 ml of drinking water, but at levels up to 10 CFU/100 ml there is a low risk of disease according to the WHO Guidelines (1998). From 10-100 CFU water can be classified intermediate risk, and the mean of households falls in the upper part of this range. However, wells, taps and river water all constitute high risk drinking water sources due to the level of contamination above 100 CFU/100 ml. It is rare for people to drink straight from the river even at the point where water is diverted to the reservoir, but people often drink from taps and wells in Siddhipur. Further research is needed on holding water in household storage containers to see if this is a reliable method of reducing contamination without additional treatment.

In contrast to previous research (Rijal, Fujioka & Ziel, 1998; Blum et al., 1990; Pinfold as cited in VanDerslice & Briscoe, 1993) the level of fecal contamination in water from the household containers was lower than from the drinking water sources, either wells or taps, indicating that there is no fresh contamination occurring in the households.

The lower levels in the household may be due to natural die-off of bacteria over time, or due to bacterial properties of the brass containers that 95% of the households use for drinking water storage in the home. Brass is an alloy of copper and zinc, and copper is commonly used as a fungicide due to its phytotoxic properties (USEPA, 2003). Kuhn (1983) found that strips of brass that had been inoculated and incubated disinfected bacteria within 7 hours. In addition, the shape of the traditional water storage containers may prevent in-house contamination because the narrow mouth precludes dipping or scooping water from the container. The United States Centers for Disease Control and Prevention's (USCDC) Safe Water System promotes the use of sodium hypochlorite, the active ingredient in laundry bleach, to disinfect water in a narrow-mouthed container to prevent recontamination in the household (Macy & Quick (2002).

The highest level of contamination (too numerous to count CFU for all three samples) was found in the Godawari River at the source where it is diverted to fill Siddhipur's central reservoir. The reservoir, in turn, feeds the system of taps in the village when the central faucet at the reservoir is turned on for several hours in the morning and evening. There is no protection of the riparian zone along the river, and it is common to see livestock in the river. The riverbank is the location for many human activities, including bathing, washing dishes, clothing and vehicles, and dumping of garbage. In addition, the riverbank is frequently used for human excreta. These activities may contribute to the high level of fecal contamination from the river samples, and source protection could reduce this contamination.

The taps, which are fed from a central reservoir that is filled from pipes directly from the Godawari River, have the next highest level of contamination. The lower levels of fecal contamination in taps versus the river may reflect natural die-off over time. The areas around the village taps, like the riverbank, are not protected, and there are many human and animal activities that could cause contamination around both taps and wells in the village itself.

Wells showed slightly less contamination than the taps. The wells are not covered, and the ground around the wells is not protected from free-range poultry, dogs, and children, all of whom contribute fecal material to the ground nearby. Each user brings her own bucket with a attached rope to bring up the water from the well.

The rope is often dragged on the ground by the well as the bucket is being raised and may also be a source of contamination for the well water. The natural filtering action through the soil may reduce the level of fecal contamination in well water compared to the tap water that is from a surface source (Entry & Farmer, 2001; Robertson & Edberg, 1997).

One specific well was preferred by some households for the quality of the drinking water. Contacts who used this well said its water was clean, and it tasted better than water from other sources. During the first two sampling rounds, the level of contamination was very low (6 CFU/100 ml in March and 8 CFU/100 ml in June), but in July it had a mean of 332 CFU/100 ml. Under 10 CFU is considered low risk, but in July the water jumped up to the high risk category (WHO, 1998). Future research on this well would be useful to identify the source of increase in contamination at the start of the rainy season.

The level of fecal contamination in this study was affected by sampling round, indicating a seasonal difference, as has been found by other researchers in Nepal, but wells and households showed a different pattern of contamination than water from taps. For taps, the fecal contamination increases steadily, from a mean of 238 CFU/100 ml (SD 279) in March, during the dry season, to 488 CFU (SD 108) in June at the start of the rainy season, and up to 598 CFU (SD 172) in July after one month of rain. The wells also had the lowest levels in March, with a mean of 124 CFU (SD 118), but reached their highest mean level in June with 401 CFU (SD 308), and in July the mean was 357 (SD 191). Households had a mean of 67 (SD 77) in March, 262 (SD 272) in

June, and down to 112 (SD 136) in July, the final sampling round, a similar pattern to the wells. Sixty percent of the households in this study got their drinking water from wells, so this pattern may reflect the drinking water source. Samples from the river were contaminated at high levels during all three samples. The results were recorded as Too Numerous To Count (TNTC) for all three samples so there are no actual numbers of CFU to compare for this source by sampling round.

This difference in pattern of fecal contamination may be due to the mechanisms of contamination between taps and wells. The soil may act as a biofilter for the wells, with increased levels of contamination in the wells at the start of the rains increasing as the bacteria respond to the additional nutrients, then decreasing to a new equilibrium. In the other case, contamination along the river banks is a continuous process, so as rainfall increases, the level of contamination in the rivers might increase, leading to the tap water results seen here, since the river is the source for the tap water in Siddhipur.

Wolfe's metaanalysis of previous drinking water quality studies in the Kathmandu Valley (2002) found a pattern of more microbial contamination in the late spring/early summer, which coincides with the start of the rainy season, compared to the dry winter season. Shrestha and Sharma (1995) found a decrease in water quality during the summer rainy season as well as an increase in water-borne disease during the rainy season. Sixty-seven percent of the contacts in this study believed diarrhea was a seasonal problem, and 75% of those said the problem was worse during the monsoon season of July/August.

Jensen et al. (2002) looked at contamination of the water during storage in the household. They concluded that when drinking water has more than 100 CFU of *E. coli* per 100 mls at the source, public domain interventions will be more important in improving water quality than household interventions like preventing contamination of the water storage container. In Siddhipur, the mean level of contamination of water from both wells and taps for all sampling rounds was greater than 100 CFUs of fecal coliform/100 ml, suggesting that public water improvements would have a large impact on water quality.

Effectiveness of SODIS in disinfecting water

SODIS successfully reduced the number of bacteria in water under the household conditions tested in this study. This is in agreement with other research in Nepal by the Environment and Public Health Organization (ENPHO), which reported a mean reduction of 89% in fecal coliform in 33 tests conducted over a period of six months, from January to July 2001, on the roof of their office in Kathmandu (ENPHO, 2002). In 2002, from April to August, Saladin tested contaminated water at various altitudes in Nepal and found that clear SODIS bottles averaged 99.2% removal of fecal coliform (Saladin, 2002a). Both of these studies noted the need for research for a complete year, as did Khayyat (2000), who found that *E. coli* was reduced but not eliminated on days with morning fog, a frequent occurrence in the winter in the Kathmandu Valley. He suggested chlorine as a more effective and comprehensive solution to contaminated water. Pandit (2002) also tested SODIS in the Kathmandu

Valley and found 40% of the samples were completely disinfected and the remaining 60% showed significant reduction, but the time of year of the study is not reported.

In the second round of testing, there was one SODIS sample where the level of contamination increased compared to the control sample from that household (July 9, 2002: Household container 30 CFU, SODIS container 168 CFU). This may be due to inadequate exposure to sunlight due to cloud cover noted in log book on July 8 or it could be caused by contamination of the bottle within the household. This could also be from exposing the bottles in an area where they do not receive full sunlight throughout the day. This raises the important issues of duration of exposure during cloudy weather, proper handling of the bottles to avoid recontamination, and correct placement of SODIS bottles to ensure maximum ultraviolet exposure.

Predictors of fecal contamination in household water storage containers

None of the predictors of fecal contamination of drinking water (age of contact, years of education of contact, number of people in the household, or presence of latrine) was statistically significant in this study. One explanation for this may be that all water is contaminated in Siddhipur at the source (tap or well), and thus, no household variables can account for a greater percentage of variance. If the overall level of fecal contamination is reduced from the source, further research may show that these variables are associated with the reductions seen between the water sources and the household level of contamination.

Effectiveness of SODIS in reducing diarrhea

The research design based the sample size for the health component on an estimated 5 people per household in each of the 36 households in the water quality component of the study, or approximately 180 people. However, this sample size assumed that all of the participating households would adopt SODIS for use every day. In fact, some households used SODIS only for a few days or a week and then stopped, others used it intermittently between surveys as time permitted, and only three households reported using it all the time. The survey data included frequency of use, but no way to record the distribution of the use of SODIS so there was no way to compare rates of diarrhea based on level of use of SODIS. The sample size using only households that adopted SODIS all the time (n=3) was too small to use for statistical analysis.

The reported episodes of diarrhea were fairly evenly distributed throughout the three sampling rounds, with 11, 9, and 12 episodes reported during the baseline, first followup and second followup respectively.

Predictors of diarrhea

Of the five variables tested in this study (age of contact, education of contact, number of members in the household, presence of a latrine, and fecal contamination of household water container), only age of the contact was found to be a significant predictor of diarrhea ($t=-2.47$, $p=0.0159$), indicating that as age increases, diarrhea decreases. Fecal contamination of water sampled from the household water storage container was not statistically significant in this analysis, but it is suggestive of a positive relationship where increase in contamination leads to increased diarrhea in the household (t=1.98, p=0.0514). Likewise, this study did not find education to be a significant predictor but it was suggestive of a negative relationship (t=1.90, p=0.0611), where increased years of education would lead to a decrease in episodes of diarrhea. Maternal education is considered to be an important factor affecting child health. Several studies report that education of the mother remains an important determinant of child survival (PAHO, 1990; Molbak et al., 1997, Omotade et al., 1995). However, the overall level of education of the contacts was very low in this study, with 71% having no education at all and 88% having less than five years of education. This low level of education reduces the power of the study to detect a difference based on level of maternal education. World Bank (2002) notes that the greatest potential to reduce diarrheal disease is handwashing with soap or ash after defecating and before preparing food, followed by safe disposal of feces in latrines, safe weaning food preparation, and safe water handling and storage. Perhaps future studies need to include handwashing behavior as a variable. As Jensen et al. (2002) noted, when the source water is highly contaminated, as it is in Siddhipur, household interventions will not have a big effect on water quality.

Ehiri and Prowse (1999) note that childhood diarrhea has a complex epidemiology, with sanitation, poverty and education confounding results of research in this area. The tendency to include only a few variables in the analysis may cause those variables to receive undue weight. And more important is the lack of understanding of the pathways by which these variables affect health.

SODIS Acceptability

In addition to the technical aspects of testing water quality and the effectiveness of SODIS, this study was designed to explore the social acceptability of SODIS in terms of ease of use, cost, effectiveness, and necessity. The study included survey questions, semi-structured interviews, and observation to identify and clarify useful Health Belief Model (Becker, Drachman & Kirscht, 1974) constructs for future research in drinking water quality. This component of the research was not designed to test hypotheses, but this information can be used to generate testable hypotheses about perceived risk of diarrheal illness, and perceived benefits and barriers of different water treatment methods for future research.

Local Understanding of Health and the Health Belief Model (HBM)

Perceived susceptibility and severity of diarrheal illness

Sixty-seven percent of the contacts said they considered diarrhea to be a problem in their household, but open-ended interviewing indicated that while susceptibility was a problem, severity was not seen as a problem, so the overall perceived risk of diarrhea is low. In fact, the most common health problem cited by the contacts was headache. Therefore, under the HBM, people will not be motivated to change their behaviors about water treatment, which was found to be the case. Several contacts did mention the graywater sewer as a source of contamination and flies. Education about sources and effects of water contamination, especially for vulnerable populations like children and the elderly, may raise the perceived susceptibility.

Saladin (2001) found that SODIS well received. In spite of low level of awareness of links between water quality and health, the participants were willing to participate in the training and try the technology during the study period. But users are still not convinced about the importance of treating drinking water, so the use of the technology may not be sustained. He points to a need for more education about water quality and health.

Perceived benefits

Many women mentioned the benefit of treating water in some way to reduce stomach problems, but it was not enough to outweigh the perceived barriers of workload and uncertainty about the necessity of treating the water. The most common answer to "What is the most common reason for diarrhea?" was "don't know," indicating a low level of understanding of the causes of diarrhea, including but not limited to drinking water. The second most common answer was "spicy food," indicating that the operational definition of diarrhea also may need to be changed to eliminate stomach upsets and diarrhea that we would classify as indigestion, a cause independent of water quality. "Bad food and water," the third most common answer, in this context includes leftover food (*bashi*), which is regarded as ritually unclean.

Perceived barriers

Previous research by EAWAG/SANDEC (no date) identified several reasons for not adopting SODIS, including "don't trust the method," "takes too long," "unpleasant taste and smell of water," and "no bottles available." In this study, the main barrier was the workload of women, as shown both in their responses to survey questions and observational data. In the first followup, 60% of the contacts said

SODIS was too much work. Forty percent said the water had a bad taste, 17% said they don't think it is necessary, and 23% said they forgot to do it on a daily basis. For the second followup, during rice planting season, the percentage that said it was too much work went up to 83%, and the percentage that said it was not necessary went up to 34%, perhaps reflecting their changing priorities during this critical time when they plant their main subsistence crop. Thirty-four percent said they did not know if SODIS worked or not. Each of these barriers requires a different approach to eliminate. No one mentioned that fetching water was a hardship, so increased access to water is not a high priority for Siddhipur.

Although 42% of the respondents said they did not know where to get empty bottles, procuring bottles did not seem to be an obstacle for this peri-urban village. However, it might be a problem farther from the road where beverages (or empty bottles) must be carried in by mules or porters. For those who wanted to continue using SODIS in Siddhipur, the researcher made arrangements with a large hotel in Kathmandu to save empty water bottles from the restaurant and bar when the village health volunteer telephones to request them. The village health volunteer will then pick up and deliver the bottles to Siddhipur. For the future, more research is required to establish the feasibility of collecting, cleaning, transporting and marketing of empty bottles.

Lack of a good place to expose bottles came up in discussion as a reason for not doing SODIS. In some cases this was because there was no roof access in the household, but in other cases there was concern that the bottles would be stolen if they were put out in a public area. This is a limitation that has not been cited in previous field testing, but appeared as a hurdle for these participants.

The women showed some awareness that dirty water makes you sick, but no understanding of what might contaminate water or how disease is transmitted. "Things we can't see are in the water, so we need to treat it," "I don't know if it is really important or not," "I am too busy now, but the water is dirty and we should do it for our stomachs," and "Water from the tap is dirty, but don't need to treat the water from the well".

Drinking water treatment behaviors should be seen in the context of water quality in Nepal, not just in terms of health and the high rates of diarrheal disease. Deforestation, riparian protection, dumping along riverbanks, and use of the riverbanks as latrines all affect water quality, and treating drinking water is one more task on top of an already heavy workload for women. Drinking water quality is poor in this study village, and the level of awareness concerning routes and causes of water contamination is low.

Local beliefs about causes of illness can generate resistance to western forms of health prevention and health care (Subedi, 1989), underscoring a need to understand local knowledge and beliefs about water quality. Understanding the context of water and water purity in Nepalese villages can assist in identifying appropriate interventions to improve the quality of drinking water and health. The HMG/UNICEF study (1997) reported 39% of respondents believed hot and cold weather were the main cause of diarrhea. Weather was not mentioned as a cause of diarrhea by the contacts in the

Siddhipur study. Excess food, second in the 1997 study with 14% of the respondents, was tied for fourth with 7.5% in Siddhipur, while "don't know", third in 1997 with 13% of respondents, was the most common answer with 40% in Siddhipur. Leftover or dirty food was mentioned as a cause of diarrhea by 12% of respondents in 1997, and 22.5 of the respondents in Siddhipur (HMG/UNICEF, 1997).

As Babb mentioned (cited in Murray, 1994), water is associated with purification in Hindi culture, not with contamination. This intrinsic property of purity in water may mean people are less able to understand it as a source of disease in Nepal. Water that is discolored is considered unclean, but not necessarily a cause of disease in Siddhipur. The acceptability of drinking water is based more on the sensory qualities of smell, taste and color than microbiological analysis (HMG/UNICEF, 1997).

Cues to Action

This study involved a single three-hour training session, and then multiple follow-ups for data collection only. There was no attempt by the researcher to motivate participants between sampling rounds, although the researcher visited the village and recorded observational data during these times. Some of the contacts said sometimes they forgot to fill the SODIS bottles in the morning. Perhaps a motivational component could be included in future research as a cue to action in order to raise adoption rates, concurrently with additional education about water quality, sources and routes of contamination, and other methods of treatment. Some of the contacts also mentioned that they use tap water in the dry season but well water when it rains because the tap water becomes very turbid after a rainfall, or when there is no tap water that day. The weather could be another cue to action to treat water, since the fecal contamination was higher in the final sampling round, during the rainy season.

Conclusions

All three water quality parameters tested (pH, turbidity, and fecal contamination) differed among the four sources sampled (household storage containers, wells, taps, and the Godawari River).

Fecal contamination is the main water quality problem in Siddhipur. The research showed that all untreated water in Siddhipur is contaminated with fecal bacteria in excess of WHO guidelines (1993), which is an indicator of the possible presence of other enteric pathogens.

The level of fecal contamination from household water storage containers was lower than the levels from wells, taps, or the river, indicating that there is no contamination occurring within the household. All but two households used traditional brass containers for storing water in the household. The shape of these containers discourages dipping into the container and may limit in-house contamination of water, and water's exposure to the copper may reduce bacterial contamination of water in the containers.

No variables were statistically significant predictors of fecal contamination of water in the household. At the existing levels of contamination at the water sources, household predictors have less power. There is no riparian protection of the Godawari

River, or around the taps and wells, and many potential sources of fecal contamination, both human and animal. In addition, the level of latrine coverage is low in Siddhipur.

The level of contamination varied significantly by sampling round, with more contamination in the rainy season (June-August) than during the dry season in March. Households and wells had the highest mean level of contamination in June, at the start of the rainy season, but taps and the river reached the highest mean level in July, about a month after the start of the rains.

The study demonstrated that SODIS is effective at disinfecting water under household conditions during the time of year of the study period. It was not possible to test for a reduction in diarrhea after adopting SODIS due to the low rate of adoption. Most women in the study did not adopt SODIS on a routine basis. Some women used SODIS intermittently during the study period, some only when they had time, and some rejected it for aesthetic reasons. The main reason given for not adopting was that they were too busy, although bad taste and temperature of water after exposure, and lack of a good place to expose bottles, also were mentioned frequently. Despite the fact that the technology was not adopted, the experience can inform future efforts to improve water quality and reduce diarrhea in Nepal. Key points from this study include emphasizing the links between water quality and health, educating about the sources of water contamination, and evaluating the perceptions of risks, benefits and barriers to SODIS.

The turbidity of water from taps during the rainy seasons was too high to use SODIS without settling or filtering the water first. However, the turbidity of the water from wells and from the household water storage containers during all three sampling rounds was low enough to use SODIS without any settling or filtering.

Increased age of contacts was a significant predictor of decreased episodes of diarrhea in that household. An increase in the years of education of contact and a decrease in the level of contamination of water in the household storage container were both suggestive of an effect, but not significant in this study.

The level of education of the contacts was low in this study. Over 70% of the women had never attended school so written educational materials will be of limited use with this population.

The study showed both that the awareness of potential health problems from drinking contaminated water is low, and that diarrhea is seen as one of the top three health problems in the village, along with headaches and colds. Water quality was seen as a function of turbidity, with dirty water meaning visible turbidity, not fecal contamination. Several people said they never had problems from drinking untreated water, so there was no need to start now.

Recommendations

There are still many gaps to fill in the understanding of SODIS as an effective household level water treatment before a blanket recommendation can be made. More research is needed to determine the effectiveness of SODIS during the winter when days are shorter and colder. A full year of research by a researcher living in the village would address this issue and also provide additional insight into the knowledge gaps in order to design better educational materials on water and health. Additional research is also needed on turbidity levels during the rainy season, along with simple, inexpensive methods of filtering or settling water.

SODIS has been shown to reduce prevalence in diarrhea in children in other countries. More research, with a larger sample size, is needed to determine the presence and magnitude of the effect of SODIS on health in Nepal. Limiting the sample to children under five would focus the research on the health effects in the most vulnerable population.

In Siddhipur, the entire water distribution system should be examined from the river to the point of consumption to identify specific points of risk of contamination. Public water improvements should be made to decrease fecal contamination in the source water. The river upstream from the intake point for the village should be protected from contamination by human and animal waste, which can be a source of disease. Monitoring is also essential to ensure that conditions that could affect the quality of water and the distribution system have not changed. An integrated water and sanitation program to increase the number of latrines, as well as preventing source contamination of water, along with education and support for behavior change, would take advantage of the interactions between water and sanitation in promoting health.

It would be useful in Siddhipur to explore the possibility of designating certain taps and wells to be used only for collecting drinking water, and other taps and wells for bathing and washing uses to limit the possibilities for cross-contaminating at the water sources. If possible, all wells should be covered and installed with a dedicated bucket and rope that winds onto a winch so the rope does not touch the ground around the well. Another option is to reintroduce a systematic bleaching program for the main reservoir and the public wells carried out by the village development committee. Under this program, training and bleach should also be made available, at cost, for private well owners who wished to disinfect their wells.

One of the objectives of the study was to identify local perceptions of water quality and disease. The level of formal education was low, as was the understanding of sources of contamination of drinking water. More education and awareness about water quality, sanitation and hygiene might increase the ability of women in Siddhipur to prevent contamination of their drinking water sources. Women should be targeted for this training because of their roles as the primary water gatherers, food preparers, and child caregivers. The local custom of boiling water for members of the household who are already ill could be explored for cues to motivating behavior change that could used in other water treatment interventions.

Instead of, or in addition to, more education for the women, a SODIS program in the schools might increase knowledge and awareness of the problems that contaminated drinking water poses for children. SODIS could be integrated into the existing environmental or health courses. While water quality is incorporated into the curricula of primary and secondary schools, non-formal adult education needs to take a different approach to reach the illiterate population that is preparing the food and carrying the water. Perhaps more important, if the children took over filling and exposing the bottles, it would relieve women of this responsibility, which was a major barrier to adoption in this study.

In the future when selecting households for pilot testing, it may be more effective to use clusters of houses rather than single households. This way neighbors can help each other, encourage each other and provide a cue to action.

Given that SODIS was not adopted, and that the most frequent reason given was that women were too busy, it is important to investigate more choices for disinfection of drinking water in future research, such as iodine or chlorine bleach. SODIS was effective in reducing fecal contamination, but other technologies may be more attractive to women who feel their drinking water is dirty but have no other options.

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APPENDICES

Appendix 1. Outline for qualitative research

QUESTIONS FOR INFORMAL INTERVIEWS

Water

- How do you feel about your current water situation?
- Are there any problems with drinking water in this ward?
- In your opinion how can drinking water be made safe and clean?
- For households that already treat their drinking water: What made you decide to start treating your drinking water?
- What do/don't you like about your current water treatment system?
- What would make you change the way you treat your drinking water?

For Followup - Water

- Are there things you particularly like about SODIS (or other treatments)?
- Are there things you do not like about SODIS (or other treatments)?
- Do you think you will continue to treat drinking water using SODIS?
- Have you noticed any difference in household health since using SODIS?

Diarrhoea

- Have you had any problems with diarrhea in your household? When?
- What do you think is the reason for diarrhea?
- How do you think people can avoid getting diarrhea?

Sanitation

- What do you think about latrines?
- Where do you defecate?
- Why do or don't you have own toilet
- Why do or don't you use a latrine?

ILLUSTRATIVE OBSERVATIONAL DATA

General Sanitation around Household

- Any human feces or animal feces inside or outside house?
- General cleanliness of kitchen
- Flies

Use of Toilet

- Where do people defecate?
- Distance to water source
- Distance to handwashing
- Distance to dishwashing area
- General cleanliness of toilet (flies, path, clean, water)
- Who in household uses or doesn't use toilet?

Handwashing

- Is there a place to wash hands? Soap? Towel?
- Does the towel look clean? Is it used for anything else?
- What is used to wash hands?

Getting Water

- Throw away old water before getting new?
- Wash the water vessel? With what?
- Possible sources of human or animal contamination around water source?

Using Water

- How to they take water from storage container?
- Storage container covered?
- Storage vessel looks clean?
- Untreated water used in chutneys?

Diarrheal Illness

- What is done when a household member has diarrhea? (food, drink, who consulted)
- Use of toilet during episodes?

For Followup

- How do people implement SODIS?
- What are the common mistakes in implementing SODIS?

Appendix 2. Voluntary consent form

Namaste! My name is Rochelle Rainey, and I am conducting a study on drinking water quality for my Ph.D. dissertation in Public Health at Oregon State University. I will be studying solar disinfection of drinking water in three villages in this district from now until next August.

> Namaste! Mero nam Rochelle Rainey ho. Ma mero bidyabareedhee ko laagi khane pani ko gooDestar baata sarwasaadaran ko swastyama pardnasaknay prabhab ko barema adhyangarna Oregon State biswabhidyalaya baataa Nepal aieko hu. Ma es gauma sauriya shakti duarah khane pani prusudan garne bisayama aundo sraun samma adhyan garnay chu.

Your household was randomly selected to participate in this research project. Participation includes testing of your water source and storage containers for dissolved oxygen, temperature, turbidity, and an indicator of fecal contamination, and an initial interview of about 45 minutes with questions about your water collection and use, and questions about health and episodes of diarrhea in the household.

> Es anusandan karya ko laagi moilay taipaiiko ghar lie pani chuneko chu. Es adhyanma tapaiharuko khani pani ko shroat, pani raknay bhaDaa haru ma, oxygenko maatra (how much needed), Tapaman, dhamilopan, ra mal mutra batta prudisit bhaye na bhaeko sumundama nirichen garee, paitalis minute samma ko antarbarta garinay chha. Antarbartama sodinay prasna haru tata bisaya pani pani ko sangrahaa tesko priyog, ani swastya ra tes baata Jhadha pakhala bhaeko bhae so sambhandama sodinay cha.

Treatment version:

You will then receive training and all the materials required to perform solar disinfection of your drinking water.

> Tyespatchi tapaiiharulie sauriya prabhidee baata punay pani prasodhan gareenay talim ra eskaryamaa chaheenay anya saaman haru opalubda garaunaychau.

Control version:

I am using your household as a control to see if solar disinfection does clean the water, and if there is less diarrheal disease. At the end of the study next August, you will also receive all of the materials and training that those households received.

> Ma tapaiiharu ko ghar lie sauriya prabhidee baataa punay pani sudha gardaa so prabhidee baata pani sudha huncha ki hundaina ra so pani ko priyog baata jhaDha pokala kom bhako cha ki chaina bhanay bharay priyog garay herna jahanchu. Aundo sraun ma mero yo adhyan samapta (to complete) bhaepachi tapailay tapaiiko ghar lie chaheenay sauriya prabhidee baata punay pani sudha garna chaheenay sabai samaan haru ra awasyak talim paunuhunay cha.

There will be two follow-up visits for water testing and short interviews, once during the dry season and once after the start of the monsoon. These follow up interviews will take about 20 minutes each. I will also visit occasionally throughout the research period to observe, and to talk about this method of water treatment and other water issues you may have.

> Espatchi pheri hami 2 patak pani jaatch garna ra choto antarbaarta lina aunay chau. Yo nirichand 20 minute hunaycha. Es bhaek, mero adhyan ko krum ma ma samaya samayma (time to time) aie punay pani prosodhan ko tarika ra es bisaya sanga sumbhandhit anya koora haru bujna ra boujauna annay chu.

You approve of the taking of photos of water sources, in-house activities related to water, and sanitation facilities in your household, and you understand that your photo may be published with the results of this research.

> Gharbeetrako paaniko sumbundamaa ki tapaiko gharko sharsafaiko sumbundamaa ra tapaiko gharko paaniko shroatko sumbundamaa tapailay kunay photo kinchnubhaema tapai kunay samasya hunay chhaina. Yo anusandhaanko reportma yo photo prakaseet hunchha hola bhanera tapai bujnuhuncha.

Your participation in the research project is totally voluntary. If you decide to participate now, you can still decide to drop out at any time during the study. The source of all data I collect will be kept confidential, and neither your name nor anyone in your household will appear anywhere in the study results.

> Es anusandan karyama tapaiko sahabhagita soitchyalay hunaycha. Tapailay es anusandan ma ahile sahabagita bhayepani tapailay na chaheko belamma

kunipani bella chordnasaknuhunaycha. Ma tapaiiharubaata prapta gareko sumpurna jankari gopya raknay chu satay es ma tapaii tata tapaiko pariwar ko kunaypani sadhasyaharu ko nam es adhayanko kunaypani parinam haru ma ulekkh garnay chaiina.

If successful, the results of this research will be used His Majesty's Government of Nepal and Non-Governmental Organizations to design drinking water programs that reduce diarrhea in the mid-hills of Nepal. I will present a summary of the descriptive information from the study to you before I leave in July, and I will send a copy of the summary of final results to the Mayor's office once they have been approved.

Yedi, mero adhayan saphal bhayama esko priyog Sri5 ko sarkaarma ra gaair sarkari sagstaharulay es probidilie punay paani prosodhan gari jhaDha pakala neyantran gaarna mudhya Nepalko pahaDhi bhegma sanchalan garnay cha. Mero es adhyan sumbhundee bristeet jankaari ko saramsa ma yehaa baata arko sraun ma jannubhanda pahile dinaychu. Ani mero antim parinam sweekrit bhaepachi adekshyasahib marphot pataunay chhu.

If you have any questions about this research, you can call me at 527492 or you can send a message to me at the Mayor's office, and I will come to your house to answer your questions.

Yedi tapaiiharulie mero es adhyan sumbundee kehi koora sodnuparnay bhaema krpipaya malai gabisa ma khobar garnu hola atawa mero dhera 527492 phon garnubhaema ma tapaiiharuko prasna ko uttar dina tapaiiko gharma nai aie pugnaychu.

If you agree to participate in this research project, please sign and date two copies of this paper in the space below. One copy is for you to keep, and the other copy is for my confidential files. Thank you very much for your participation in this research.

Yedi tapaii es anusandhanatmak karyama sahabhagi hunna monjur garnu huncha bhane kripaya es paanaako 2 pruhtima hastacher garidinuhola. 1 pruhti tapaiiko laagi ho ra arko pruhti mero gopya filema rahanaycha. Es anusandhanma sahabhagi hunubhaekoma tapaiilai dherai dherai dhanyabaad.

I consent to participate in the pilot study of solar disinfection of drinking water from March to August 2002 as described above.

Ma tapaiiko es sauriyaa prabhidee baata punay pani prosodhan garnay prabhidee ko adhyanma yo baarsa ko chait dekhi sraun samma sahabhagi huna monjur gardachu.

Name Nam ______________________ Date meetee ______________

Signature hastachhur ______________________

Appendix 3. Laboratory procedures for bacteriological analysis

Lab Procedures for Bacteriological Analysis

1. Put on latex gloves and safety glasses
2. Wipe down lab area with isopropyl alcohol
3. Sterilize filtration unit by flaming with methanol
4. Write sample numbers on petri dishes
5. Open petri dishes on countertop
6. Flame sterilize tops and bottoms of petri dishes with methanol
7. Add one media pad to each petri dish, flame sterilizing tweezers in between each one
8. Add sterile media to pads
9. Close petri dishes, flaming tweezers in spirit lamp between each dish
10. Note time in lab book for sample processing time
11. Open and assemble bottom of filtration unit, touching only external surfaces
12. Flame tweezers in spirit lamp
13. Open sterile 0.7 µm membrane filter and place in filtration unit with tweezers
14. Attach top to filtration unit, touching only external surfaces
15. Remove next whirlpak sample bag from cooler
16. Open whirlpak sample bag and pour 100 ml of sample into filtration unit
17. Attach vacuum pump and suck sample thorugh filter
18. Flame tweezers in spirit lamp
19. Open filtration unit and remove membrane filter with tweezers
20. Open petri dish for that sample and place filter over media-saturated pad.
21. Close petri dish
22. Note any comments in lab book
23. Wipe gloves with isopropyl alcohol
24. Repeat steps 9-18 until all samples have been processed
25. End each day's processing with one blank of boiled water and one spike of known contaminated water
26. Incubate petri dishes 18-24 hour at 44.5C in Del Aqua incubator
27. At end of processing, wash all equipment in hot soapy water, rinse in distilled water and air dry.
28. Wipe down lab area with bleach solution

Laboratory Procedures for Bacteriological Analysis: Results

1. After 18 to 24 hours, remove samples from incubator
2. Open each petri dish and count the number of blue colony-forming units (CFU)
3. Note time, results and any comments in lab book
4. Report results in number of colonies per 100 ml sample water
5. Drop pads, and filters into bleach solution and soak for 30 minutes before discarding
6. Drop petri dishes into pan of water, boil for 10 minutes and allow to air dry before reuse
7. Discard any leftover open tubes of sterile media

Appendix 4. Baseline survey form

Baseline Health and Demographics Survey – Nepal

Household ID #_______________
Interview Date__________
Control? __________

A: Water Source

1 Which sources of water does your household use now on a regular basis? Choose all that apply.

	YES	NO	DON'T KNOW	NO RESP
a Public tap	1	2	9	0
b Public well	1	2	9	0
c Irrigation channel	1	2	9	0
d Describe other	1	2	9	0

2 What is your **PRIMARY** source of **drinking** water?

1	*PUBLIC TAP*
2	PUBLIC WELL
3	*DESCRIBE OTHER*

3 Who collects the water for this household?

	YES	NO	DON'T KNOW	NO RESPONSE
a Contact	1	2	9	0
b Daughter	1	2	9	0
c Sister/Daughter in law	1	2	9	0
d Worker girl	1	2	9	0

e *Other* *Describe other:*	1	2	9	0

4 Approximately how many meters from your home is your primary water source?

_____________METERS

5 How many households rely on this water source on a daily basis?

______ HOUSEHOLDS

Note: in Siddhipur, tap water available twice a day all year round, well water available 24 hours a day but have to bring up with buckets

6. Do you store drinking water in your household?
1 YES
2 NO

7. If yes, what kind of container do you use to store drinking water in?

	YES	NO	DON'T KNOW	NO RESPONSE
a. Brass Gagri	1	2	9	0
b. Ceramic vessel	1	2	9	0
c.Plastic bucket	1	2	9	0
d. Other Describe other	1	2	9	0

8. Do you usually cover your water containers?
1 YES
2 NO

8a If yes, with what?
1 FABRIC
2 DISH
3 BOTH
4 OTHER

9. Do you usually throw away the remaining water from your container before refilling it?
1 YES
2 NO

10. How often do you estimate that you clean your water container?
1 EVERY TIME IT IS FILLED
2 ONCE DAILY
3 OTHER

B. Water treatment

11. Do you currently use any of the following water treatments?

	YES	NO	FOR SICK PERSON ONLY	DON'T KNOW	NO RESPONSE
a. *Fabric filter*	1	2	3	9	0
b. *Chlorine or iodine*	1	2	3	9	0
c *Boil*	1	2	3	9	0
d. Copper or brass gaagro	1	2	3	9	0
e. Ceramic filter	1	2	3	9	0
f. *Let settle for a few hours*	1	2	3	9	0
g. *Cover with cloth or dish*	1	2	3	9	0
h. Describe other	1	2	3	9	0

12. What is the main type of sanitation service your household uses currently?
Note Siddhipur approx 25% toilets, wards 2,5,6,7 don't have public toilets, which are only for women

1. *PRIVATE LATRINE IN HOUSEOR COMPOUND*
2. *PUBLIC TOILET OR LATRINE*
3. *IN THE FIELD OR FOREST*
4. OTHER *DESCRIBE OTHER:*

13. *How many meters away is this facility (subida)?*
______ METERS (0 METERS means IN HOUSEHOLD)

14. *How many households do you estimate use this facility on a daily basis?*
_____ HOUSEHOLDS

C. Health Status

15. *Do you or anyone in your household have stomach problems sometimes?*
1 YES
2 NO

16. Do you consider diarrheal illness to be a problem in your family?
1 YES (and treat for it if necessary)
2 NO

17. *For this study, diarrhea is defined as 3 episodes of loose stools in 24 hours. In the past two weeks, has anyone in your household had diarrhea?*
1 YES
2 NO

if no skip to

18. *Who in the household has problems with diarrhea?*

DIARRHEA	SEX	AGE	RELATIONSHIP TO CONTACT
A	M/F		
B	M/F		
C	M/F		
D	M/F		
E	M/F		
F	M/F		
G	M/F		
H	M/F		
I	M/F		
J	M/F		
K	M/F		
L	M/F		
M	M/F		

19. *Are there times of the year when diarrhea is more of a problem than others?*

1 YES
2 NO

20. What seasons or times of year do you have more diarrhea?

	YES	NO	DON'T KNOW	NO RESPONSE
Sukkha mahinama Dry season	1	2	9	0
Barkhama asar sraun Monsoon	1	2	9	0
Chayt baisakhma *Spring snow melt*	1	2	9	0
Aru bella Describe other:	1	2	9	0

Demographic Information

21. Age of contact in years
____________YEARS

23. Number of years contact has gone to school
____________ YEARS

24. *Please list the sex and age and relationship of the people that regularly eat meals in this house:*

NAME	SEX	AGE (yrs)	REL. TO CONTACT
A	M/F		Contact
B	M/F		
C	M/F		
D	M/F		
E	M/F		
F	M/F		
G	M/F		
H	M/F		
I	M/F		
J	M/F		
K	M/F		

Thank you for your time

Appendix 5. First followup survey form

First Follow-up Health Survey and SODIS Acceptability - Nepal

Household ID #_______________
Interview Date__________
Control? __________

1 *Are you satisfied with SODIS?*
1 YES
2 NO

2. Do you have any comments about using SODIS? (open ended, and probe: social and cultural – used bottles, warm water, not enough bottles, hassle etc)

3. *Diarrhea is defined as 3 episodes of loose stools in 24 hours. Since you began using SODIS (or since the last followup), has anyone in your household had diarrhea?*
1 YES
2 NO
if no skip to 5

4. *Who in the household has had diarrhea? (List by age and relationship)*

	SEX	AGE	REL
A	M/F		
B	M/F		
C	M/F		
D	M/F		

5. *Have you been using SODIS regularly?*
1 YES
2 NO

6. Did you ever miss a day of using SODIS since the training?
1 YES
2 NO

6a. *If yes, how many days do you estimate that you did not use SODIS?*
________DAYS

7. Why did you skip treatment? Open ended

8. *For what reasons do you skip treatment? Circle all that apply*

	YES	NO	DON'T KNOW	NO RESPONSE
a. Too slow	1	2	9	0
b. *Bad taste*	1	2	9	0
c. *Too much work*	1	2	9	0
d. *Too complicated to understand*	1	2	9	0
e. *Don't have access to bottles*	1	2	9	0
f. *Don't believe it is necessary*	1	2	9	0
g.*Don't believe it works*	1	2	9	0
h. *Cost*	1	2	9	0
i. *Forgot*	1	2	9	0
j. *Neighbors stopped*	1	2	9	0
k.*Describe other:*	1	2	9	0

9. Do you feel that water treatment has led to an improvement in your own health?
1 YES
2 NO
If no, skip to 10

9a. Describe the change you noticed in your health after treating water

10. *Do you feel that water treatment has led to an improvement in your household's health?*
1 YES
2 NO
if No skip to 11

10a. Describe the changes you noticed in your household's health

11. Would you get bottles on your own for SODIS?

12.Where would you get more bottles for SODIS?

13.*Is it important to do SODIS?*
1 YES
2 NO
If no, skip to 14:

13a. Why do you think SODIS is important? Open ended

14. *Do you think that SODIS is:*

	YES	NO	DON'T KNOW	NO RESPONSE
a. *Slow*	1	2	9	0
b. *Gives good tasting water*	1	2	9	0
c. *Necessary*	1	2	9	0
d. *Time-consuming*	1	2	9	0
e. Easy	1	2	9	0
f. *Kills keera in the water*	1	2	9	0
g.*Expensive*	1	2	9	0
h. *Adds too much extra work*	1	2	9	0
i. Unimportant	1	2	9	0
j. *Hard to get new bottles*	1	2	9	0
h. *Describe other:*	1	2	9	0

15.*Do you have any questions about SODIS?*
1 YES
2 NO

16. If yes, *what are your questions about SODIS? Open ended and then probe*

17. *Do you think you will continue to use SODIS?*
1 YES
2 NO

18. What would you tell your neighbors or relatives about SODIS?

Thank you very much for your time and assistance.

Appendix 6. Second followup survey form

Final Follow-up Health Survey and SODIS Acceptability - Nepal

Village_Siddhipur, Lalitpur District, Nepal

Household ID #________________

Interview Date____________

Control? ____________

1. Have you been using SODIS regularly for your drinking water?
1 YES
2 NO
3 SOMETIMES – Time, Weather, Remember
9 DON'T KNOW
0 NO RESPONSE

2. Did you ever miss a day of using SODIS in the past month?
1 YES
2 NO
9 DON'T KNOW
0 NO RESPONSE

2a.*If yes, how many days do you estimate that you did not use SODIS?*
________DAYS (n=30)

3. If yes, Why did you skip treatment? Open ended

4. If yes, f*or what reasons do you skip treatment? Circle all that apply*

	YES	NO	DON'T KNOW	NO RESPONSE
a. Water is warm	1	2	9	0
b. *Bad taste*	1	2	9	0
c. *Too much work*	1	2	9	0
d. *Too complicated to understand*	1	2	9	0
e. *Don't believe it is necessary*	1	2	9	0
f. *Don't believe it works*	1	2	9	0
g.*Forgot*	1	2	9	0
h. not enough sunshine	1	2	9	0
i. *Describe other:*	1	2	9	0

5. *Are you satisfied with SODIS?*
1 YES
2 NO
9 DON'T KNOW
0 NO RESPONSE

6. Do you have any comments about using SODIS?

7. *Diarrhea is defined as 3 episodes of loose stools in 24 hours. In last 15 days, has anyone in your household had diarrhea?*
1 YES
2 NO
9 DON'T KNOW
0 NO RESPONSE
if no skip to 5

7a. *Who in the household has had diarrhea? (List by age and relationship)*

	SEX	AGE	REL
A	M/F		
B	M/F		
C	M/F		
D	M/F		

8. Do you feel that water treatment has led to an improvement in your own health?
1 YES
2 NO
9 DON'T KNOW
0 NO RESPONSE

8a. Describe the change you noticed in your health after treating water

9.*Do you feel that water treatment has led to an improvement in your household's health?*
1 YES
2 NO
9 DON'T KNOW
0 NO RESPONSE

9a. Describe the changes you noticed in your household's health

10. *What do you think is your family's biggest health problem?*

11. What do you think is the biggest reason for stomach problems?

12. *Do you have any questions about SODIS?*
1 YES
2 NO
9 DON'T KNOW
0 NO RESPONSE

13. If yes, *what are your questions about SODIS?*

14. Do you have any comments about drinking water and sanitation in Siddhipur?

Thank you for your time!