DRINKING WATER QUALITY AND POINT-OF-USE TREATMENT STUDIES IN NEPAL

Final Group Project
May 5, 2000

Andy Bittner
Tricia Halsey
Amer Khayyat
Kim Luu
Benoit Maag
Junko Sagara
Andrea Wolfe
Advisor: Susan Murcott

INTRODUCTION

This paper describes the MIT Nepal Water Project, conducted over the course of the 1999-2000 academic year in Cambridge, Massachusetts and in the Terai and Foothill regions of Nepal. The objectives of this project were to assess the water quality of selected urban and rural locations in Nepal and to recommend point-of-use (POU) treatment methods to decrease the incidence of waterborne illnesses. Seven Master of Engineering students from Massachusetts Institute of Technology (MIT) and advisor, Susan Murcott, spent three weeks in Nepal in January 2000 collecting and analyzing samples, evaluating water treatment methods, and investigating the water supply system and water culture in Nepal. The water quality team focused on microbial, arsenic, and nitrate and ammonia contamination of drinking water. Coagulation, filtration, and disinfection were studied for adaptation to an affordable POU application appropriate for use in households throughout Nepal, especially in rural areas that will not be served by centralized water treatment systems in the foreseeable future.

Nepal has abundant freshwater resources including springs, rivers, and groundwater supplies, however drinking water quality varies greatly. Only 34% of Nepal's population have access to safe drinking water.[1] Most settlements and households do not have access to piped water. In the urban areas such as the capital, Kathmandu, access to piped water is available to 58% of urban households.[2] Table 1 shows the distribution of households by source of drinking water.

Table 1: Distribution of households by source of drinking water, 1996[2]

Sources of drinking water	Rural	Urban
Piped water	29.1	57.4
Well water	7.0	8.7
Hand pump	33.3	27.3
Spring water	20.8	0.0
River/stream	7.6	3.3
Stone tap	1.6	1.8
Other	1.7	1.5

There are three distinct geographic regions in Nepal: the southern plains, the foothills, and the Himalayas. The plains region, called the Terai, is densely populated and has heavy industrial and agricultural activity. In the Terai, much of the drinking water comes from groundwater wells. The foothills lie between the plains and the mountains. This region is also densely populated and contains the major cities including Kathmandu. Drinking water sources in the foothills include both surface and groundwater. The population of the mountainous Himalayan region is sparse and often migratory. In this region, drinking water comes mostly from surface water sources.

DRINKING WATER QUALITY

INTRODUCTION

Drinking water was studied in the Kathmandu Valley and the Terai region for microbial, arsenic, and nitrate and ammonia contamination. Nearly 200 ground and surface water samples were collected from various source types including municipal systems, traditional sources such as water spouts, hand-dug wells and tube wells.

Microbial Contamination

Microbial contamination studies focused on drinking water in the Kathmandu Valley. In this region, drinking water sources are varied and water quality often changes dramatically between source and consumption. Urban drinking water is collected from surface or groundwater sources and about 60% of Kathmandu's water supply is treated at a municipal water treatment plant before being distributed through a piping network to households and street taps for collection. Many users collect their water from these public taps. At some distribution points, water is collected from the source and then distributed without treatment. In other places, water is collected directly from a source, such as a tube well or spring. The goal of the microbial portion of the overall study was to determine the prevalence and main locations of microbial contamination.

Arsenic Contamination

Arsenic is a highly toxic chemical with wide ranging acute and chronic health effects that depend on the duration and extent of exposure. The World Health Organization (WHO) has set the maximum contaminant level for arsenic at 10 ppb. This portion of the Nepal study was inspired by the current crises in the neighboring countries of Bangladesh and India. The geology and hydrology of Nepal suggest that arsenic may be a problem where tube wells are used as the primary source of drinking water. This part of the overall study sought to determine the extent of arsenic contamination in these regions of Nepal and to make recommendations for future monitoring and testing.

Nitrate and Ammonia Contamination

Environmental nitrates in groundwater have been linked to anthropogenic sources such as septic systems, agricultural fertilizers, and inadequate treatment and disposal of sewage wastes. Nitrates in drinking water can cause methemoglobinemia or “blue-baby” syndrome in infants less than a year of age. The WHO has set a limit of 10 mg/L NO_3^- -N based on the occurrence of “blue-baby” syndrome. The WHO has also set a limit of 1.5 mg/L NH_4^+-N because ammonia generally accompanies human and animal waste and is therefore an indicator of microbial contamination. The goal of this portion of the overall study was to assess potential groundwater contamination due to nitrates and ammonia in drinking water supplies in urban and rural areas of Nepal.

METHODS

Samples taken in the Kathmandu Valley were analyzed for turbidity and microbial contamination. Turbidity was measured using a 2100P Portable HACH Turbidimeter. Microbial samples were analyzed using both HACH Presence/Absence (P/A) tests that indicate total coliform and *E.coli* presence and HACH hydrogen sulfide tests (H_2S). The H_2S test is a color change, Most Probable Number (MPN) test. For each set of tests, a blank was run using either distilled or bottled water to insure that laboratory practices did not contaminate the samples.

EM Quant® test strips, Affiniti Concentration kits, and Graphite Furnace Atomic Absorption Spectroscopy (GFAAS) were used to analyze arsenic concentrations in the drinking water samples. EM Quant® test strips have a detection limit of 100 ppb, well above the WHO standard of 10 ppb. Due to this, Affiniti Concentration kits were also used in conjunction with the EM Quant® kits to achieve a detection limit of 10 ppb. GFAAS has a minimum detection limit of 5 ppb and is a more accurate measure of arsenic concentration than the field kits. A portion of each sample was preserved to 1% acidification and sealed in plastic tubes for transport back to MIT, where they were analyzed on the GFAAS unit at the Ralph M. Parsons Laboratory.

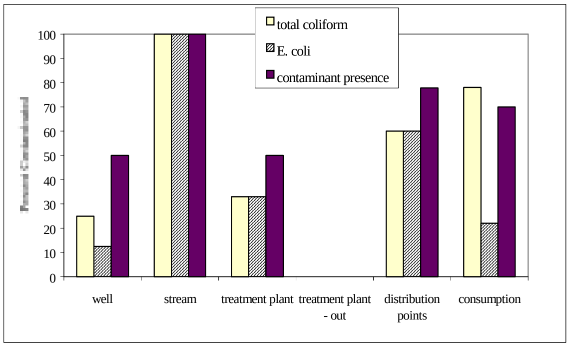
Drinking water samples were tested for nitrates using the Cadmium Reduction Method. Samples were tested for ammonia using the Ammonia Salicylate Method. Analysis was performed using two spectrophotometers: the Spectronics 20 Genesys spectrophotometer loaned to the project by Spectronics Instruments and the HACH DR/2010 spectrophotometer.

RESULTS AND DISCUSSION

Microbial Contamination

Drinking water source types were divided into several categories for analysis. The different source type distinctions included: well and stream sources, influent and effluent treatment plant samples, distribution points, and consumption points. Consumption points include samples taken from drinking water in restaurants and stores. All samples were tested for turbidity, total coliform, and *E.coli* and/or hydrogen sulfide producing bacteria.

Figure 1 shows how the level of microbial contamination varies throughout the Kathmandu Valley water supply system. "Contaminant presence" indicates the detection of any type of contamination in the sample, either total coliform, *E.coli*, or hydrogen sulfide producing bacteria. The numbers of samples analyzed for each of the various points in the water distribution system are shown in Table 2.



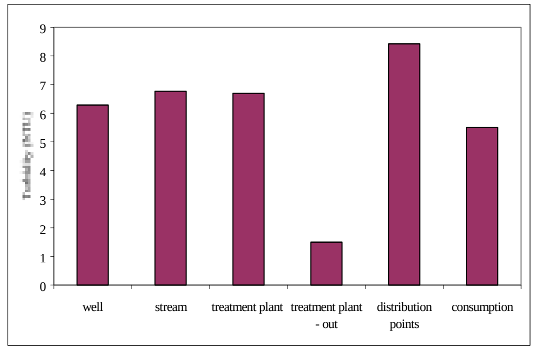


Figure 1 – Microbial contamination and turbidity levels – January 2000

Table 2 – Number of samples analyzed (total = 39)

	Turbidity	Total coliform	*E.coli*	Contaminant presence
Well	8	8	8	8
Stream	4	3	3	4
Treatment plant	4	3	3	4
Treatment plant – out	3	3	3	3
Distribution points	10	5	5	10
Consumption	10	9	9	10

Different microbial contamination levels were found in samples from surface and groundwater sources. Tube wells generally had better water quality than the other sources, although more than 50% show contaminant presence. Samples were collected within the treatment plant system at several different stages of treatment Although raw water flowing into the treatment plants and water at differing stages of treatment was also contaminated 50% of the time, no samples taken at the outflow of the treatment plants had total coliform, *E.coli*, or H_2S producing bacteria contamination. This is largely because all treatment plants were using chlorination as the final step in the treatment process.

Even though the treated water was found to be free of total coliform, *E.coli* and H_2S bacteria, the distribution points were not. This indicates that water becomes contaminated within the distribution system. Almost 80% of the samples taken at distribution points showed microbial contamination. There are few differences between the contamination at the distribution points and the consumption points. This indicates that additional contamination does not occur beyond the distribution points. This is perhaps because people in Kathmandu restaurants and stores that were sampled use some form of simple household treatment such as filtration and/or boiling of water supplies.[3]

The turbidity data show that turbidity levels in the wells, streams, and treatment plants during the three-week January 2000 field study are about the same. Turbidity is low at the treatment plant outlet but increases at the distribution points. This reinforces the theory that contamination occurs within the distribution system. Low turbidity was found at commercial consumption points, perhaps due to household filtration and/or boiling.

One of the main problems with water quality in Kathmandu is that it varies drastically over the course of the year. In the dry season there are often fewer incidences of pollution in the water supply system than in the wet season when microbial contamination increases significantly. Figure 2 shows some of the cyclical variations in total coliform levels in the Kathmandu Valley water distribution system. These data were obtained from two papers written on the microbial contamination problems.[4,5] Data was normalized to provide a better seasonal comparison. The results indicate a pattern of contamination that makes high contamination levels predictable, according to season.

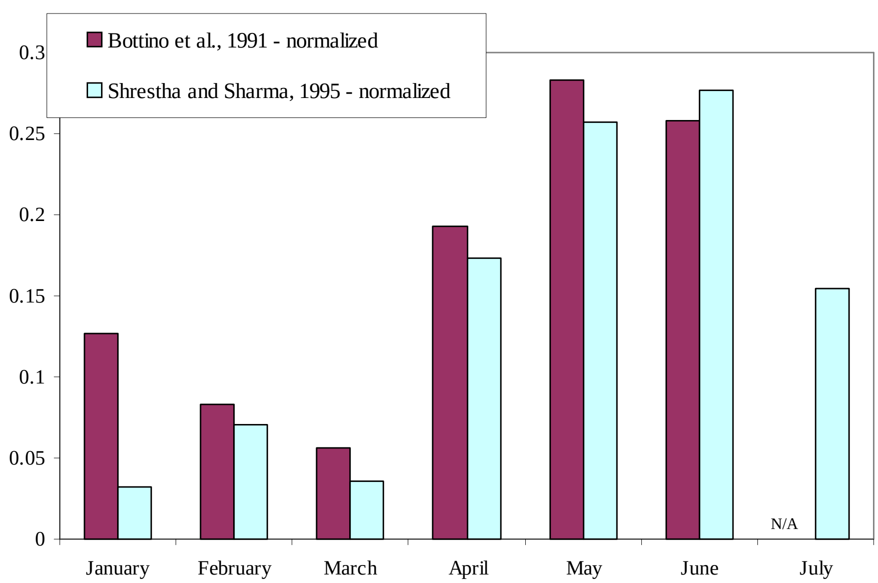


Figure 2 – Seasonal variation of total coliform in the Kathmandu Valley water distribution system

Arsenic Contamination

A total of 172 samples were analyzed for arsenic from various sources in Nepal. The samples were taken from four main locations: the Parsa, Bara, and Lumbini Districts in the Terai region, and from the Kathmandu Valley. Figures 3 to 5 summarize the results obtained in each of these locations based on the three different analytical methods used: two field test methods, EM Quant® Test Strips and Affiniti Concentration Kits, and one laboratory method, GFAAS.

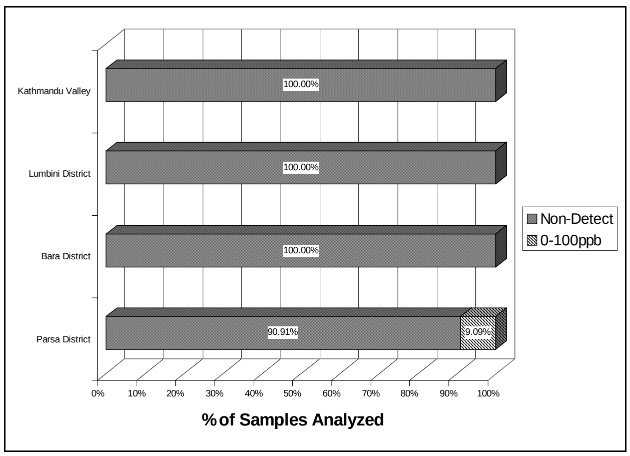


Figure 3: EM Quant® Test Strip Results

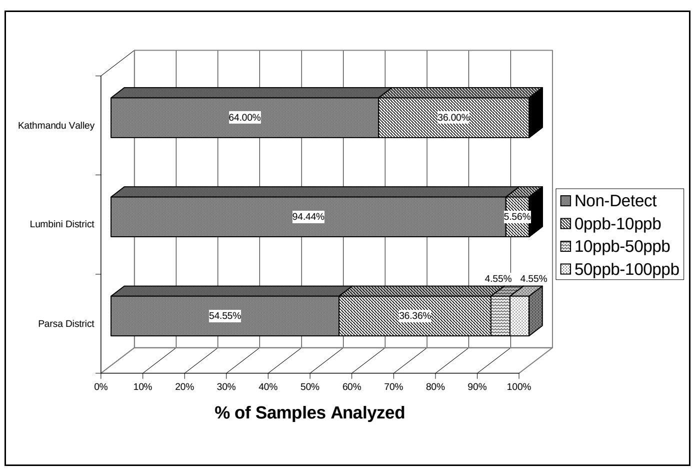


Figure 4: Affiniti Concentration Kit Results

The data in each of the figures show that no arsenic levels above the WHO limit were found in the Kathmandu Valley. Most of the water sources sampled in the Kathmandu Valley were municipally supplied water, hand dug wells, and traditional stone spouts. The figures also show that concentrations above the WHO limit were found in a portion of the samples taken from the Terai region. These samples were from tube wells operated with hand pumps. Results from the GFAAS method, the most accurate of those used, indicate that 18% of the samples analyzed from the Terai region were above the WHO limit.

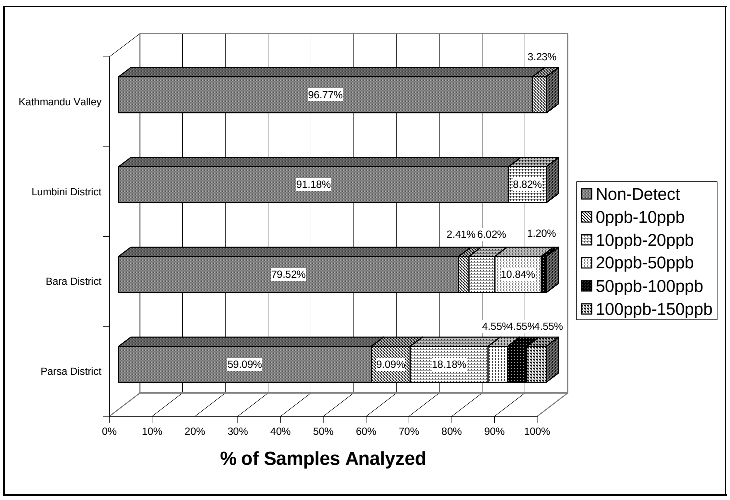


Figure 5: GFAAS Results

Results for the different test methods vary. For instance, 100% of the Bara District samples were non-detect when analyzed with EM Quant® test strips. However, 20% of samples contained detectable levels of arsenic when analyzed with GFAAS. Far greater accuracy is associated with the GFAAS method. Although, based on this data, the accuracy of the test strips is questionable, it provides a general indication of arsenic concentrations in the field. When the test strips are used with the Affiniti Concentration kits, a more sensitive and reliable measurement can be obtained. One conclusion of the arsenic portion of this study is that field kits should be used in conjunction with more accurate laboratory methods if more precise arsenic measurements are required.

Figure 6 shows the depth variation of arsenic contamination. Detectable levels of arsenic were found in wells up to 300 feet deep. These depths correspond with a thick top layer of alluvial deposits in the Terai region similar to the geology of areas with arsenic contamination in Bangladesh and West Bengal. Some of these alluvial deposits are from the same rivers that flow through the contaminated areas in Bangladesh and India. The deposits, therefore, could be from the same arsenic rich source as in these countries. This suggests that the arsenic contamination that was found may be of natural origin.

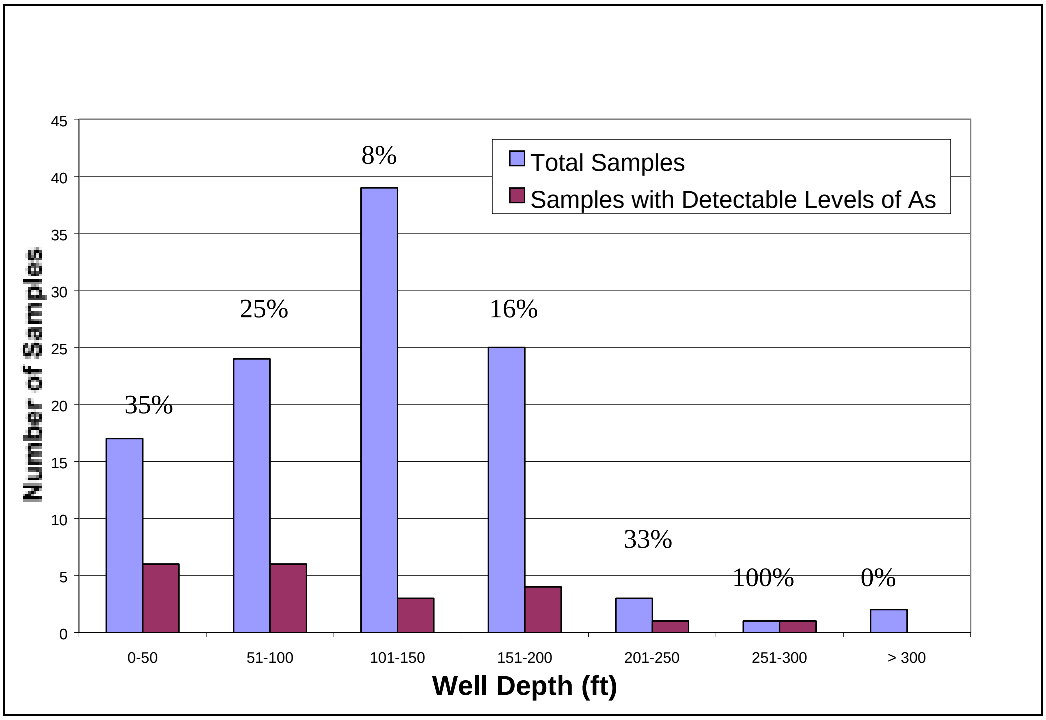


Figure 6: Sample Frequency by Well Depth

Figure 7 depicts well age variation of arsenic contamination. Forty-eight percent of samples taken from wells aged 9 to 12 years contained detectable levels of arsenic. An explanation for this may be that extensive drawdown of the water table associated with long-term operation of a well is causing a change in subsurface chemistry. Consequently, the change in water table height may result in a conversion of immobile species to more mobile arsenic species that leave solid substrates to enter the groundwater.

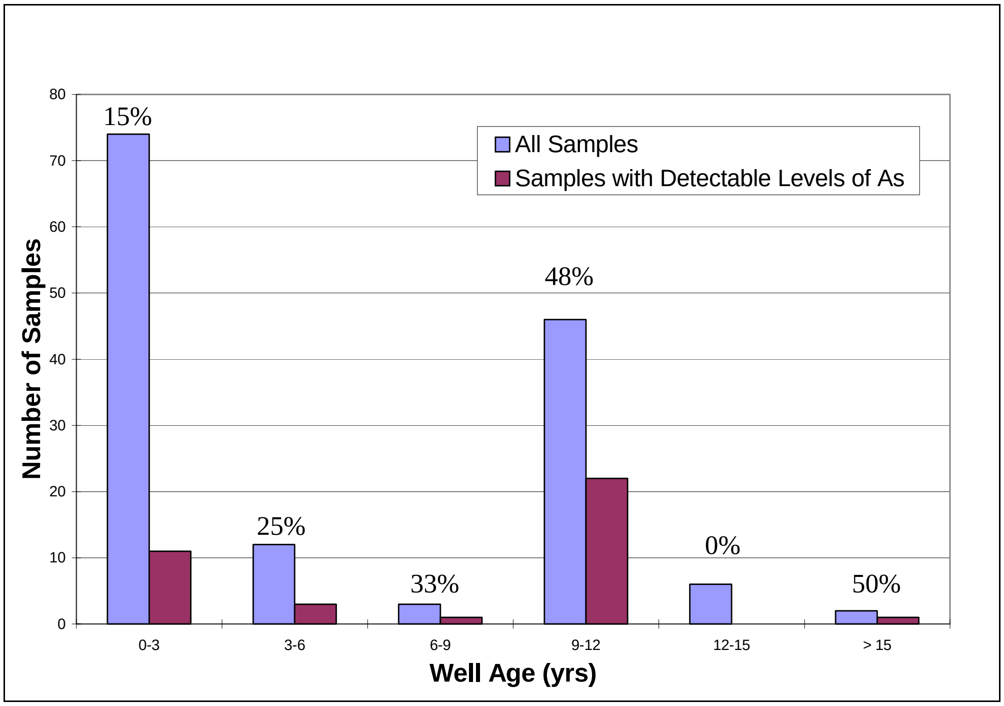


Figure 7: Sample Frequency by Well Age

Preliminary analysis of the data presented in Figures 6 and 7 indicate that arsenic contamination in the Terai is of natural origin. Recommendations to further characterize the Terai region include: further testing, study of the geology, and analysis of potential anthropogenic sources.

Nitrate and Ammonia Contamination

Groundwater samples were collected and analyzed for nitrates and ammonia from a variety of source types including tube wells, deep boring wells, and traditional water spouts. Samples were collected from rural, agricultural, industrial, and urban areas. Figure 8 shows the concentrations of nitrates and ammonia. The average nitrate concentration was 2.37 mg/L NO_3^- -N. Nine percent of all samples were contaminated with nitrate levels above the WHO guideline. The average ammonia concentration was 5.2 mg/L NH_4^+ -N. Twenty-nine percent of all samples were contaminated with ammonia concentrations above the WHO guideline.

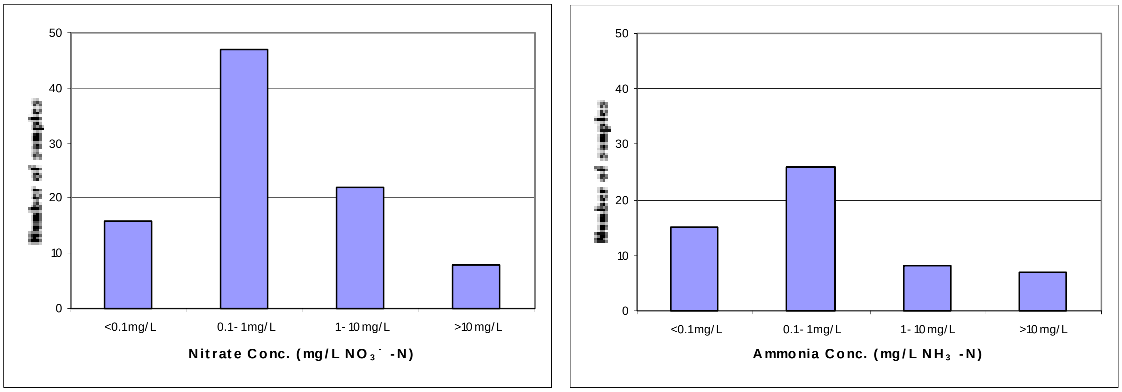


Figure 8: Nitrate and Ammonia Concentrations

Nitrate contamination of groundwater generally occurs in the top meter of an unconfined aquifer. The absence of oxygen in deeper regions causes microbes to denitrify any available nitrates, thus producing nitrogen gas. Nitrate contamination is present in Nepal due to anthropogenic sources at shallow depths. Nineteen percent of samples from wells shallower than 50 feet were contaminated with nitrate levels above the WHO limit. No wells deeper than 100 feet were contaminated with nitrate concentrations above 1 mg/L NO_3^- -N. The depth variation of nitrate concentrations is shown in Figure 9.

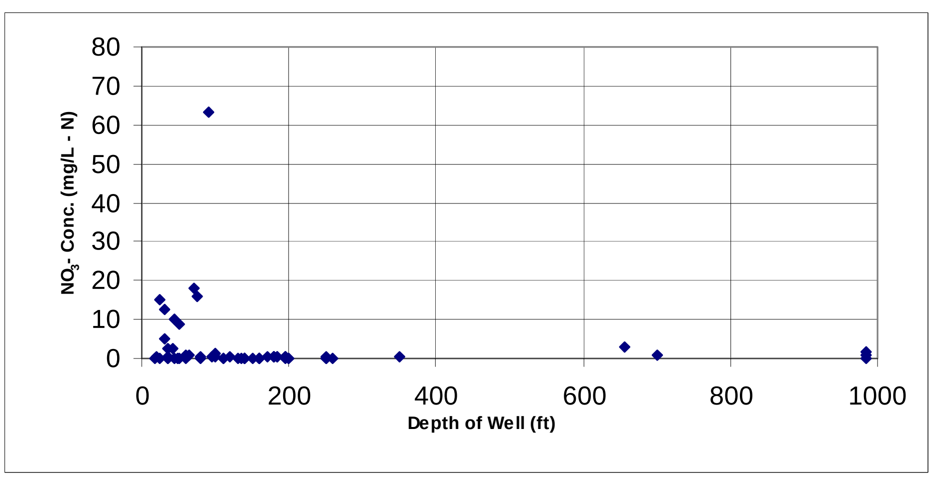


Figure 9: Nitrate Concentration vs. Well Depth

Figure 10 shows ammonia concentration versus depth. Ammonia contamination was minimal in the shallow wells because, in the presence of oxygen, ammonia will nitrify. However, high ammonia concentrations exist in the deep aquifers due to geologic depositions of peat and lignite. There is no oxygen at these depths to nitrify the ammonia. In the Kathmandu Valley, deep boring wells are normally 600 to 900 feet deep. Sampled deep boring wells contained ammonia at an average level of 48 mg/L NH_3-N; this is well above the WHO limit for ammonia. Samples from all other sources had negligible ammonia concentrations.

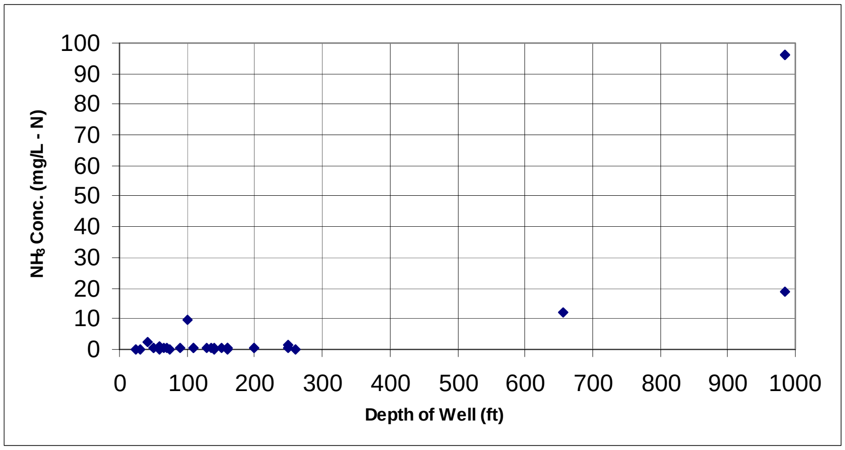


Figure 10: Ammonia Concentration vs. Well Depth

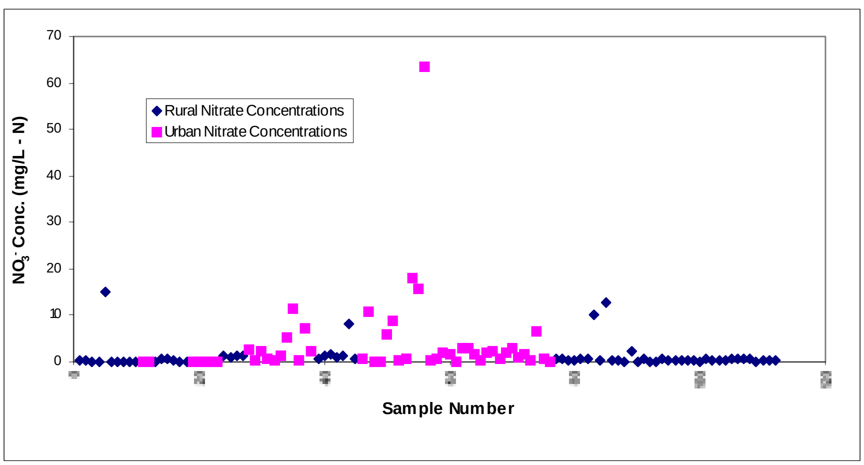


Figure 11: Nitrate Concentrations in Urban vs. Rural Regions

Figure 11 shows nitrate concentrations from groundwater samples in both urban and rural areas. Nitrate contamination in Nepal is much more prevalent in urban areas than in rural agricultural regions. The average urban nitrate concentration was found to be 3.9 mg/L NO_3^- -N. Ten percent of the urban samples contained nitrate concentrations above the

WHO limit. Septic systems, inadequate sewage treatment, and animal waste are common urban anthropogenic sources of nitrates. The main rural anthropogenic source of contamination is from nitrate fertilizers leaching into soil and groundwater. The average rural nitrate concentration was 1.2 mg/L NO_3^- -N. Only 5% of rural samples contained nitrate levels above the WHO guidelines. Low rural nitrate contamination may be due to dry season conditions that cause reduced infiltration and surface runoff. For this study, sampling was only performed during the dry season. Sampling during both the dry and monsoon seasons is recommended to determine if nitrate concentrations in groundwater from rural areas is consistent year-round.

POINT-OF-USE TREATMENT STUDY

INTRODUCTION

One in ten children in Nepal die before the age of five[6], and many of these deaths are caused by water borne diseases. The current state of the economy (Nepal is the seventh poorest country in the world[7]) and infrastructure in Nepal makes attempts to achieve widespread coverage by centralized water treatment systems infeasible and prohibitively expensive. POU household water treatment systems might be an alternative. The main objective of this year-long project was to identify key water quality parameters and then to try to determine an appropriate and affordable POU system within the economic reach of all Nepalese citizens. POU treatment options were analyzed according to the following criteria: viability, cost, and equipment availability.

The three elements of a centralized water treatment process are coagulation, filtration, and disinfection. Each of these processes was reconceptualized and adapted for POU applications. Coagulation and settling is the first step for removing raw water turbidity and color. Filtration takes out particulate matter in addition to reducing microbial contamination. Disinfection is designed to reduce or eliminate pathogens.

Coagulation

Coagulation and settling experiments were performed at the Nepal Water Supply Corporation's central laboratory using a mechanized flocculator donated to the MIT team by the Phipps & Bird Company. Manual coagulation experiments applying optimum alum doses determined by conventional jar test procedures were then tested to determine effectiveness and practicality of this non-mechanized approach practical for rural Nepal. These tests were conducted using materials locally available in rural Nepalese villages. The results of these experiments determined the applicability of manual coagulation with a POU treatment regime.

Filtration

Filtration is a simple and effective method of treating drinking water. Three filter/purifier systems, including one that is currently manufactured in Nepal, one that is manufactured in India and one that is manufactured in Haiti, were studied as possible drinking water filtration options for Nepalese households. The systems were tested for their efficiency at removing turbidity and microbial contamination.

Disinfection

Three disinfection options, chlorination, ultraviolet, and solar, were initially included in this study. Ultraviolet disinfection proved infeasible due to unreliable electric power supply in Nepal. Chlorination also proved impractical because chlorine is not readily available in Nepal. Thus solar disinfection became the primary focus of this study. Solar disinfection is just beginning to garner attention. Research into the field of solar water disinfection was initiated by a group of scientists at the American University of Beirut in the late 1970s[8]. The most extensive field-testing to date has been performed in a number of developing countries by the Swiss Federal Institute for Environmental Science and Technology. Although there has been an independent field trial conducted in the Terai region by Peter Moulton of Global Resources Institute, no previous solar disinfection tests have been performed in the Kathmandu Valley until this study.

METHODS

The water used for each test was bacterially contaminated tap water supplied by Sundarighat treatment plant.[i] The coagulation, filtration, and disinfection studies measured removal efficiencies of turbidity using the 2100P Portable HACH Turbidimeter. Filtration and disinfection studies measured removal efficiencies of microbial contamination using the same methods outlined in the microbial portion of the study described earlier.

Coagulation and settling experiments were performed using two different types of imported Indian alum taken from the Bansbari and Mahankal water treatment plants in Kathmandu. Raw water samples were dosed with a 2% dissolved alum solution. Experiments to determine optimum dose, using both mechanized and manual stirring adapted to imitate mechanized stirring, were conducted under a mixing regime of 30 seconds of rapid mix at 100 rpm, 10 minutes slow mix at 30 rpm, and a settling period of 30 minutes.

Solar disinfection tests were conducted on the south-facing black tarred roof of the Nepal Water Supply Corporation central laboratory. Three locally available bottle types were tested: untinted transparent plastic, blue-tinted transparent plastic, and untinted transparent glass. Solar intensity was logged hourly using a SOLRAD™ CM3/CC20 Solar pyranometer/datalogger loaned to the MIT team by Kipp and Zonen, which is responsive to wavelengths between 350 nm and 1500 nm. Bottle transmissivity tests were conducted at MIT.

---

[i] NOTE: The treatment plant water is contaminated because of poor operation and maintenance and sporadic or nonexistent chlorine disinfection.

RESULTS AND DISCUSSION

Coagulation and Settling

Two locally available types of alum were tested from the Bansbari and Mahankal treatment plants. Of the two local alum products, Bansbari alum yielded the best results. Analyses using raw water samples with Bansbari alum show effective removal results for dosages greater or equal to 35 mg/L. Raw samples were chemically untreated water that has not undergone any type of mixing and settling. Dosages less than this value were ineffective in removing turbidity. Dosages between 35 and 75 mg/L achieved turbidity removal efficiencies between 64% and 81%. The final turbidity values at these doses ranged between 1.89 and 3.49 NTU, well below the WHO guideline of 5 NTU. Doses greater than 75 mg/L did not produce better removal efficiencies.

Analyses using raw water samples with Mahankal alum produced turbidity removal values ranging between 51% to 47% at dosages between 40 mg/L to 50 mg/L. As the alum dosage increases above 40 mg/L, the efficiency of removal decreases. Optimum final turbidity values ranged between 2.2 NTU to 2.5 NTU. Final turbidity and turbidity removal efficiencies are shown in Figures 12 and 13, respectively.

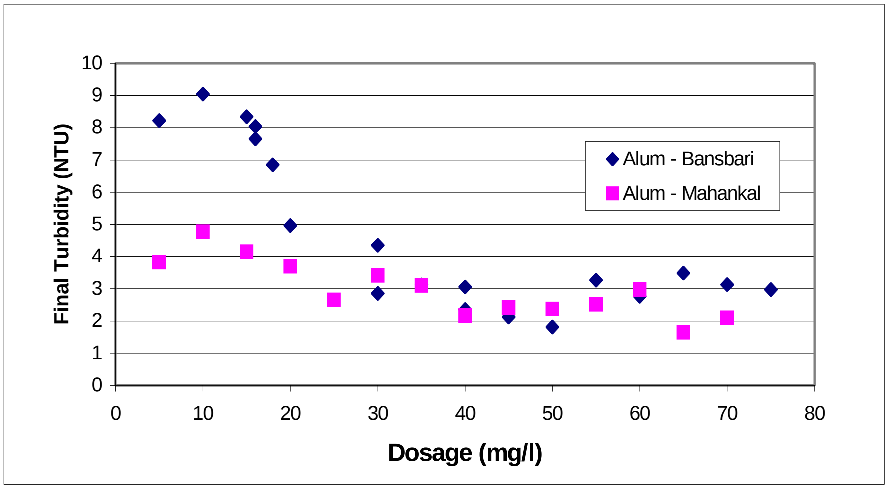


Figure 12: Final Turbidity versus Alum Dosage

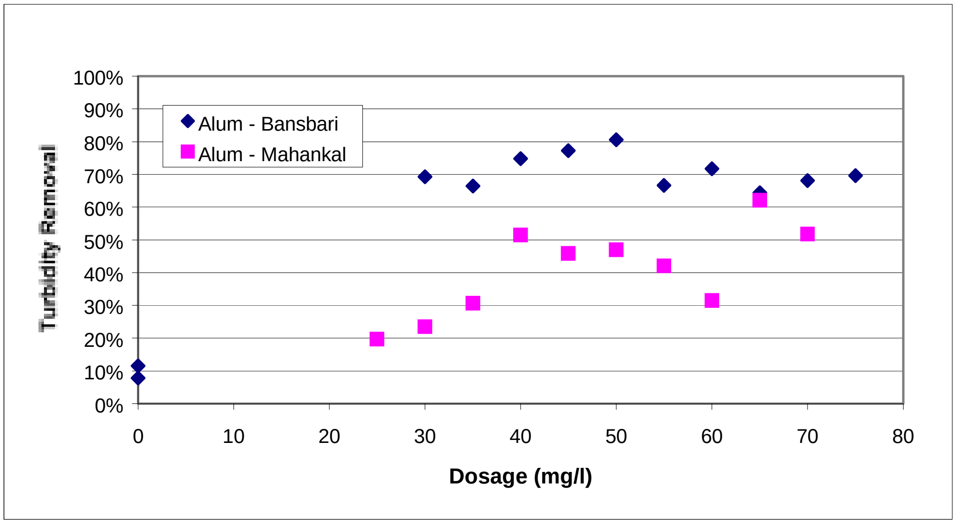


Figure 13: Turbidity Removal Efficiencies versus Alum Dosage

The rate of mixing during the coagulation and flocculation phase of POU treatment is extremely important. Excessive stirring results in an increased susceptibility of floc breakup. Initial experiments in which water was shaken instead of stirred yielded poor flocculation results. To make manual coagulation resemble laboratory jar-stirring, a utensil with a paddle-like tip should be used during mixing to ensure good interparticle contact. The direction of stirring should be consistently and gently changed so that the water is not simply being moved around as one unit volume.

In manual coagulation experiments, after 15 minutes of settling, the size of floc particles was approximately 2 mm. After 30 minutes, floc particles reached a size of 4 mm and a layer of settled floc particles formed on the bottom of the container. Noticeable color reduction was observed (See Figure 14). After a full hour of settling, more floc particles settled out of the system, but some color remained.

Translating recommended dosages into quantities measurable by Nepalese people is crucial to the success of POU coagulation. Solutions and dosages were measured in terms of locally available plastic drinking water bottles. The cap of the bottle can be used for measuring coagulant and the bottle itself can hold dissolved coagulant solution. In order to achieve a 40 mg/L dose, one capful of 2% coagulant solution should be used for every 2 liters of water to be treated. The 2% solution can be made by adding two level capfuls of ground alum to 500 mL of clean water, the equivalent of one small water bottle commonly available in shops in Nepal.

Figure 14: Manual coagulation and settling experiment. (a) raw water; (b) at start of settling time; (c) after 30 minutes of settling.

POU coagulation is a feasible option for pretreatment of Nepalese drinking water. Compared to filters, costs of the drinking water bottles and alum are minimal, therefore it is an economically viable means of effectively reducing, but not eliminating, turbidity and color from raw water. However, informally polled villagers in the Kavre District indicated to our team that manual coagulation was too much work for women all ready overburdened with household and agricultural work and filtration would be the preferred means of particle removal.

Filtration

Three filter/purifier systems were studied as possible drinking water treatment options for Nepalese households. The systems considered were an Indian ceramic candle filter (Figure 15), a Nepalese ceramic candle filter (Figure 16) and a Haitian purifier developed by the U.S. non-governmental organization, Industry for the Poor, Inc.(IPI) (Figure 17).

Figure 15: Indian Ceramic Candle Filter

Figure 16: Nepalese Ceramic Candle Filter

Figure 17: Haitian Purifier

Indian ceramic candle filters are commonly used household filtration systems in Nepal among the middle and upper income levels. The system consists of two stainless steel containers. The top container holds the ceramic candle filter and the untreated water. The bottom container stores and dispenses treated water through a spigot.

The Nepal Ceramic Co-operative manufactures the Nepalese ceramic candle filters. The Nepalese ceramic candle filter is much less expensive than the Indian ceramic candle filter, yet its use is not widespread. Nepalese ceramic candle filters are similar in design to those manufactured in India. Since these filters are handmade in a small workshop, the supply is limited.

The Haitian purifier developed by Industry for the Poor, Inc. consists of two filters, and a string wound sediment filter and an activated carbon filter. The string wound filter removes particulates and microbes and the activated carbon filter removes unwanted chemicals such as chlorine, heavy metals, and pesticides. This unit requires chlorine disinfection prior to filtration because the activated carbon filter is susceptible to bacterial growth within the filter.

Test results show that all three filter systems remove turbidity to levels below the WHO limit of 5 NTU. As shown in Figure 18, the average raw water turbidity level was 12.3 NTU and the average turbidity of treated water was below 1 NTU for each filter.

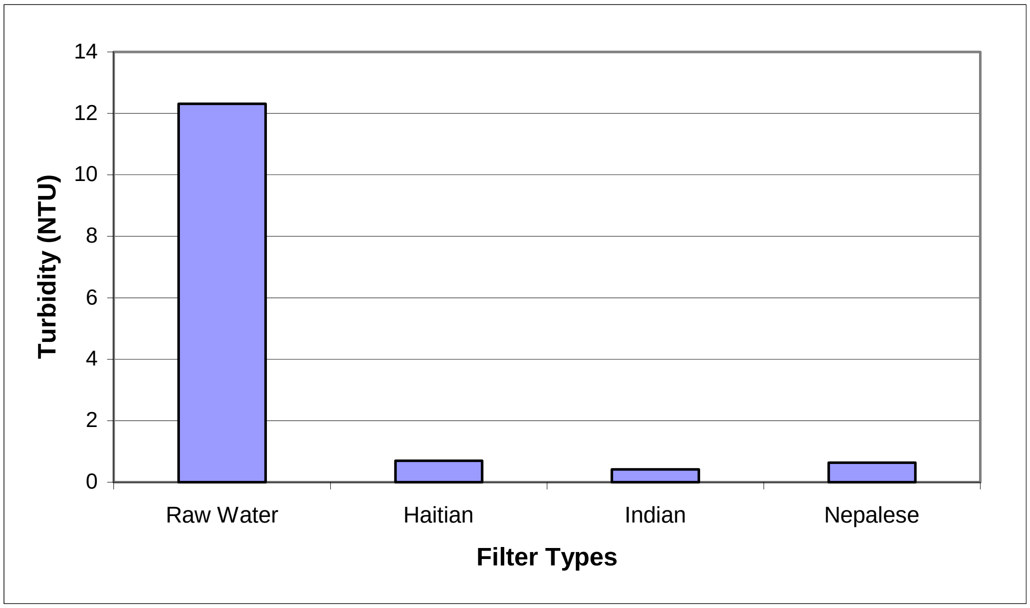


Figure 18: Turbidity Removal of the Filter Systems

P/A test results are summarized in Table 3. These data indicate that neither the Indian nor the Nepalese ceramic candle filters adequately remove total coliform or *E.coli* contamination. The Indian ceramic candle filter removed *E.coli* but not total coliform. The Nepalese ceramic candle filter did not remove all *E.coli* or total coliform. Water treated by the Haitian IPI purifier removed both *E.coli* and total coliform when 20 ppm of chlorine was added as a disinfectant. However, the purifier did not remove *E.coli* or total coliform without the addition of chlorine.

Table 3: P/A Test Results

Filter Type	Total Coliform	*E.coli*
IPI Purifier (with Cl)	-	-
IPI Purifier (without Cl)	+	+
Indian Ceramic Filter	+	-
Nepalese Ceramic Filter	+	+

The IPI purifier with chlorination addition was found to remove hydrogen sulfide producing bacteria to levels less than the lowest detection limit of 1.1 bacteria per 100 ml of water. Between the two ceramic filters, tests indicated that the Indian ceramic filter removed hydrogen sulfide producing bacteria better than the Nepalese ceramic filter. However, neither of the ceramic filters produced water free from total coliform, *E.coli* or H_2S contamination.

In the filtration study, test results indicate that none of the three filtration units were adequate in treating water to an acceptable quality. The Nepalese ceramic candle filter remains the most affordable filter of all the systems tested. Although it does not remove pathogenic organisms, it is an effective method of removing turbidity. Filtration needs to be combined with disinfection in order to produce microbe free drinking water.

Solar Disinfection

Solar disinfection uses infrared heat and ultraviolet radiation (UVR) from solar energy to disinfect water. The simplest application of this technique is the batch model in which small volumes of water (<3L) are exposed to the sun in transparent containers. This technique is highly dependent on the availability and quantity of solar energy and the clarity of the water being treated. This study seeks to determine the applicability of solar disinfection in the Kathmandu Valley.

Bacterial and viral inactivation is possible through both optical and thermal mechanisms. Ultraviolet-A (UV-A) is responsible for optical inactivation of microorganisms.[9] Inactivation causes strand breakage and base changes in DNA. Strand breakage is usually lethal, while base changes block replication and other mutagenic effects.[10] Although there has been no significant correlation observed between mean water temperature and bacterial survival in the range of 5 to 37^{o}C, thermal inactivation remains an important part of the solar disinfection process. There is strong evidence of a synergetic heat effect on solar disinfection when water temperatures are above 45^{o}C.[11] Thermal pasteurization is the primary means of disinfection at temperatures exceeding 65^{o}C.[12] Although it is difficult to heat water to 65^{o}C using batch type solar disinfection, temperatures around 45^{o}C might be possible.

A number of factors effect the intensity and duration of solar radiation on Nepal. These factors include latitude, geographic location, pollution level, time of year, and meteorological conditions. Mean daily solar radiation ranges between 3,800 Wh/m^2/day in January to 6000 Wh/m^2/day in July.[13] The relatively clear skies during the winter months are counterbalanced by fewer hours of available sunlight. Conversely, the cloud cover of the monsoon offsets increased solar radiation associated with longer days in the summer months. At the altitudes in the Kathmandu Valley, the intensity of ultraviolet radiation is significantly greater than at sea level. Air pollution over Kathmandu robs solar radiation of a significant portion of its ultraviolet light. Because of all these factors, it is difficult to conclude from this January 2000 field study whether Nepal will be suitable for year round solar disinfection.

Previous studies conducted in the Terai lowlands region of Nepal (Moulton, 1999) indicate that removal of indicator organisms by solar disinfection in direct sunlight required 4700 Wh/m^2 (5 or 6 hours exposure during the peak sunlight hours). The same study reports that using a blackened rack reduces the requirement to 3000 Wh/m^2, (3 to 4 hours peak sunlight) and a solar reflector reduces it further to 1000 Wh/m^2, (approx. 1 hour peak sunlight). However it is important to note that these studies were conducted in the months of April and May in the Terai region in which the climate and meteorological conditions are considerably different.

In order to maximize disinfection effectiveness, it is essential to minimize solar transmission losses through the water container. These losses depend on the optical properties of the container. The plastic and glass bottles used in this study have transmission ratios shown in Table 4.

Table 4: Transmission Percentages

Bottle Type	Percent Transmittance
Transparent Glass	73%
Transparent Plastic	88%
Blue Transparent Plastic	87%

Solar radiation passing through water is further attenuated by turbidity. The commonly recommended turbidity threshold for water undergoing solar disinfection is 30 NTU. Turbidities above 200 NTU can absorb as much as 99% of the incident radiation within the first centimeter of optical path.[14] Optical inactivation is significantly retarded under these highly turbid conditions. Turbidity in the sample water tested during January 2000 averaged 8 to 12 NTU.

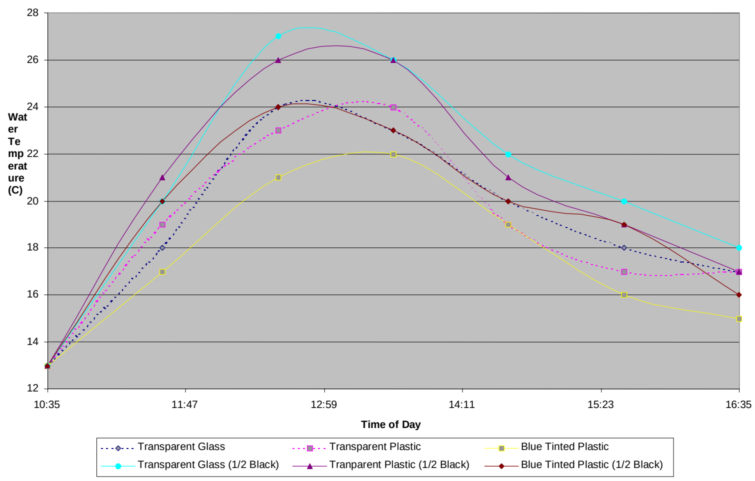


Figure 19: Water Temperature vs. Time of Day

Clear and half-blackened bottles were used to measure the solar heating effect. Figure 19 summarizes the sample temperature at various times during an average January day in Kathmandu. A slight increase in temperature was observed in the half-blackened bottles. However, the temperature did not approach the threshold temperature of 50^{o}C required for thermal inactivation. Thus, disinfection occurred only due to ultraviolet radiation.

The limited data collected precludes a generalization of the results by statistical or analytical methods. Total removal of H_2S producing bacteria was achieved in all trials. Removal of total coliform and *E.coli* varied widely from test to test.

Since initial results are inconclusive, a comprehensive study of annual fluctuations in solar radiation availability in the Kathmandu Valley must be conducted prior to recommending the use of this disinfection method.

CONCLUSION

Water quality studies found that most drinking water supplies in the Kathmandu Valley are microbially contaminated based on tests using the indicator organisms total coliform, *E.coli* and/or H_2S bacteria. Arsenic contamination is not found in the Kathmandu Valley but is above WHO guidelines in 18% of tube wells in the Terai; and nitrates are found mostly in urban shallow tube wells while ammonia is found in Kathmandu Valley's deep boring wells. To treat the widespread microbial contamination of Nepal's drinking water supply a multifaceted POU treatment regime is recommended. Specifically, drinking water should undergo filtration to remove turbidity, followed by an effective disinfection process to inactivate microbes. A two step, point-of-use treatment system, consisting of a Nepalese ceramic candle filter followed by either solar or chlorine disinfection offers a possible alternative drinking water treatment regimen for the Nepalese households. The choice of chlorine or solar disinfection depends on availability of chemical supplies or solar radiation.

ACKNOWLEDGEMENTS

The project was undertaken as part of the Master of Engineering Program in the Massachusetts Institute of Technology's Department of Civil and Environmental Engineering. The group was hosted by the Department of Water Supply and Sewerage, the Nepal Water Supply Corporation, and UNICEF-Nepal. We would like to thank Kipp and Zonen, Phipps and Bird Co. and Spectronics Instruments for donating the equipment that made this study possible. This project was generously sponsored by the John R. Freeman Fund administered through the Boston Society for Civil Engineers Section/ASCE.

REFERENCES

[1] Adhikari A., “Environmental Problems in the Kathmandu Valley," in Urban and Environmental Planning in Nepal. IUCN The World Conservation Union, 1998

[2] UNDP, Nepal Human Development Report 1998. (New York: United Nations Development Program, 1998)

[3] Khayyat, Amer. “Study of Point of Use Water Disinfection Methods for the Treatment of Drinking Water in Nepal.” MIT Master of Engineering Thesis. May 5, 2000.

[4] Bottino, A., A. Thapa, A. Scatolini, B. Ferino, S. Sharma, and T.M. Pradhananga. *Pollution in the Water Supply System of Kathmandu City*. Journal of the Nepal Chemical Society. Kathmandu, Nepal. 1991.

[5] Shrestha RR, Sharma S., Bacteriological Quality of Drinking Water in Kathmandu City: A Review of ENPHO/DISVI Reports, 1988-1992, (Katmandu: Environment and Public Health Organization, 1995)

[6] United Nations Childrens Fund. “Nepal.” Internet. April 27, 2000. Available: www.unicef.org/statis/Country_1Page123.html.

[7] U.S. Agency for International Development. “USAID Assisstance for Nepal.” Internet. April 21, 2000. Available: www.info.usaid.gov/country/ANE/nepal.html.

[8] Acra, A., Jurdi, M., Mu'allem, H., Karahagopian, Y. and Raffoul, Z., Water Disinfection by Solar Radiation: Assessment and Application, (Ottawa, Ontario, Canada: International Development Research Centre, 1990)

[9] McGuigan KG, Joyce TM, Conroy RM, Gillespie JB, Elmore-Meegan M., “Solar disinfection of drinking water contained in transparent plastic bottles: characterizing the bacterial inactivation process,” J Appl Microbiol. 1998 Jun; 84 (6): pp. 1138-48.

[10] McGuigan KG, Joyce TM, Conroy RM., “Solar disinfection: use of sunlight to decontaminate drinking water in developing countries,” J Med Microbiol. 1999 Sep; 48(9): pp. 785-7.

[11] Wegelin, M., Canonica, S., Mechsner, K., Pesaro, F. and Metzler, A., . “Solar Water Disinfection: Scope of the process and analysis of radiation experiments,” J. Water SRT-Aqua, 43, No. 3, 1994, pp. 154-169.

[12] Andreatta D, Yegian DT, Connelly L, and Metcalf RH., “Recent Advances In Devices For The Heat Pasteurization Of Drinking Water In The Developing World” in Proceedings of the 29th Intersociety Energy Conversion Engineering Conference, American Institute of Aeronautics and Astronautics, Inc., 1994.

[13] Mani A, Randgarajan S., Solar Radiation over India, (New Delhi, India: Allied Publishers Private Limited, 1982)

[14] Joyce TM, McGuigan KG, Elmore-Meegan M, Conroy RM "Inactivation of fecal bacteria in drinking water by solar heating." Appl Environ Microbiol. 1996 Feb;62(2):399-402.