MICROBIAL CONTAMINATION IN THE KATHMANDU VALLEY DRINKING WATER SUPPLY AND BAGMATI RIVER

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ABSTRACT

The purpose of this investigation was to determine and describe the microbial drinking water quality problems in the Kathmandu Valley. Microbial testing for total coliform, *E.coli*, and H_2S producing bacteria was performed in January 2000 on drinking water sources, treatment plants, distribution points, and consumption points. Existing studies of the water quality problems in Kathmandu were also analyzed and comparisons of both data sets characterized seasonal, treatment plant, and city sector variations in the drinking water quality. Results showed that 50% of well sources were microbially contaminated and surface water sources were contaminated in 100% of samples. No samples from three of the Kathmandu City's drinking water treatment plant outflows (Mahamkal, Balaju, and Maharajganj) were microbially contaminated; however almost 80% of samples collected at distribution points had microbial contamination and 60% were contaminated with *E.coli*. Drinking water quality varied little throughout the city but had significant seasonal variation.

Microbial contamination in the Bagmati River was also studied and extremely high levels of microbial pollution were found. Pollution concentrations in the river are increasing over time as the population of the Valley grows rapidly. Wastewater treatment is virtually non-existent and most of the wastewater generated in the City flows untreated into the river. This causes increased pollution concentrations as the Bagmati flows downstream from the sparsely populated headwaters through the heavily urbanized Kathmandu City. Despite the high microbial pollution levels, many people use the river for washing, scavenging, and religious purposes. These activities, as well as contaminated drinking water, threaten the health of the population.

Recommendations for drinking and surface water quality improvements can be divided into three areas: regulatory, policy, and technical. Laws and regulations are needed that specify those individuals and agencies who are responsible for water quality and monitoring, set water quality standards, and assign penalties to polluters. Drinking water policy must focus on fully funding programs and educating the public. Technical recommendations include separating drinking water and wastewater pipelines to eliminate leakage between the two and community or household-scale systems for both drinking water and wastewater treatment.

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To

My Parents Pam and Bruce for Teaching Me Everything I Really Know,

My Sister Mimi for her Uniqueness and Sense of Humor,

and My Dearest Tim for his Love and Encouragement

– thank you.

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1 INTRODUCTION

1.1 BACKGROUND

Nepal is a country located south of western China and north of India as shown in Figure 1. There are three distinct geographic regions in Nepal: the plains, the foothills, and the Himalayas. The plains region is called the Terai; it is densely populated and has many industrial and agricultural activities. Much of the drinking water in the Terai comes from wells. The foothills region lies between the plains and the mountains. This region is also densely populated and contains most of Nepal's major cities including the capital Kathmandu and Pokhara. The sources of drinking water from this region include both surface and ground water. The mountainous Himalayan region is sparsely populated and the population is often migratory. Drinking water is usually collected from surface water sources in the Himalayan region.

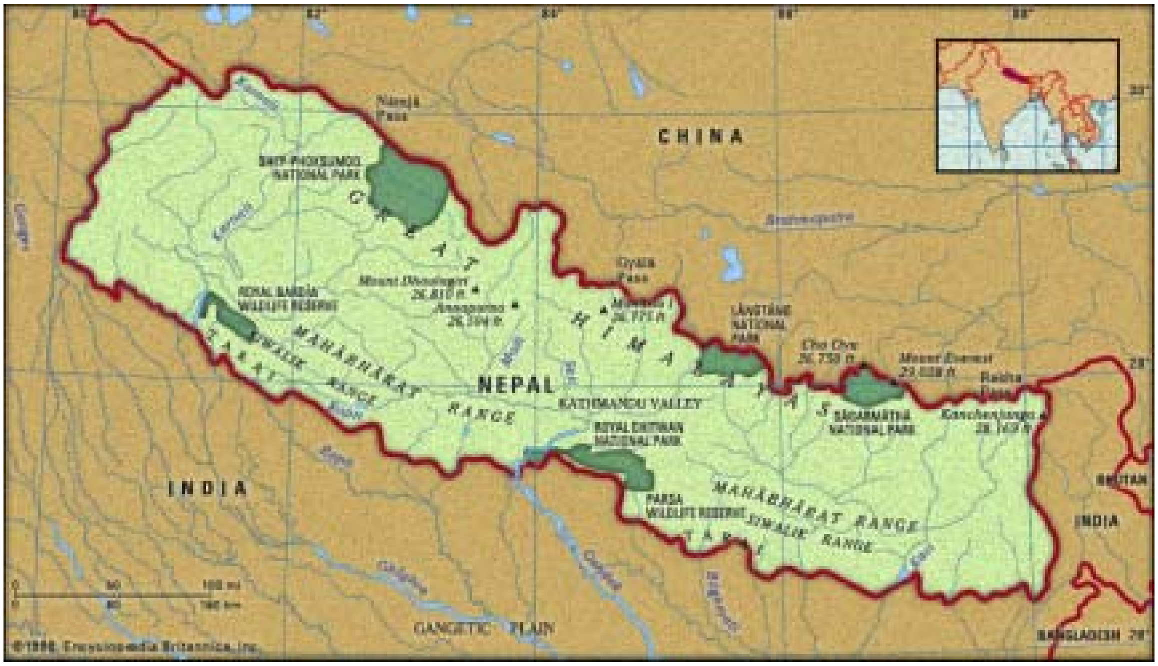

Figure 1: Map of Nepal.[1]

Nepal has abundant freshwater resources including streams and rivers fed by glacial and watershed runoff and groundwater; however water availability and quality varies greatly.

The inaccessibility of safe drinking water is endemic in both the densely populated Terai and foothill regions. Out of Nepal's estimated population of 24 million[2], only 66% have access to safe drinking water.[3] Most rural settlements and households do not have access to piped water. In the urban areas such as Kathmandu, access to piped water is available to about 58% of urban households. Table 1 shows the distribution of households by source of drinking water in urban locations.

TABLE 1: DISTRIBUTION OF URBAN HOUSEHOLDS BY SOURCE OF DRINKING WATER.[4]

Sources of drinking water	Percent
Piped water	57.4
Well water	8.7
Hand pump	27.3
Spring water	0.0
River/stream	3.3
Stone tap	1.8
Other	1.5

Even in areas where water is piped to the settlement or to the house, it is often microbially contaminated. Output from the treatment plants is not only of uncertain microbial safety it is also intermittent and usually water is only released for about 3 to 4 hours a day.[5] Of those not serviced by piped water slightly more than one-third obtain drinking water from tube wells or covered wells. The rest utilize open wells, open reservoirs, and streams as drinking water sources.[6]

1.2 PURPOSE OF INVESTIGATION

This study was motivated by reports of endemic waterborne diseases in Nepal. The reported sources of disease were drinking water supplies contaminated by pathogenic organisms. To control disease outbreaks, a better water treatment and distribution system is necessary. However, before either improving the drinking water infrastructure (the drinking water treatment plants and distribution system) or designing small-scale (community or household) treatment systems it is necessary to determine the specific

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[1] "Nepal" Encyclopædia Britannica Online.
[2] *The World Factbook*, CIA, 1999
[3] *Nepal at a Glance*, The World Bank, 1999
[4] *Nepal Human Development Report*, UNDP, 1998
[5] Rijal and Fujioka, 1998

water quality problems. Therefore, the purpose of this study was to determine the extent of microbial contamination in drinking water. This was accomplished in two ways: by sampling and analysis of Kathmandu Valley's drinking water during three weeks in January 2000 and by the evaluation and synthesis of several existing studies.

Since microbial testing was limited to three weeks of sampling and analysis in January 2000 it was not completely comprehensive. By examining data from other drinking water studies performed in the Kathmandu Valley,[7] this report seeks to determine a long-term trajectory of drinking water quality. Studies usually find poor water quality and are they are generally accompanied by recommendations to improve the system. A synthesis of the recommendations provides an indication of the changing water quality over time and may help guide future policies and programs.

In the Kathmandu Valley, the drinking water supply sources are varied and water quality often changes dramatically as it travels through the distribution system. As noted above, 58% of the water supply in urban areas is piped. In some places the piped water is treated before distribution, in other places the water is distributed through the distribution network without treatment. Piped water is distributed in taps on the street or in individual dwellings. There are also places where water is collected directly from a source, such as a tube well or spring, and either consumed on the spot or stored for future consumption. Since water supplies are intermittent throughout the day, water is stored for future use.

Drinking water quality in Kathmandu is also subject to seasonal variation. Nepal has a summer rainy season, called the monsoon, and a winter dry season. During the rainy season the water levels in the rivers rise and the water quality through out the Valley worsens. It is of particular interest to quantify the differing water quality during the rainy and dry seasons and determine if the seasonal variation in precipitation causes a seasonal variation on people's health.

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[6] *Nepal Human Development Report*, UNDP, 1998

[7] Bottino et al., 1991, Karmacharya, Shrestha, and Shakya, 1991/92, Rijal and Fujioka, 1998

A corollary of the drinking water problems in the Kathmandu Valley is the problem of surface water quality. The quality of surface water can be indicative of the state of public and domestic sanitation practices. When people come into contact with contaminated surface water they are more likely to ingest or otherwise be infected by waterborne viruses and pathogens that cause disease. Further, surface water is often used as the source of drinking water either directly at the inlet to a treatment plant or distribution system or indirectly after it infiltrates into the ground and is pumped out of wells. For these reasons, surface water quality in the Kathmandu Valley was also studied.

1.3 WATER QUALITY INDICATORS

Water quality is classified using many different water quality parameters that can be divided into four general categories: physical, chemical, biological, and radionuclide.[8] Physical parameters include color, odor, turbidity, and temperature. Turbidity is also a parameter used in biological evaluation. The effects of the physical parameters of water are not a health concern, but they are often indicative of other problems. Chemical parameters are divided into two general categories: organic and inorganic compounds. Both types of chemicals enter water supplies naturally and as a result of pollution. Inorganic chemicals include many elements such as arsenic, lead, nitrate, sodium, calcium, and oxygen. Organic chemicals include various hydrocarbons, sulfur compounds, and oxygen derivatives and come from pollutants such as pesticides and detergents. Some chemicals found in water have sudden health impacts if they are present in large enough concentrations, however most problems with chemicals concern their long-term cumulative health effects. While chemicals pose some health problems, bacteria and viruses, both biological parameters, are of the most concern because it is these organisms which often have immediate effects on the human body.

Microbiological parameters are indicators of potential waterborne diseases and are usually limited to bacteria, viruses, and pathogenic protozoa.[9] Examples of waterborne diseases include cholera, typhoid fever, dysentery, Gastroenteritis, Giardiasis,

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[8] DeZuane, p. 5

Cryptosporidiosis, and Hepatitis-A. Waterborne microorganisms can be divided into two general categories: pathogens and viruses that cause disease and bacteria that can be used as indicators for the disease causing pathogens.

Disease causing pathogens and viruses of fecal origin are of interest to public health officials; however both disease causing and benign microbes can originate from fecal material. Even in the wastes of sickened individuals pathogens are not generally present in high concentrations; yet other bacteria such as hydrogen sulfide producing bacteria, fecal coliform, and *E.coli*, are present in large quantities in fecal waste. These abundant yet benign bacteria do not produce diseases themselves, but since they are always present in fecal waste their detection in water is an indication that human wastes contaminate the water.

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[9] DeZuane, p. 299

2 KATHMANDU VALLEY WATER SUPPLY AND DISTRIBUTION SYSTEM

2.1 OVERVIEW

As noted above, Nepal is comprised of three general regions: the flat Terai, the foothills, and the Himalayas. The Kathmandu Valley is in the foothills region though on clear days the Himalayas can be seen in on the northern horizon. The city of Kathmandu is contained within the Kathmandu Valley. Figure 2 shows a map of the Kathmandu Valley and the city highlighted within it. The two other major cities in the Kathmandu Valley are Patan and Bhaktapur; though the Valley also contains many smaller communities. Samples and analysis in this report focus on the urban areas of the Kathmandu Valley.

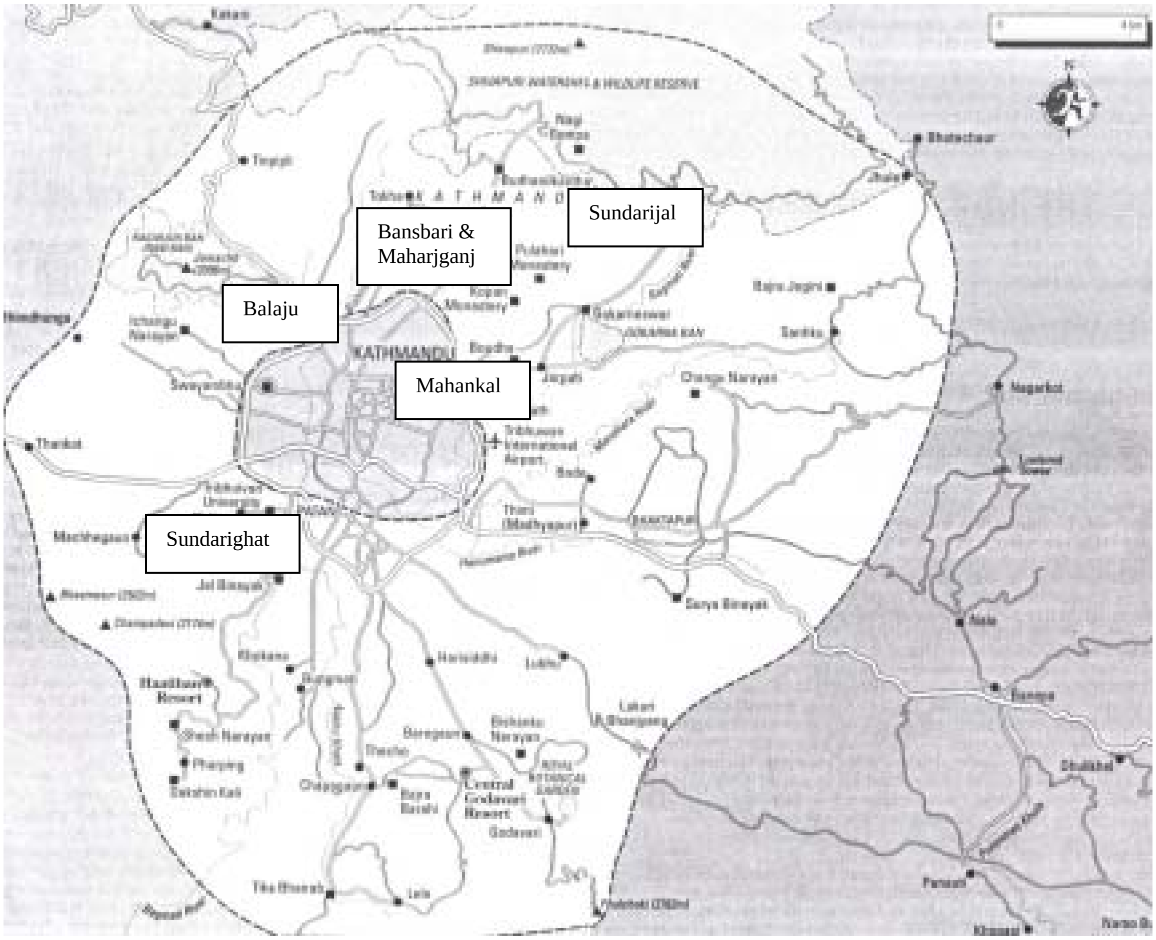

Figure 2: Map of the Kathmandu Valley and its treatment plants[10]

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[10] Reed, 1999.

The current water distribution system in the city of Kathmandu dates back to 1895[11] when the British constructed the Maharajganj water reservoir.[12] Despite this early reservoir construction, organized planning of the water distribution system did not begin until the establishment of Nepal's Department of Water Supply and Sewerage (DWSS) in 1972.[13] The DWSS is responsible for water supply and sanitation all over Nepal, not only in the Kathmandu Valley. In 1988 a separate government agency, the Nepal Water Supply Corporation (NWSC), was formed to address water problems within the Kathmandu Valley. The NWSC is responsible for all treatment plants and the water supply systems in the Kathmandu Valley. Additionally, many other international non-governmental organizations (NGOs) and Nepali NGOs are also interested in water quality. Some NGOs such as ENPHO play a role in water quality monitoring for the water supply and distribution system.

In 1998, His Majesties Government of Nepal (HMGN) released their ninth five-year plan in which they stated that they were committed to providing a safe and adequate drinking water supply.[14] Before this, the government, through the water supply and sanitation sector had focused on achieving physical targets such as the construction of treatment plants and pipelines. However, water quality was not evaluated regularly and it was difficult to determine whether these projects improved people's standard of living. HMGN claimed that the effort to provide a safe water supply had been limited to the central government and there had been no local initiatives to improve water supply and delivery. To change this top-down organization, HMGN declared that their focus would now be on inter-organizational and inter-regional coordination instead of centralized control. They would no longer act as the provider and instigator of large projects; they would just act as the supporter and facilitator for NGOs, private donors, and communities.

Even though drinking water coverage is increasing in the Kathmandu Valley under HMGN's new policies, a large proportion of the population is still not covered by

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[11] Shakya and Sharma, 1996
[12] Personal communication with Dilli Raj Bajracharya, director of the NWSC Central Lab
[13] Shakya and Sharma, 1996

drinking water and sanitation services. For example in 1996, only 64% of the population in the Valley was covered by the drinking water distribution system and in 1993, 20% of the population was covered by sewage access.[15] The ninth five-year plan sets a target of providing piped and clean drinking water to 100% of the population and sanitation coverage to 50% of the population by 2002.[16]

Despite the expanding water supply distribution system, the growing coverage of piped water, and the commitment by the government to make water supply a national priority, there have been no regular water quality monitoring programs. A few scattered tests were performed beginning in the 1970's, but these were never on-going or comprehensive.[17] The NWSC's Central Laboratory is now in charge of all water quality testing for the drinking water system. They perform testing by taking samples of both the treatment plants and the distribution system. Tests of the treatment plants are supposed to occur once a week to once a month; unfortunately the testing schedule must be relaxed sometimes due to lack of funds to cover the expense of collecting the samples.[18]

One reason why the water quality situation in the Kathmandu Valley is difficult to understand and monitor is because of the complicated sources and collection points in the treatment and supply system. In order to get a better idea of where all the water comes from it is necessary understand the many collection points and distribution types. The schematic in Figure 3 shows the methods that water gets from its source (streams, springs, and groundwater) to consumption.

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[14] *National Water Supply Sector Policy: Policies and Strategies*, 1998
[15] Shakya and Sharma, 1996
[16] *National Water Supply Sector Policy: Policies and Strategies*, 1998
[17] Shakya and Sharma, 1996
[18] Personal communication with Dilli Raj Bajracharya, director of the NWSC Central Lab

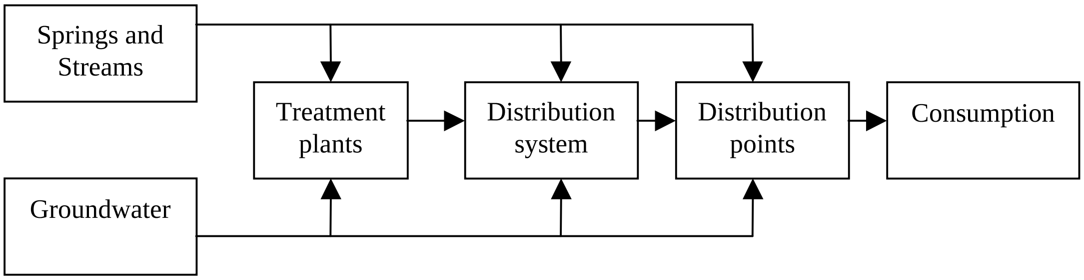

Figure 3: Water distribution system.

2.2 SOURCES

As shown in Figure 3, the sources of water to the Kathmandu Valley drinking water system are springs, streams, and groundwater. Springs are used as sources in some higher elevation areas and both springs and perennial streams feed some treatment plants.[19] Another water source for individuals and treatment plants are tube wells. Both shallow and deep tube wells are used in the Terai and the Kathmandu Valley. Some small communities who do not have gravity fed springs or pumping system harvest rainwater for drinking purposes.

Water in rural hilly areas of the Valley is considered safe, although the growing population is causing increased microbial contamination. Rural streams have water quality problems too because they are often microbially polluted and have high turbidity levels. The Kathmandu Valley's major river, the Bagmati, is used as the source for some treatment plants. Water from the Bagmati is collected in north of the Kathmandu Valley in the Shivapuri protected watershed and wildlife area.

2.3 TREATMENT PLANTS

All three water sources, springs, streams, and groundwater are used to feed the Kathmandu Valley drinking water treatment plants. The major treatment plants in the Kathmandu include Sundarijal, Mahankal, Balaju, Bansbari, Maharajganj, and Sundarighat. The approximate location of these plants can be seen in the map of the

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[19] Shakya and Sharma, 1996

Kathmandu Valley in Figure 2. Water treated by Kathmandu's water treatment plants provides 60% of the total water supply in Kathmandu.

Sundarijal

The source of water to the Sundarijal water treatment plant is the Bagmati River. Water is collected from the river up near its source in the north of the Valley in the Shivapuri protected watershed and wildlife reserve. Water collected in Shivapuri is pumped through the Sundarijal treatment plant to Mahankal and other treatment plants in Kathmandu Valley. The flow rate at Sundarijal averages 230 L/s. The treatment plant has an aeration system, sedimentation, filtration, and chlorination.[20] Currently, chlorination is the primary means of treatment at Sundarijal.

Mahankal

Mahankal, the largest drinking water treatment plant in Nepal, supplying 60% of treatment plant treated water in the Kathmandu Valley, receives water from the Bagmati via Sundarijal and also from several tube wells. Flow rates in the 5 or 6-year-old Japanese designed plant average 315 to 320 L/s with a portion of that coming from Sundarijal. Water is treated with aeration, alum coagulation, and chlorination before being piped and trucked to the system and consumers. The design, engineering, and equipment used in this plant are from Japan.

There is a small water quality lab in the Mahankal treatment plant where engineers perform daily water quality testing for pH, turbidity, and residual chlorine. Currently, there are no microbial tests performed at Mahankal because they lack the means for testing. The NWSC's Central Lab performs weekly microbial testing on Mahankal's water. A chemist at Mahankal claims that the water coming out of the plant does not usually have microbial contamination though contamination sometimes occurs once water is in the distribution system.[21] Contamination generally occurs only during the rainy season and when microbial contamination is found in the output of the plant the chlorine dosage is increased. Turbidity, while low during the dry winter months (around

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[20] Personal communication with Susan Murcott

10 NTU in and less than 3 NTU out), can apparently get as high as 1500 NTU coming into the plant during the summer monsoon season.

Balaju

Another large treatment plant in the Kathmandu Valley is Balaju supplying 20% of piped water and has an average flow rate of 350 L/s. Water at Balaju is collected from five springs, stored in a large reservoir, and then chlorinated before distribution. The plant is only turned on to release water twice a day. Recently, a sedimentation tank was built but it was not working in January 2000 because engineers were still in the testing it. The Balaju plant also has a filtration unit but it was not working because of on going repair work. When the plant is fully operational it will treat drinking water with alum coagulation and filtration as well as chlorination. Projections estimated that the plant would be fully operational by May 2000, however the engineers and operators were having problems locating materials.

Water quality samples are supposed to be taken from Balaju once a month, but staff from the Central lab has difficulty getting there that often. When water samples are taken both the raw water and the treated water are analyzed. The raw water has a fairly constant chemical composition though microbial concentrations vary.[22] Turbidity is reduced from 40 NTU in the raw water to around 5 NTU in the treated water and there usually is no microbial contamination in the treated water. The main problem at Balaju is that the treatment plant has high turbidity in the rainy season.

Bansbari

Bansbari, constructed in 1995, is another treatment plant built by JICA, Japan's international aid agency. The flow rate at this plant is about 160 L/s and its sources are springs and the Bishnumati River. It also receives inflow from deep boring wells. Treatment at Bansbari consists of pH adjustment, sand filtration, and chlorination with bleaching powder.

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[21] Personal communication with Upendra Bahadur Shrestha, chemist at Mahankal

[22] Personal communication with Dilli Raj Bajracharya, director of the NWSC Central Lab

Maharajganj

The underground Maharajganj reservoir was built by the British and is 96 years old. Water stored in Maharajganj is now treated at the Bansbari treatment plant. Even though Maharanjganj used to be a treatment plant using sand filtration, it is now only used as a drinking water storage reservoir.

Sundarighat

Sundarighat is a small treatment plant located southwest of Kathmandu. It is the smallest of the six described reservoirs and its source is the Nakhu River.[23] Treatment at Sundarighat consists of alum coagulation, slow sand filtration and chlorination. The conditions of the treatment system in January 2000 were questionable because the coagulation and filtration systems were not working. Use of chlorine disinfection was observed.

2.4 DISTRIBUTION SYSTEM

Water is piped from the treatment plants to distribution points in underground pipelines. These pipelines are often quite old and lie in the same vicinity as the sewage network.[24] This can be problematical both because of the proximity of the two pipelines and because of the age of the network. Both factors increase the likelihood that sewage and other polluted water infiltrates the drinking water network. Drinking water pipelines pose a sanitary risk because they are sometimes laid in the banks of streams.[25] They are also sometimes found in open trenches or exposed in the ground.

Aside from leaking pipes and sewage infiltration, another problem with the distribution system is back siphoning. Since water is only supplied to the system for a few hours a day, residents who receive water leave the tap open to ensure that they will collect water when it is supplied.[26] This practice is potentially harmful to the quality of water because

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[23] Personal communication with Susan Murcott
[24] Shrestha and Sharma, 1995
[25] Pandit, 1999
[26] Rijal and Fujioka, 1998

when water is not flowing in the system the system may have a lower pressure than water in contact with the household taps. This means that the household water can be sucked back into the pipes, thus exposing all the water in the pipes to any contamination that exists in households.

There are some instances when water is not treated before it enters the distribution system. This water is exposed to the same above-mentioned problems that the treated water faces except with the added disadvantage that it has not been treated first. When the water is treated with chlorine in the distribution system, there is a chlorine residual left over when the water leaves the plant. This means that it can handle some degree of contamination in the distribution system because the residual chlorine will kill some of the introduced bacteria. However, if there is no residual chlorine in the water in the distribution system, it will be more vulnerable to contamination that is introduced in the distribution system.

2.5 DISTRIBUTION POINTS

Water leaves the distribution system at one of two types of points: household water taps and public water taps. The household taps are ones that most readers will be familiar with as they are similar to those in western countries. Public taps are spigots or spouts on the street and these are the places that people come to if they do not have access to water within their houses or if the water piped to their houses is not adequate to their needs.

Drinking water distributed on the street is collected in plastic jugs or metal and clay gagros (a traditional water-carrying jug). Water coming from these distribution points is not only used for drinking, but also for bathing and washing. Within the city of Kathmandu there are some public water taps whose water is treated at a treatment plant before distribution and there are other taps that are traditional taps. Traditional taps are those that are generally older and often come directly from spring sources with receiving any treatment. Public tapstands sometimes have poorly maintained pipe fittings and this also causes deteriorated sanitary conditions.[27]

2.6 HOUSEHOLD COLLECTION

Residents of the city collect water from public and private taps and store that water in their homes for use throughout the day. This storage is necessary to have an adequate water supply, however it also increases the likelihood that water will become contaminated. Within the home, water may become contaminated due to prolonged containment stimulating biological growth or through poor sanitation practices. There is a growing movement within Nepal to educate people on proper sanitation practices, because better cleanliness will lessen the incidence of contamination on the household level.

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[27] Pandit, 1999

3 METHODS

Sampling in the Kathmandu Valley was performed in January 2000. Samples were taken from the Bagmati River, hand dug wells and tube wells, at the inflow, within the system, and at the outflow of treatment plants, from piped supplies in Kathmandu, at traditional sources such as stone spouts, and in restaurants and businesses. All samples were collected and temporarily stored in either 250 mL or 1 liter polyurethane bottles. These bottles were then taken back and analyzed in the Nepal Water Supply Corporation's Central Lab. All microbial and turbidity analysis was performed with four hours of collection.

3.1 TURBIDITY

Turbidity was measured using a HACH 2100P portable turbidimeter. This turbidimeter measured turbidity in the range of zero to 1000 NTU with a resolution of 0.1 NTU. Turbidity measured in NTU (nephelometric turbidity units) passes a light of specific wavelength through a sample and measures the 90° scatter.[28] The amount of transmitted light of the sample is compared to the amount of transmitted light that is absorbed by a turbidity-free standard. When working with the turbidimeter it is crucial that the sample cells be kept clean and free from scratches and fingerprints, because scratches and oils will effect the measurement. It is also necessary that turbidity measurements are taken quickly because turbidity is time sensitive and subject to degradation.

3.2 MICROBES

The two microbial tests performed to determine the presence of indicator bacteria were the HACH Presence/Absence with MUG reagent and the PathoScreen Medium using MPN Pillows. They were chosen for their simplicity and ease of use since we were not sure of the laboratory conditions that we would be working in once we arrived in Nepal.

Some samples were analyzed using both the Presence/Absence (P/A) and the MPN methods; others were only analyzed using one or the other. For each daily batch of tests,

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[28] Wilde and Gibs, 1997

a blank was run using either distilled or bottled water to insure that laboratory practices did not contaminate the samples. Before each set of tests was run the laboratory area was cleaned with bleach. Gloves were worn at all times to lessen the likelihood of contaminating the samples.

Glassware and caps for the 120 mL P/A bottles and the 25 mL MPN tubes were reused. After each use they were autoclaved and the washed in a bleach solution. The glassware was then baked in an oven until the next use. The caps were boiled for several minutes before reuse. Samples were transferred directly from the sample bottles to the testing bottles by pouring to minimize the possibility of contamination.

Presence/Absence Testing

The Presence/Absence test is a simple yes/no test for determining whether there is coliform in water. Total coliform and *E.coli* are both present in human waste and are common indicators of disease-causing pathogens. The *E.coli* test is especially useful because these microbes are only related to fecal wastes. Total coliform may come from a fecal origin, but it may also come from more benign sources such as soils and plants. Therefore, while total coliform is a useful indicator of bacteria in the water, *E.coli* is much more useful for determining whether or not water has been contaminated from fecal wastes.

For analysis, 100 mL of sample was transferred from its sample bottle to the testing bottle. Samples were combined with the P/A reagent broth that was packaged in a glass ampule. The glass ampule was opened using an ampule breaker. Broth reagent was poured into testing bottles then the bottle was capped and incubated for 24 to 48 hours at 35 °C. A color change from purple to yellow indicated the presence of total coliform. Since the reagent broth contained the MUG reagent, an ultraviolet light shone on the testing bottle after the incubation period indicated *E.coli* presence if the bottle fluoresced.

Hydrogen Sulfide Testing

One advantage of the H_2S screening test is that the H_2S producing bacteria are less sensitive to temperature changes than other tests. Therefore, these tests can be performed in rural and remote areas where screening is often difficult and resources such as skilled technicians, power, equipment, and laboratory facilities are often limited. Further, H_2S test reagents are inexpensive to produce, easily stored, and the test results are easy to interpret.[29] There are also disadvantages associated with the H_2S test. One is that even though it detects microorganisms that produce hydrogen sulfide, most of the common indicator bacteria already discussed, fecal coliform, total coliform, and *E.coli*, do not produce H_2S. This means that comparisons between results of the H_2S test and standard tests are difficult.

In this study the HACH PathoScreen Medium MPH Pillow H_2S test was used. The procedures used for this test were similar to the procedures used for the Presence/Absence test. First, 20 mL of sample was transferred from the sample bottle to five testing tubes. Then end of a PathoScreen Medium MPN Pillow was swabbed with alcohol or chlorine and aseptically cut with clippers. The contents of five powder pillows were added to the five testing tubes filled with sample. The cap was then replaced, the mixture inverted several times to mix the sample and medium, and the bottles were placed in an incubator at 35 °C for 24 to 48 hours. After 24 hours of incubation the reaction was noted. If tubes were cloudy or clear yellow they were incubated for an additional 24 hours. If they changed black, or if any black precipitate was formed, that was taken as a positive sign of the presence of hydrogen sulfide producing bacteria.

Using statistical methods, it is possible to estimate the number of organisms present in the multiple-tube technique from the combination of positive and negative results from the five tubes of a given sample.[30] The MPN values in the following table are based on 20 mL of undiluted sample in each of the five tubes. If the sample was diluted, then the right hand side should be multiplied by a dilution factor.

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[29] Kromoredjo and Fujioka, 1991

TABLE 2: FIVE TUBE MPN VALUES (95% CONFIDENCE LIMITS) FOR UNDILUTED, 20 ML SAMPLES.[31]

Positive Tubes	MPN/100 mL
0	<1.1
1	1.1
2	2.6
3	4.6
4	8.0
5	>8.0

3.3 COMMENTS

In many respects the tests used in this analysis are very good. These methods are simple to use, usable and storable under a variety of temperatures, and cheap; therefore non-technical people could use them under a variety of conditions and without much training. This is important because it means that with some assistance many people could assess their own water quality. Using these tests, individuals would not be dependant on officials and government agencies to monitor their water because they would be able to do so themselves.

Despite the fact that both the hydrogen sulfide and the total coliform and *E.coli* tests are simple to perform, they had some drawbacks during the testing. There was not always good correlation between the results of the Presence/Absence testing for total coliform and *E.coli* and the results of the H_2S testing (see section 4.2). The total coliform/*E.coli* P/A test was usually more sensitive than the H_2S test.

Given that the actual testing conditions that we had in Kathmandu were better than the conditions we expected, it is recommended that a more robust screening for indicator organisms be performed in future tests. For research purposes, there are many other tests available that would be more precise in their results. The Presence/Absence type tests were simple to use, however they did not give an accurate idea of the concentration of bacteria in the water. A better test might be a Membrane Filtration type test. This would allow for the actual counting of colonies of bacteria and would give an indication of the severity of bacterial contamination.

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[30] *Analytical Procedures: Screening for Hydrogen-Sulfide Producing Bacteria*
[31] *Analytical Procedures: Screening for Hydrogen-Sulfide Producing Bacteria*

4 RESULTS AND DISCUSSION

4.1 TESTING IN JANUARY 2000

Samples collected in the Kathmandu Valley during January 2000 have been divided into six categories for analytical purposes: well sources, stream sources, inflow or within a treatment plant, outlets from treatments plants, distribution points, and consumption points.[32] All samples were tested for turbidity, total coliform and *E.coli*, and/or hydrogen sulfide producing bacteria. Only drinking water samples, or samples from sources to be treated and then distributed, were considered in this analysis.

The primary results from the microbial analysis and turbidity testing are displayed in Figures 4 and 5. Table 3 shows the number of samples for each of the various points in the water distribution system. Due to a limited amount of sampling time, some categories did not have many samples. The bar chart in Figure 4 shows the percentage of total coliform, *E.coli*, and contaminant presence in the drinking water sampled from each category. Total coliform and *E.coli* analysis was conducted using the P/A tests discussed. The term "contaminant presence" indicates the detection of any type of contamination in the sample, either total coliform, *E.coli*, or hydrogen sulfide producing bacteria and generally represents a larger number of samples than any individual test.

TABLE 3: NUMBER OF SAMPLES ANALYZED IN EACH CATEGORY†.

	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

† In total, 39 samples were analyzed.

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[32] Consumption points were samples taken from drinking water in restaurants and other businesses. Raw data is in the Appendix.

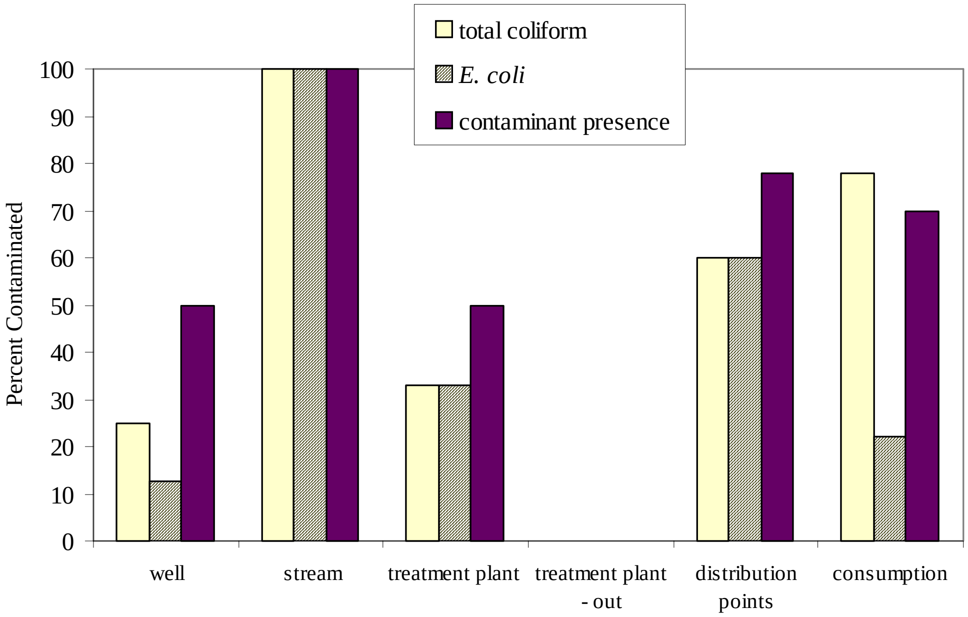

Figure 4: Microbial contamination in the Kathmandu Valley water supply system, January 2000

Figure 4 shows that the microbial contamination was not consistent throughout the Kathmandu Valley water supply system. Wells and streams had different contamination levels even though they are both direct sources. Wells were generally less contaminated although Figure 4 does show that over 50% of them had some sort of contaminant presence. Not surprisingly, streams had the highest contamination levels of all the sources tested, probably because it has many opportunities for exposure to contaminants.

Treatment plant samples were taken at all stages of treatment: at the inflow, during the settling, coagulation, and filtration processes, and at the outflow. Microbial presence in treatment plant inflow comes from the spring, stream, and well water that feed the plants. Figure 4 shows that about 50% of the samples taken at either the inflow or within the treatment plants were microbially contaminated. Due to the small number of samples, these two categories were not distinguished in Figure 4. No samples taken at the output of the treatment plants had microbial contamination. Microbial absence is not unexpected since all treatment plants that were analyzed for this study used chlorination in the last step of their treatment processes.

Even though the three treatment plants tested were found to be microbe-free, the distribution points were not. Almost 80% of the samples taken from distribution points, tap stands and faucets, showed some type of microbial contamination. About 60% of distribution point samples had *E.coli* presence. This suggests that most water distributed through Kathmandu Valley's water distribution system is polluted with fecal material. Considering that none of the water at the outflow of the treatment plants contained microbial contamination it appears that water was contaminated within the distribution system.

It has also been suggested that there is significant drinking water contamination during consumer handling.[33] Figure 4 shows that these analyses found little difference between contamination at distribution points and consumption points, though there was a little increase in contamination from wells to consumption points. This data indicates that most contamination was not originating at the household level. There also was a drastic decrease in *E.coli* levels between the distribution points to the consumption points (from 60 to 22%). This might be because people have improved their hygiene practices. That is not an unreasonable assumption given the attention focused on the need for consumer education about hygiene.[34] It is also possible that people are using some form of simple treatments in the restaurants and stores such as filtration or boiling.

Another indication that people were using some means of drinking water treatment can be inferred from the turbidity data shown in Figure 5. These data show that the turbidity levels in the wells, streams, and treatment plants were about the same, around 6.5 NTU. Then turbidity decreased significantly in the treatment plant outlet. At the distribution points the turbidity increased suggesting contamination in the distribution system. However, at the consumption points the turbidity decreased again. This might be due to filtration or settling of particles after collection.

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[33] Karmacharya, Shrestha, and Shakya, 1991/92, Shrestha and Sharma, 1995, Shakya and Sharma, 1996

[34] Karmacharya, Shrestha, and Shakya, 1991/92., Shrestha and Sharma, 1995, Shakya and Sharma, 1996

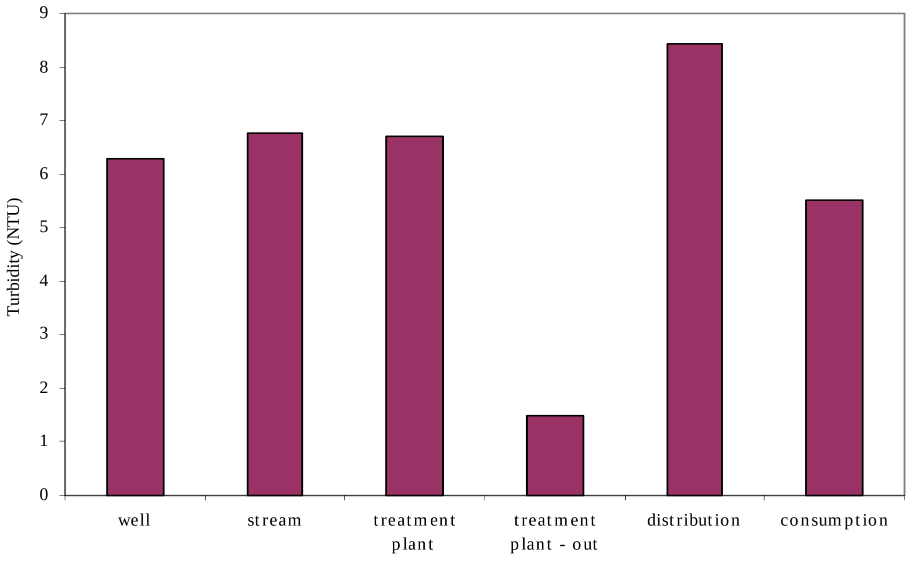

Figure 5: Turbidity levels in the Kathmandu Valley water supply system, January 2000

To make comparison between turbidity and contaminant presence at the different points in the drinking water system data from Figures 4 and 5 were normalized and graphed together. Figure 6 shows this normalized comparison between the turbidity levels at each source type and the microbial contamination levels.

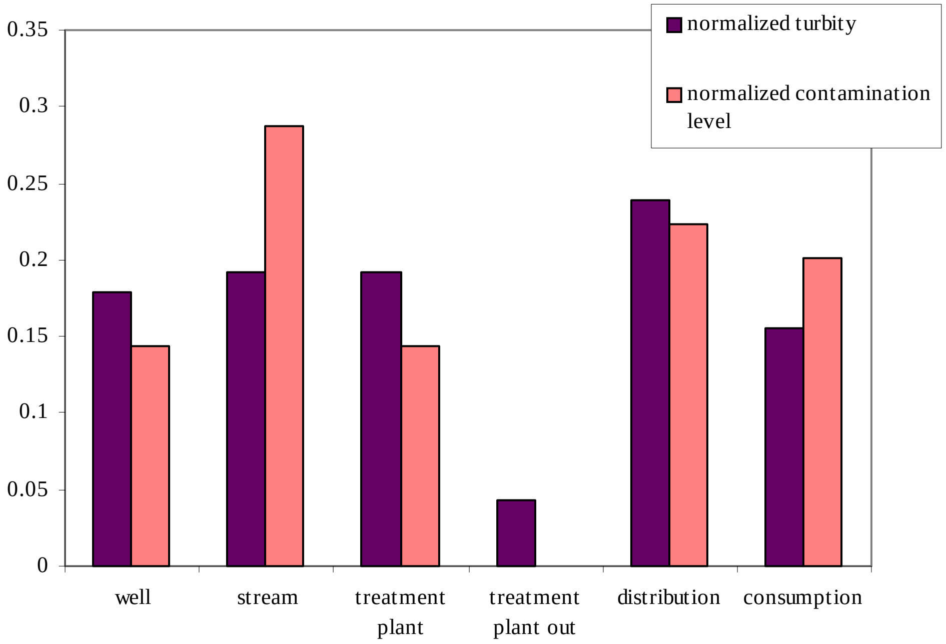

Figure 6: Normalized values for turbidity and microbial contamination level in the Kathmandu Valley water supply system – January 2000

The results shown in Figure 6 indicate there was a fairly good correlation between a source's turbidity and microbial contamination. While a direct relationship cannot be established from these data, in general it appears that when there was a higher turbidity level in a sample there was also a higher likelihood of microbial contamination. Conversely, when the turbidity level was low, there were fewer chances that the sample was contaminated.

4.2 CORRELATION BETWEEN H_2S AND COLIFORM/*E.COLI* TEST RESULTS

During research in the early 1980s it was observed that the presence of coliform in drinking water is often associated with fecal bacteria that produced hydrogen sulfide (H_2S).[35] A simple Presence/Absence test was developed to test for H_2S bacteria in water samples. Several studies were performed to determine whether the presence of hydrogen sulfide producing bacteria could be linked to the presence of other fecal related bacteria such as coliform and *E.coli*.

Research by Grant and Ziel in 1996 to evaluate the H_2S test as a viable screening test for fecally polluted water showed good correlation between the presence of H_2S producing bacteria and other fecal-related bacteria such as fecal coliform.[36] They claimed that because the correlation between total coliform and H_2S producing bacteria was not as strong, it was postulated that the total coliform tests measured coliform from fecal and non-fecal origins, while H_2S producing bacteria only measured bacteria that originate from fecal materials. A stronger correlation was found between H_2S producing bacteria and total coliform when the number of total coliform in a sample exceeded 40 colonies per 100 mL.

In contrast to the findings of Grant and Ziel, research performed by the International Development Research Centre (IDRC) showed that the production of H_2S was generally better correlated with total coliform than with fecal coliform.[37] This was because over

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[35] Manja, Maura, and Rao, 1982
[36] Grant and Ziel, 1996
[37] Jangi et al., 1997

85% of hydrogen sulfide producing bacteria isolated in the IDRC testing were identified as *Citrobacter freundii*, also *lebsiella pneumoniae* and *Enterobacter cloacae* represent 4%, and 1% each of *Enterobacter aerogenes* and *Kluyvera* species was found. All these bacteria are found in fecal material but are also, with the exception of *Klebsiella pneumoniae* and *Enterobacter cloacae*, commonly found in the natural non-fecal-contaminated environment. Hence their numbers in a water sample are more likely to be reflected by the total coliform population than by the fecal coliform population. This research relating H_2S producing bacteria to total coliform directly contradicts the previous research by Manja, Maura, and Rao and by Grant and Ziel. The first two studies said that H_2S producing bacteria did not come from non-fecal material and the Jangi et al study from the IDRC said that H_2S producing bacteria do come from non-fecal sources.

The IDRC also found that in water where there were fewer than 250 coliforms per 100 mL, the H_2S test did not show blackening even after 48 hours in approximately 20% of the cases in such waters tested.[38] However, in some samples H_2S production was detected at 48 hours in waters with total coliform counts as low as 7 in 100 mL. Hydrogen sulfide production was also observed in water with no detectable fecal coliforms. The IDRC stated that bacteria such as *Citrobacter feundii* are fairly common in surface waters and will elicit a positive result with the H_2S test. Therefore, the test would probably be of greater use with waters that are believed to be very clean such as deep wells and chlorinated water.

Of the 39 tests performed on drinking water samples in January 2000, 25 were analyzed using both the H_2S and the total coliform/*E.coli* tests. In order to gain a better understanding of the correlation between the three types of tests, the results were plotted and can be seen in Figure 7. All bars in Figure 7 are of unit length and represent a positive result for a given test. For example, the results from 19/01 show that there was no H_2S, total coliform, or *E.coli* present; 19/04 only had total coliform; 20/01 had total coliform and *E.coli*; and 24/03 were positive for all three.

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[38] Jangi et al., 1997

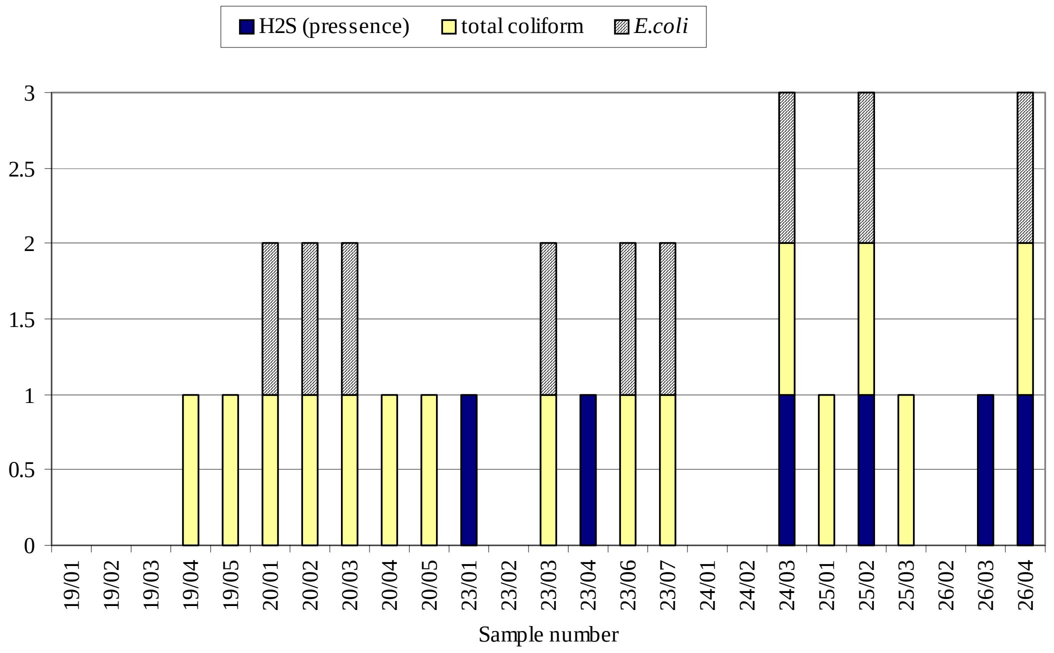

Figure 7: Correlation between the Hydrogen Sulfide test, total coliform, and *E.coli*.

Figure 7 shows that the nine times there was *E.coli* present in the sample, total coliform was also present in the sample. There were also six time where a sample was positive for total coliform but not for *E.coli*, indicating that contamination was perhaps not of fecal origin in those cases. However, of the six times that H_2S producing bacteria was found only half of those times corresponded to other indications of fecal contamination. The three samples that were positive for both H_2S bacteria and total coliform were also positive for *E.coli*. There were no samples found which were contaminated with both H_2S producing bacteria and total coliform but not *E.coli* and there were three samples that were positive for H_2S bacteria but no other types of bacteria. These results are hard to explain and it is unclear why some samples would show contamination with H_2S producing bacteria but not total coliform. The results from these tests is another suggestion that a correlation between H_2S producing bacteria and other fecal indicator bacteria might not be as straightforward as some research suggests.

4.3 OTHER WATER QUALITY STUDIES IN THE KATHMANDU VALLEY

As shown, several conclusions about the water quality of the Kathmandu Valley were drawn from the relatively few samples that were taken in January 2000. The analysis of these samples provided comparative information about water sources, treatment plants, distribution points, and consumption points. In addition to the research original to this thesis, other studies were also examined to compile more information on the water supply's seasonal quality variation, variations between different districts within the city, and the changing quality of water over time. These studies, combined with the January 2000 study, provide an overview of Kathmandu Valley's water supply.

The earliest study used in this report was a 1991 article from the Journal of the Nepal Chemical Society, written by Bottino et al, called *Pollution in the Water Supply System of Kathmandu City*.[39] They collected weekly samples for six months from January to June 1988 in order to address the relatively few water quality studies for Kathmandu City's drinking water treatment plants, reservoirs, and distribution system. They also sought to compare water quality in the treatment plants to the water quality at distribution points. They tested for total coliform using Membrane Filtration techniques. In all they tested 174 samples from 7 treatment plants, 25% of which were microbially contaminated. They also collected 282 samples from 44 distribution points, and over 60% of those were microbially contaminated. Various data from their study, including data from treatment plants, distribution points, and seasonal data, was used in this paper.

The next two papers studied were from the Environment and Public Health Organization (ENPHO), a local Nepalese NGO working in cooperation with the Italian INGO, DIVSI. The first ENPHO study, from July 1991 to June 1992, came out of a meeting in 1991 attended by the Nepal Health Ministry, the DWSS, the NWSC, Kathmandu municipality, ENPHO, and other agencies.[40] Recommendations following this meeting included a one-year monitoring project of microbial contamination in Kathmandu City performed by ENPHO focusing water quality in treatment plants and distribution points. The purposes

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[39] Bottino et al., 1991
[40] Karmacharya, Shrestha, and Shakya, 1991/92

of this monitoring project were to exhibit the importance of regular water quality monitoring, develop a water quality database, and to identify means for maintaining safe water quality. During their sampling, the researchers tested 39 samples from 6 treatment plants and 172 samples from 37 public taps for fecal coliform. Testing was performed once a month in 10 months. Fecal coliform tests were analyzed using membrane Filtration techniques. Also free residual chlorine was tested using a HACH field kit. They found that 18% of treatment plants and 50% of distribution points were contaminated with fecal coliform. Data about treatment plants and the distribution system was used from this paper.

Several years after ENPHO's first report, they issued a second report.[41] This 1995 report had much of the same data from the 1991/92 report and included more information about the specific problems in the piped water supply, traditional stone spouts, restaurants, government schools as well as the river water. This report made more extensive recommendations than the first ENPHO study. No samples were collected for this report, it only analyzed existing data.

In March to May 1994, researchers from the University of Hawaii performed a study in an effort to analyze potable water for fecal indicators and determine if a H_2S test method would work in a monitoring program.[42] They tested various treatment plants and distribution points for a wide variety of fecal indicators including fecal coliform, *E.coli*, *C. perfringens*, H_2S producing bacteria, total bacteria, and F RNA coliphage. They collected 106 samples, 48 samples from 5 treatment plants and 68 samples from drinking water distribution points. E.coli, total bacteria, and fecal coliform were analyzed using Membrane Filtration. A HACH H_2S producing bacteria were tested for using the H_2S strip test. They concluded that the H_2S test works well and could be used in Nepal to monitor water for fecal pollution.

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[41] Shrestha and Sharma, 1995

[42] Rijal and Fujioka, 1998

Another study, funded by the World Health Organization (WHO) and released in 1996 was about drinking water quality surveillance programs in Nepal.[43] This informational paper outlined the history behind water supply projects in Nepal, the history of water quality monitoring, and the legal framework concerning Nepal's water. The authors outlined the current water quality policies, addressed the constraints on improving water quality, and made recommendations to improve water quality. No water quality samples were taken for this paper.

As discussed earlier, HMGN also formulated a document that outlined the status of the water supply sector. It defined the national government's objectives for improving water quality and stated the policy goals that they wished to accomplish in order to improve the water quality and coverage for the Nepalese people.[44] This study, as well as the WHO document, focused on water quality and supply policy rather than actual water quality data.

The final large study was by Thakur Pandit, an engineer with the DWSS, in 1999.[45] This extensive monitoring study provides water quality data from sources, treatment plants, and distribution points. Its goals were to create a water quality database and to provide information and guidelines for a full-scale monitoring program. Most data provided in this study were from rural areas of the Kathmandu Valley not the urban areas.

The following sections examine the water supply and distribution system using the additional data from these reports to make comparisons such as the variations between different sectors of the city, variations between different treatment plants, and finally seasonal variations in drinking water quality.

4.4 TREATMENT PLANT VARIATION

The six major treatment plants within the Kathmandu Valley all provide different types and levels of drinking water treatment. Therefore, it might be expected that water

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[43] Shakya and Sharma, 1996

[44] *National Water Supply Sector Policy: Policies and Strategies*, 1998

coming out of the different treatment plants is of differing quality. However, from the data collected during January 2000 and displayed in Table 4 it appears that the biological contamination and turbidity concentrations in the water exiting the three treatment plants tested was uniform. The data also indicate that there was low turbidity and no total coliform, *E.coli*, or H_2S producing bacteria contamination.

TABLE 4: MICROBIAL AND TURBIDITY CONTAMINATION IN WATER EXITING KATHMANDU TREATMENT PLANTS, JANUARY 2000

	Mahankal	Balaju	Maharajganj
Turbidity	1.2	1.3	2
Total coliform	0	0	0
E.coli	0	0	0

Several other sources of data were examined to get a clearer idea of the water quality leaving the drinking water treatment plants.[46] The results from the January 2000 and other studies are plotted in Figure 8. Percent contamination was used so that all the results would be comparable.

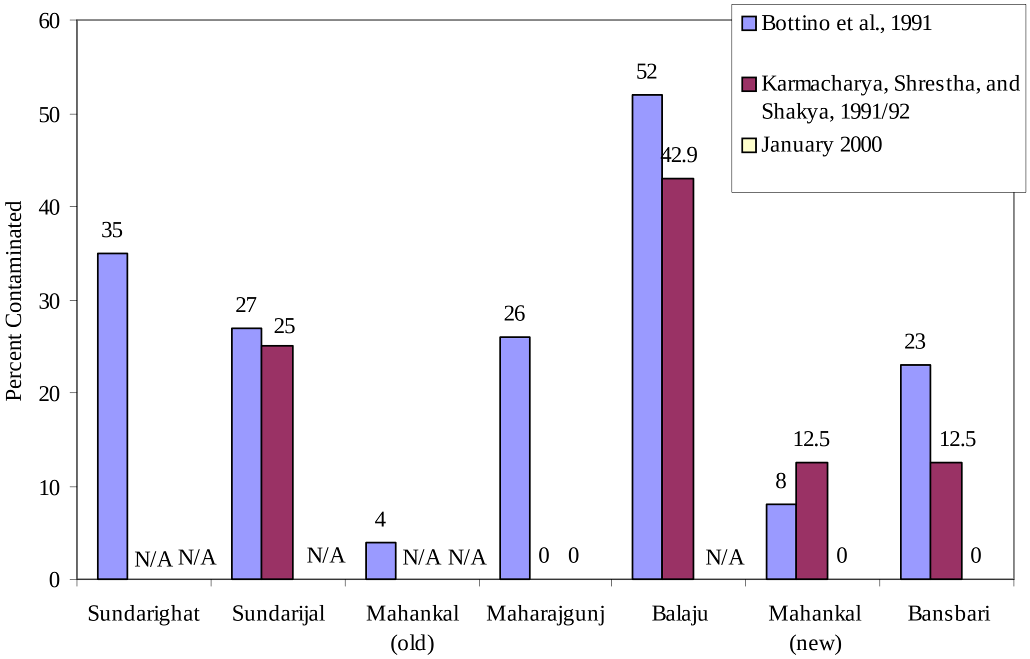

Figure 8: Percentage of contaminated samples found in the Kathmandu Valley water supply system.

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[45] Pandit, 1999

[46] Bottino et al., 1991 and Karmacharya, Shrestha, and Shakya, 1991/92

Another way to view the treatment plant data is by the average coliform found. Table 5 shows the average coliform concentrations found in the Kathmandu Valley treatment plants during three different studies.[47] This data also shows that different treatment plants have differing levels of contamination with some plants like Bansbari consistently performing better than others such as Sundarijal.

TABLE 5: AVERAGE COLIFORM CONCENTRATION IN KATHMANDU VALLEY'S TREATMENT PLANTS.

	Sundari-ghat	Sundarijal	Mahankal (old)	Maharajgunj	Balaju	Mahankal (new)	Bansbari
Bottino et al., 1991[a]	154 / 20	3 / 26	0.1 / 24	9 / 27	51 / 25	2 / 26	1 / 26
Karmacharya, Shrestha, and Shakya, 1991/92[b]	N/A / 0	15 / 8	1 / 8	0 / 8	3 / 4	N/A / 0	2 / 7
Rijal and Fujioka, 1998[c]	N/A / 0	$4.0\text{x}10^4$ / 2	N/A / 0	0 / 2	0 / 2	0 / 2	0 / 2

[a] Average number of total coliform colony forming units/number of samples taken
[b] Average number of fecal coliform colony forming units/number of samples taken
[c] Average number of fecal coliform colony forming units/number of samples taken

The conclusions drawn from this data are that the different treatment plants have different levels of bacteria removal performance. Also, it appears that the bacterial quality is getting better with time because the earliest data set, sampled in 1988, was the most contaminated of all the data examined. The least contaminated samples were those analyzed in January 2000. A more complete comparison of the different treatment plants would include and data linked to season.

Another indicator of water quality is the amount of free residual chlorine (FRC) in a sample compared to the fecal coliform count of that sample. In ENPHO's 91/92 study, measurements were made of both fecal coliform and FRC in both the treatment plant and distribution point samples.[48] The data summarized in Figure 9 shows that the amount of FRC declines between the treatment plants and distribution points while the samples containing fecal coliform rise between the treatment plants and distribution points.

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[47] Bottino et al., 1991, Karmacharya, Shrestha, and Shakya, 1991/92, and Rijal and Fujioka, 1998
[48] Karmacharya, Shrestha, and Shakya, 1991/92

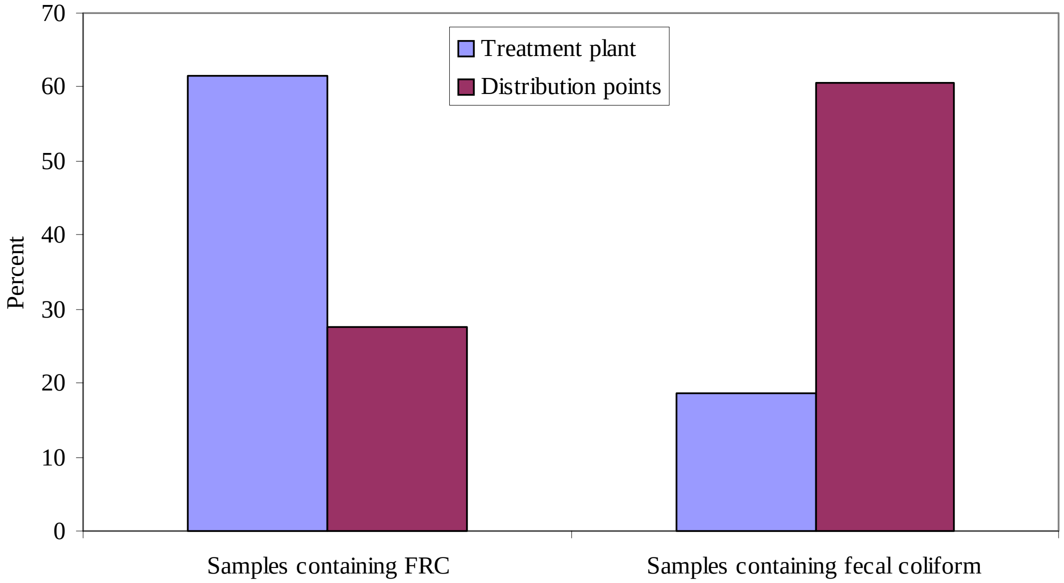

Figure 9: Relationship between free residual chlorine and fecal coliform.[49]

This comparison is another indication of infiltration in the distribution system and shows that the consequence of declining levels of chlorine is increasing incidence of fecal coliform contamination. When samples contained FRC they were less likely to contain fecal coliform. Polluted water that infiltrates into the distribution system dilutes the purified water and introduces bacteria. Concentrations of FRC decline because of dilution, through depletion in during the disinfection process, and in the formation of chloro-organic compounds. Once the chlorine is depleted, coliform levels increase and there is a high level of bacterial contamination at the distribution points.

4.5 SECTOR VARIATION

Just as not all treatment plants provide the same quality of water, not all city sectors receive the same quality of water. This may be because the treatment plant supplying water to particular sectors of the city is not as good as the others, or it might be due to more sewage infiltration in some sectors than others. Older sections of the city would probably have more problems due to the age of their systems. For comparative purposes, the city of Kathmandu has been divided into several sectors based on area and household density.[50] These divisions make it possible to compare the water quality in different sectors to determine whether or not water quality in the city is dependent on location. The map in Figure 10 shows these sector divisions.

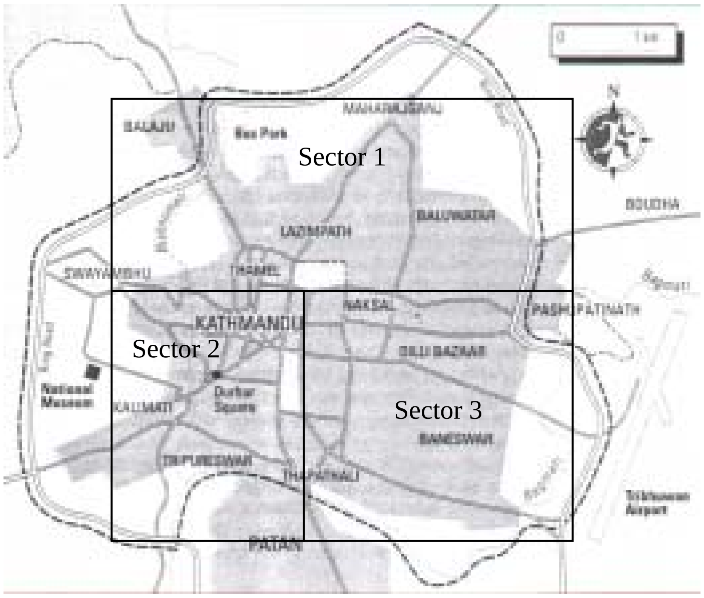

Figure 10: Map of Kathmandu City divided into sectors.[51]

The data in Figure 11 indicate some differences in the microbial quality in different sectors of the city. Yet, it shows only a moderate trend towards decreasing the overall microbial contamination levels in the Kathmandu Valley’s water supply system. The conclusion drawn from this data is that there are no significant sector variations.

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[49] Karmacharya, Shrestha, and Shakya, 1991/92
[50] Shrestha and Sharma, 1995
[51] Reed, 1999

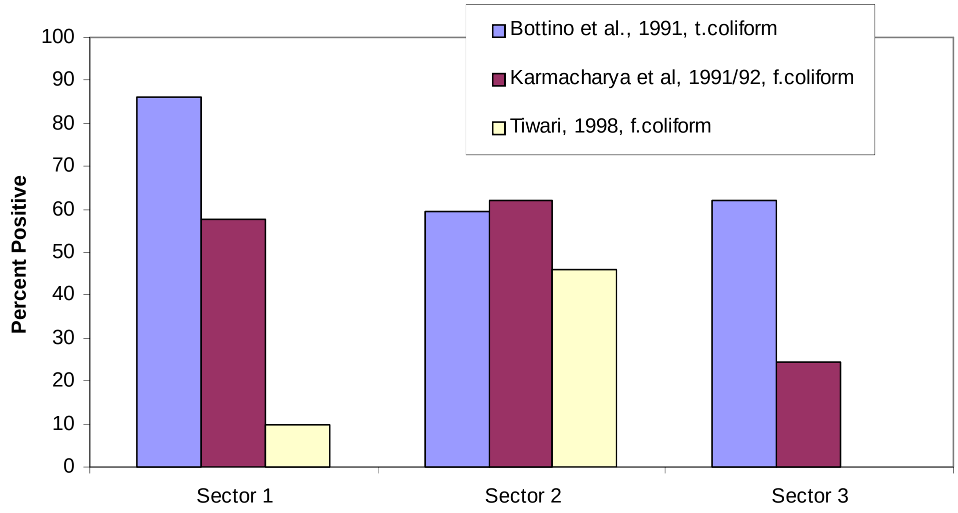

Figure 11: Percent contamination at distribution points in different sectors of Kathmandu City

4.6 SEASONAL VARIATION

One of the main problems with water quality in Nepal is that it varies a lot over the course of the year. In the dry season, there are often fewer incidences of pollution in the water supply system. In the wet season fecal contamination of drinking water increases significantly. Figure 12 shows the seasonal variation of total coliform contamination in drinking water from two different studies.

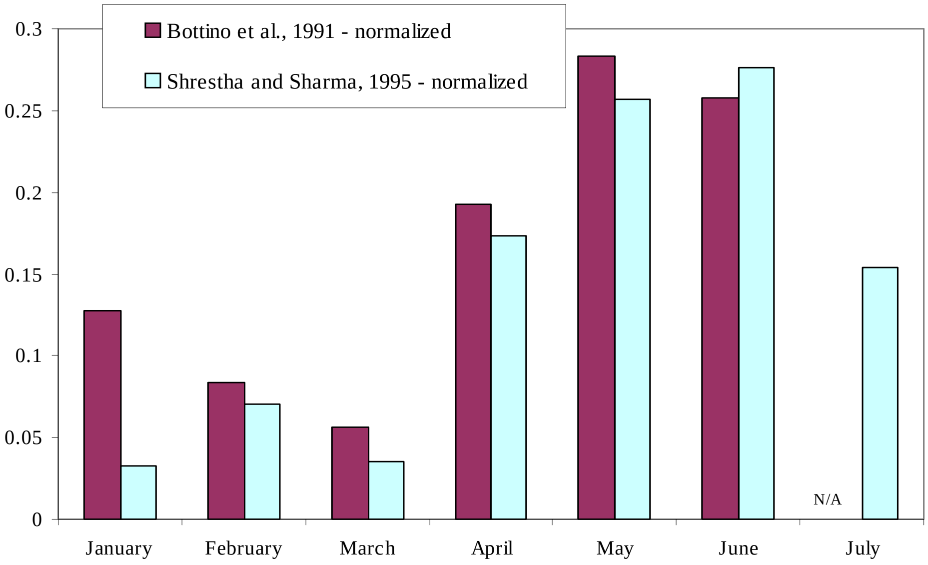

Figure 12: Normalized seasonal variation of total coliform at drinking water distribution points.

The data shown in Figure 12 was normalized to provide a better comparison between the two sets of data. The two studies both show highly seasonal variations in total coliform levels. The results indicate a fairly predictable pattern of contamination with more microbes found in the late spring than in the winter. This pattern makes it easy to predict when high contamination levels would be found.

The maximum total coliform in the tap water in the eight hospitals tested by Bottino et al., were frequently above 2000 colony forming units/100 mL.[52] The maximum total coliform that Shrestha and Sharma found at the distribution points was about 450 colony forming units/100 mL.[53] Both sets of sampling were done in 1988. Despite the differences in the maximum total levels for both studies, they both still show a similar pattern of contamination.

Along with the increases in fecal contamination in the late spring there is a corresponding increase of water borne diseases. Shrestha and Sharma recorded incidents of disease over an 18-month period in one of Kathmandu's hospitals.[54] These results are shown in Figure 13. By comparing Figure 12 and 13 it appears that there is a strong correlation between the incidents of disease and the level of contamination in the drinking water system.

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[52] Bottino et al., 1991

[53] Shrestha and Sharma, 1995

[54] Shrestha and Sharma, 1995

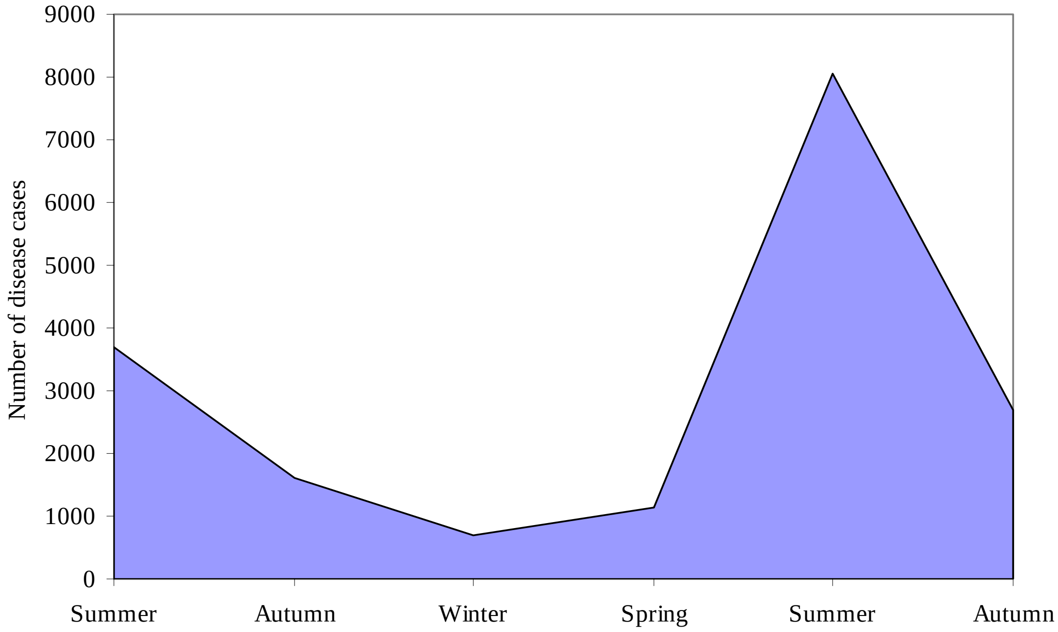

Figure 13: Water borne diseases (1993-1995) Teku Hospital

4.7 CHANGES OVER TIME

Since there are so many factors effecting the water quality of the Kathmandu Valley drinking water supply, it is difficult to determine whether the water quality at the distribution points is improving over time or not. From the treatment plant data in Figure 5 and in Table 5, the treatment plants appear to have improving water quality as the microbial contamination levels are generally decreasing over time. From Figure 7 it also looks like the drinking water at distribution points is improving over time. The trends do not appear to be significant and it is unclear whether the decreases are a function of the time of year the tests were taken, not over the trends of the entire year.

4.8 RECOMMENDATIONS

Recommendations to improve the supply of drinking water range from legal regulations to drinking water policy to specific technical solutions. This section seeks to organize and synthesize the recommendations from various drinking water quality papers. It is interesting to note that the earlier papers from the late 1980s and early 1990s recommend more technical solutions while the later papers from the mid to late 1990s emphasize the need for a drinking water policy to guide the specific technical solutions.

Regulatory Recommendations

The only regulation dealing solely with public water supply is the Nepal Water Supply Corporation Act of 1993.[55] This act addresses the functioning of the Nepal Water Supply Corporation but also includes provisions for water sources, storage, and treatment plant protection. Parts of other regulations, including the Soil and Water Conservation Act (1982), the Municipal Act (1992), and the Kathmandu Valley Development Authority Act (1985), have also addressed some issues of public water supply. All these other acts deal primarily with protection of water sources and water supply system facilities. They specify the penalties for vandalism and pollution of drinking water sources. Critics of the current legal structure argue that the Nepalese drinking water supply regulations limit the actions of consumers but they do not address the responsibilities of the water suppliers. So some have suggested that regulations be enacted that would delineate the roles and responsibilities of water providers and the government as well as consumers.

In addition to not specifying the water provider’s roles and responsibilities, the Nepalese also have no drinking water quality standards. Recommendations for improved regulations include: enacting drinking water standards that set water quality standards and designating a monitoring agency that is independent of the water suppliers.[56] These water quality standards would not automatically insure better drinking water quality, but they would refocus attention on drinking water problems. The monitoring agency would perform a regular set of drinking water tests.

Policy Recommendations

There have been a number of regulatory recommendations to set both water quality standards and specify the responsibilities of the water suppliers and consumers. There have also been a number of water related policy recommendations. These policy

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[55] Shakya and Sharma, 1996
[56] Shakya and Sharma, 1996

recommendations come from several NGOs, the HMGN, and the drinking water supply agencies themselves.

In 1995, ENPHO reported that drinking water was highly contaminated and the contamination was getting worse. They also reported that while there were scattered studies by many different agencies, there were no regular drinking water quality monitoring programs. ENPHO first recommended that a regular drinking water quality monitoring program be started.[57] They also advocated informing people of drinking water quality problems because they believe that water suppliers should either protect and clean the water or tell people the health risks associated with that particular water source. ENPHO's policy recommendations were not limited to drinking water quality at distribution points; education was another large area of concern. According to ENPHO's data, some contamination of drinking water takes place between distribution and consumption due to poor hygiene practices of the consumer. ENPHO wants to have school and restaurant workers trained so institutional water does not become contaminated during handling. They also advocated community wide training on household treatment.

The 1998 paper by Rijal and Fujioka recommend that sewage be collected and treated in order to improve drinking water quality.[58] Perhaps the most difficult but most relevant recommendation of this study was that there should be repair and maintenance of pipes that distribute drinking water. This would decrease the likelihood of contamination in the distribution system. The difficulty of implementing that recommendation is that there would be high costs in replacing so much pipeline infrastructure.

Shakya and Sharma, writing for the WHO, have also made recommendations for the improvement of water quality in Nepal. Similar to ENPHO, they would like to see a comprehensive and regular water quality monitoring program and the promotion of personal hygiene. They also stress the need to have separate supply and monitoring agencies and would like to see the strengthening of the regional water quality

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[57] Shrestha and Sharma, 1995

laboratories.[59] Constraints they pointed out included the shortage of skilled people, resources, and money; people's ignorance of hygiene importance; people's willingness to trust piped drinking water without question; and no follow up to data showing drinking water problems.

HMGN has also made a number of policies regarding water supply. Their objective is to provide a safe and adequate drinking water supply and sanitation to reduce the incidence of water related diseases.[60] Their planning and program policies state that they want to increase the coverage of piped water from 60 to 100% and improved the quality of service. Even though the government is pledging that they want to increase coverage they also want to decrease the role that the central government plays in implementing these programs. They feel that communities should take the lead in their own water supply and sanitation projects.

In their technology policy, HMGN wants to see technological options that are affordable and match the resources of the beneficiary communities. They want to safeguard the biological, chemical and physical quality of the drinking water. They also want to see a change in the institutional policies regarding water quality. This would be accomplished by redefining the roles and responsibilities of the central, district, and local organizations making them more autonomous and self-sustaining utilities.

Technical Recommendations

While regulatory and policy changes are necessary to improve drinking water quality in Nepal, they can only set the framework for improving water quality by providing standards and promoting change. In order to improve the drinking water quality in Nepal technical changes need to be made in the drinking water distribution system. It is important that these technical changes follow regulatory and policy changes because without the laws and policies, change is likely to occur more slowly.

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[58] Rijal and Fujioka, 1998

[59] Shakya and Sharma, 1996

[60] *National Water Supply Sector Policy: Policies and Strategies*, 1998

The report by Bottino et al in 1991 recommended that the drinking water distribution system be changed in such a way to make sure that only one treatment plant or reservoir serve a given section of the city.[61] Under the current system treatment plants and reservoirs release treated water into the distribution system where it mixed with other treated water. When drinking water quality problems arise at distribution points there is no way of knowing exactly which treatment plant or what part of the distribution system the problem is coming from. They believe that if the treatment plants and distribution system were separated according to area, it would be easier to pinpoint contamination problems.

In ENPHO's 1991/92 report, they recommend that to improve the microbial quality of drinking water it is necessary to have regular monitoring for chlorine in the treatment plants and distribution system. When chlorine levels fall below a certain level, boosting stations along the distribution system could raise the level of chlorine within the system.[62] Karmacharya, Shrestha, and Shakya believe this would decrease the effects of fecal contamination at distribution points.

In a report for the DWSS and its Water Quality Monitoring Program, Mr. Pandit makes recommendations on the structure and components of a good water quality monitoring regime.[63] He recommends selection of monitoring sites based on source type and a site reconnaissance. Site reconnaissance would include a survey of the area surrounding a site and would emphasize areas that are the most vulnerable. The survey would focus on high priority sites and whenever possible should try to determine the mode of fecal contamination. Finally, sampling frequency recommendations would be made at a given site based on the source type and vulnerability.

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[61] Bottino et al., 1991
[62] Karmacharya, Shrestha, and Shakya, 1991/92
[63] Pandit, 1999

5 BAGMATI RIVER

5.1 BACKGROUND

The Bagmati River was studied to gain a better understanding of Kathmandu's surface water quality since the quality of surface water often affects drinking water quality and can be linked to public health problems. Some useful insights into the country and the Nepalese relationship with water were gained by observing the uses of the Bagmati even though the downstream sections are no longer used as a drinking water source. Rivers of Nepal, especially the Bagmati, are traditionally sacred to Hindus and are used in their worship. The Bagmati is famous for its associations with the Goddess Ganga and Lord Pashupatinath.[64] It is also used for irrigation, bathing, washing, and recreation.

The Bagmati is important to the traditions of the Nepalese, but it also has severe water quality and pollution problems. Most private and industrial wastewater generated in Kathmandu is discharged into the river without treatment. Despite its very low quality caused by all the wastes entering the river, the Bagmati is still used by many people. The goals for studying the Bagmati River were to observe how people use the river, assess how the water quality is changing over time, and determine how should be done to improve it. Therefore, the Bagmati was followed from close to its headwaters through the city and to the southern Valley. Observations were made on how people used the river and the location of some major and minor sewage discharges. Also, a small number of water samples were taken and tested for their microbial content.

The Bagmati River originates in the Sundarijal protected watershed area in the north of the Valley where stream flow is generated from springs and monsoon generated runoff. A map of the Kathmandu Valley highlighting the Bagmati is show in Figure 14. The Mahabharat range that forms the Kathmandu Valley surrounds the upper Bagmati sub-basin and the Valley basin ends at the Chobhar gorge.[65] The Valley's area is approximately 622 km^2 and it has a population of 1.4 million people that is growing 3.8%

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[64] Shrestha and Sharma, 1996

[65] Paudel, 1999

annually. There are several major tributaries to the Bagmati in the Kathmandu Valley including the Bishnumati, Dhobi Khola, and Manohara.

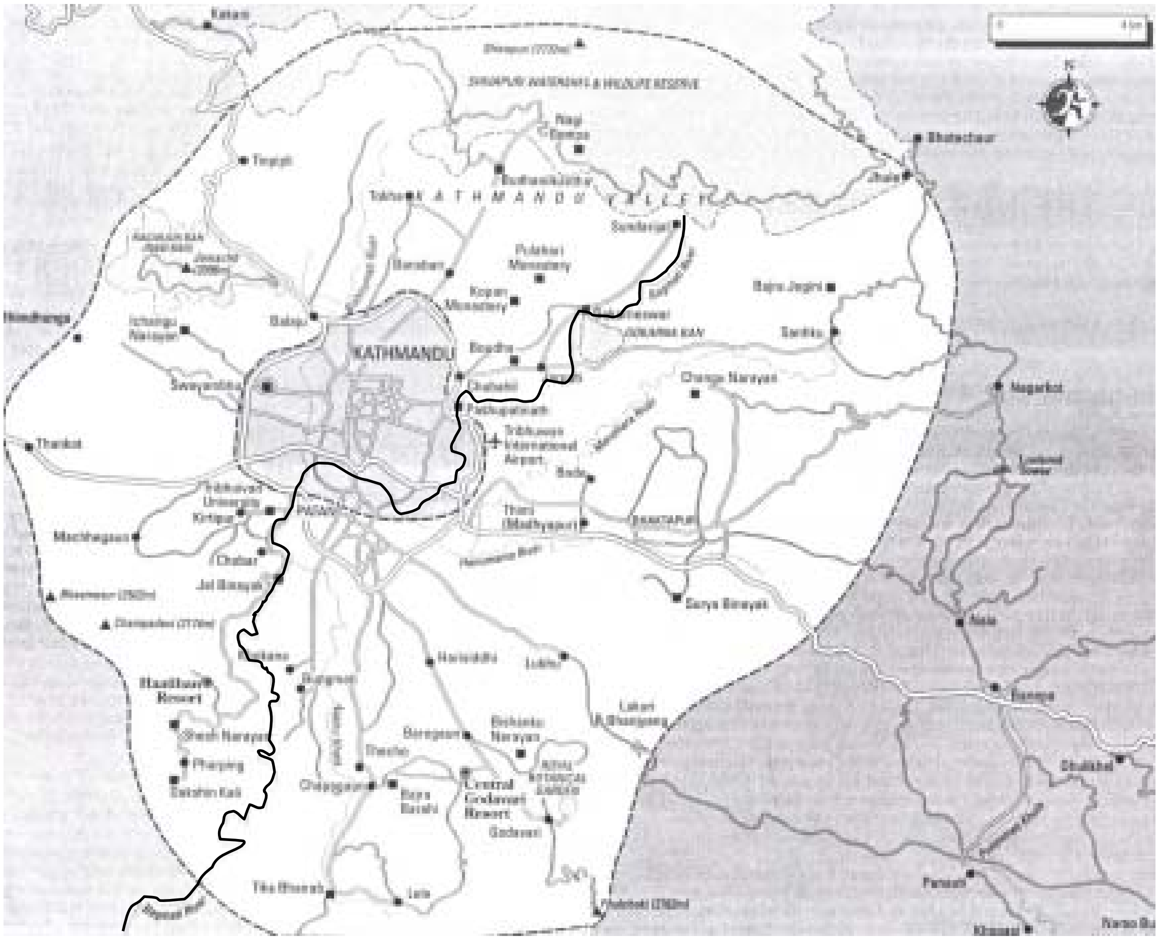

Figure 14: Map of the Kathmandu Valley Highlighting the Bagmati River.[66]

5.2 SAMPLING RESULTS AND OBSERVATIONS

In an effort to see as much of the Bagmati River as possible the river was divided into six sections from Sundarijal to south of Chobhar. These sections included Sundarijal to Gokarna, Gokarna to Bouddha, Bouddha to Gaushala, Gaushala to the Sankhamul Ghat, the Sankhamul Ghat to Sundarigat, and finally Sundarigat to south of the Chobhar Gorge. All stretches were observed except Gaushala to Sankhamul Ghat. Walks along the Bagmati were taken during the morning and early afternoon of five days in Kathmandu. During these walks field notes were taken and samples were collected, see Figure 15.

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[66] Reed, 1999

Figure 15: Picture of me sampling on the Bagmati River.

Table 6 summarizes the results of the analysis performed on the nine Bagmati Samples collected. Once again, like the drinking water test results, not all samples that were positive for total coliform and *E.coli* were also positive for H_2S producing bacteria. Turbidity does appear be generally increasing further downstream.

TABLE 6: BAGMATI RIVER SAMPLE ANALYSIS.

Sample	# positive for H_2S of 5	Total coliform	*E.coli*	Turbidity	Comments
1	2	+	+	N/A	Sundarijal
2	0	+	+	N/A	A tributary downstream of Sundarijal
3	5	+	+	16.5	Gokarna Mahadev Temple
4	5	+	+	40.5	Agricultural area downstream of Gokarna
5	5	+	+	27.5	Under the Jorpati bridge
6	5	+	+	14.5	Near Basukichok
7	5	+	+	72	Upstream of the Gujeshwari Temple
8	0	+	+	68.5	At the Pashupatinath Temple
9	0	+	+	N/A	Tributary Nakha Khola

Sundarijal to Gokarna

In Sundarijal, the Bagmati runs at the bottom of a small Valley whose bed is lined with very large boulders as shown in Figure 16. The water looked fairly clear with good aeration and though the water level was low, usually less than one or two feet deep, it showed signs of having higher depths during the rainy season. There were many pipes for the Sundarijal reservoir and treatment plant running down the Valley and across the river. The town of Sundarijal was next to the riverbank. Several outfalls emptied into the river near the town. The water from these outfalls did not look like or smell like sewage. A water sample was taken near Sundarijal. It was positive for total coliform, *E.coli*, and H_2S producing bacteria.

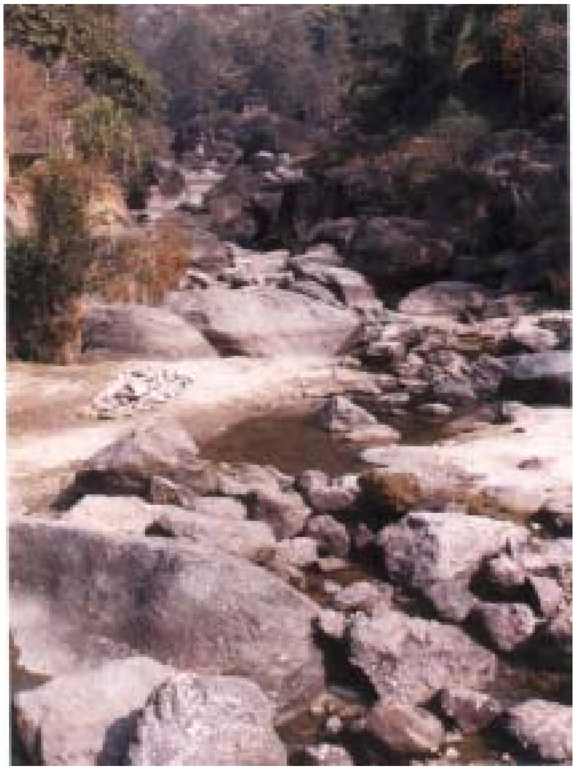

Figure 16: Picture of the Bagmati near Sundarijal.

After leaving Sundarijal, the Valley turned into a flat agricultural plain and the Bagmati lost much of its clarity. In many places the river was diverted into earthen irrigation channels and water was used to water crops. Some farmers were observed washing their clothes and animals in the river. Figure 17 shows two very happy water buffalo having their daily bath. Near here there were areas where gravel mining was taking place. In these area people dug gravel out of the riverbed. Then the gravel was put on trucks that drive up and down the river as shown in Figure 18.

Figure 17: Picture of farmers washing water buffalo in the Bagmati.

Figure 18: Picture of a truck removing gravel from the Bagmati.

There were several small tributaries running into the Bagmati north of Gokarna. One of these, Thulo Khola, was sampled. The sample from Thulo Khola was positive for coliform and *E.coli* but not H_2S producing bacteria.

Gokarna to Bouddha

At Gokarna, the river is still a small stream with a low volume but fairly fast flow rate. A sample was taken near the Gokarna Mahadev temple, an ancient Hindu shrine. There was a lot of debris in the river, some of it organic material such as leaves and the leaf plates that people use and some non-organic material such as plastic bags. Figure 19 shows the temple right next to the river and all the debris nearby. People were picnicking by the river, there were also ducks swimming and feeding near by.

Figure 19: Picture of the Gokarna Mahadev temple next to the Bagmati River.

The next sample was taken downstream of Gokarna, near Atarkhel. This spot was downstream of a small riffle where the water was turbid. In this stretch, the land adjoining the river is fairly agricultural with grazing areas for livestock and heavily eroded banks as seen in Figure 20. Near the riverbank was a small wool mill or carpet factory and a carding or weaving machine was heard. There was a reddish effluent coming from the mill. Houses lined the road about a quarter of a mile away; the population density appears moderate.

Figure 20: Picture of river bank erosion near Gokarna

The third sample this day was taken just after the Jorpati Bridge. Among the garbage under the bridge was a dead dog, human feces, and a sewer outfall. Before the bridge there was a wool drying area and women washing clothes and bathing. Wool drying activities, such as those shown in Figure 21, were seen several times over the course of several days. This whole section was fairly barren and agricultural and the current remained strong with a low volume.

Figure 21: Picture of wool drying on river bank and laborers in river.

The last sample for this day was taken near Basukichok, which is close to the end of the Tribhuwan International Airport's runway. There were lots of cows both in and next to the river and some small industry. The lower stretch of this section had Gabian blocks along the bank, some blocks are shown in Figure 22. The blocks looked fairly new and had probably been constructed to protect against erosion of the fields. A sewer line ran parallel to and about 100 feet away from the river. In parts the sewer was open and sewage pooled around in the open, sometimes in fields as shown in Figure 23. There was construction in progress for the sewer line and the Gabian blocks. Eventually, the untreated sewage spilled right out into the river as shown in Figure 24. All samples taken this day were positive for H_2S bacteria, total and fecal coliform, and *E.coli*.

Figure 22: Picture of gabion blocks

Figure 23: Picture of an open sewer in a field next to the Bagmati River.

Figure 24: Picture of a large outfall discharging raw sewage into the Bagmati River.

Bouddha to Gaushala

Sampling and observations between Bouddha and Gaushala was concentrated around the Pashupatinath temple. It started where sampling downstream of Gokarna left off. The entire day was spent upstream and downstream of the temple area. The water in this area both looked and smelled like raw sewage. Two samples were taken, one upstream of the Gujeshwari Temple and one right at the Pashupatinath temple.

The Gujeshwari Temple area was just downstream from construction and agricultural areas. The river was about 15 feet wide and 1 foot deep here with a swift current and looked and smelled like raw sewage. One sewage outfall at the Gujeshwari Temple was near an area of worship as shown in Figure 25. At the Pashupatinath Temple area there were people worshiping and performing cremations. The temple area is in a highly developed gorge, not a flood plain like much of the rest of the riverbank. The cremations necessitated that some people enter the river to worship and clear ashes as shown in Figure 26. Just downstream of the temples a laborer was mining gravel from the middle of the river using a small shovel as shown in Figure 27. Trash can be seen lining the banks in this picture.

Figure 25: Picture of the sewage outfall at the Gujeshwari Temple.

Figure 26: Picture of a cremation at the Pashupatinath Temple.

Figure 27: Picture of man digging gravel from the Bagmati.

Samples taken around between Buddha and Gaushala were both positive for total and fecal coliform as well as *E.coli*. There was an unusual result for H_2S bacteria: the Gujeshwari Temple samples all indicated a presence of H_2S bacteria, but the Pashupatinath temple results indicated no H_2S bacteria. These results must be due to error in sampling procedure because the two samples were only taken ¼ to ½ a mile away from each other.

The most interesting discovery of this day was a sewage treatment plant under construction. Engineers at this plant told us that the treatment plant would provide both primary and secondary treatment and showed us the diagram of these plans as shown in Figure 28. The plant was supposed to be finished in about a year, though construction had not begun yet. The treatment plant would supposedly reduce the BOD in the river from what they said was its current level of 300 mg/L to 25 mg/L. Engineers also informed us that they were going to build a by pass tunnel which would take the treated sewage past the Gujeshwari and Pashupatinath temples and discharge it downstream. The motivation for both the treatment plant plans and the bypass tunnel was religions. The river plays a central role in Hindu worship and Pashupatinath, right downstream of the treatment plant, was being actively used for religious purposes. Part of the worship ceremony involves drinking a little bit of river water and this could no longer be done since the water quality of the river was so poor.

Figure 28: Picture of the sewage treatment plant plans.

Thapathali to Sundarigat

The stretch from Thapathali to Sundarigat was similar to the areas around and south of Pashupatinath. There were piles of trash everywhere, lots of human and animal feces along the banks especially near bridges and agricultural areas, and many sewer pipes draining what looked and smelled like raw sewage straight into the river. The few direct river uses observed included several areas of Hindu worship characterized by red powder and rice and signs of individuals mining gravel.

Even though there was minimal direct river uses, there were signs of indirect river uses. There were also many activities that people did right next to or near the river. Theses activities included several groups of women washing (see Figure 29), children playing soccer and retrieving a soccer ball from the river, several tent clusters right near the river bank, a small market selling meats (see Figure 30), a slaughter house, and several agricultural patches. In one area there was an area on the riverbank planted with trees.

There were also some sections of the river with Gabion blocks that were probably several years old. No samples were taken in this stretch because the water quality was so poor.

Figure 29: Picture of women washing clothes next to the River.

Figure 30: Picture of a meat market next the River.

Sundarighat to Khokana

The furthest downstream on the Bagmati that was explored was the section between the Central Lab and south of the Chobhar Gorge. This southern section of the river was much less populated than the sections and around the city though there were a few squatter tents along the bank as shown in Figure 31. There was a lot of agricultural activity in the area but for the most part it was not right next to the river. Fewer piles of garbage lined the bank further south, however the river never lost its raw sewage look and smell. One sample was taken this day from Nakhu Khola, a small tributary to the Bagmati.

Figure 31: Picture of squatter tents along the river bank.

Nakhu Khola was a fast flowing little stream with riffles and bed of small boulders reminiscent of the upper stretches of the Bagmati near Sundarijal. The water looked clear with low turbidity in comparison to the Bagmati. It was flowing from an agricultural area and the water did not have much trash. From this tributary the river went into another gorge larger than the one at Pashupatinath as shown in Figure 32. There was a very large cement factory and more agricultural areas on the other side of the gorge. The Nakhu Khola sample was positive for both fecal and total coliform as well as *E.coli*, but was negative for H_2S producing bacteria.

Figure 32: Picture of the Chobhar Gorge.

5.3 OTHER FINDINGS

Several other studies of the Bagmati were investigated to obtain a more complete understanding of the surface water quality in the Kathmandu Valley. These other studies, combined with the above observations made in January 2000, make for a better analysis of the water quality of the Bagmati and its tributaries and reveal trends in water quality over time. The additional observations and data in this section comes from several sources including a 1990 article in the Journal of the Nepal Chemical Society, a study by ENPHO on the trend of degrading water quality in the Bagmati River over time, and two reports on Bagmati water quality management by Arjun Paudel.

In the late 1980's, the water quality of the Bagmati was pretty good upstream of the densely populated urban areas. Pradhananga et al said that the main causes of pollution was untreated sewage discharged into the river, though other activities such as dredging and gravel excavation were also sited as adversely effecting the river ecosystem.[67] At the time of this study, the poorest quality water was found just south of Kathmandu City around Thapathali and Sundarigat. While still polluted as it exited the Valley, the Bagmati was able to recover slowly as it moved downstream. However, highly polluted water still persisted 10 km south of the urban center.

Pradhananga et al also identified most of the poorest water quality as in the Bagmati's tributaries: Bishnumati, Dhobi Khola, and Manohara. The authors describe the Bishnumati at Kalimati, a dense urban area of Kathmandu, as follows: "The banks are covered with every sort of waste while the stream looks like sewage. The river has high turbidity and the bed is covered with a black layer and animal carcasses."[68] Other tributaries were also described as having a lot of animal carcasses.

Then in 1996 a study was performed by Shrestha and Sharma that studied the trends in water quality of the Bagmati from 1988 to 1995.[69] The main conclusion of this report was that water quality keeps worsening and the sections of river around the city are getting worse the fastest. The water quality on the whole river was worsening quickly and some chemical parameters were found to have increased by 300% in two years. The study also found that seasonal disease outbreaks might be linked with river water quality since people still use the river for vegetable washing, bathing, clothes and utensil washing, and irrigation.

Figures 33 and 34 are from two sampling stations and show several interesting things about the water quality on the Bagmati. First, these figures show the water quality was worsening over time. The dissolved oxygen concentrations were decreasing while the biochemical oxygen demand (BOD) and ammonia concentrations were increasing. It also shows that the water quality was worse as the river progresses downstream and receives more sewer discharges. At Sundarighat, which is about 8 km downstream from

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[67] Pradhananga et al, 1990

[68] Pradhananga et al, 1990

[69] Shrestha and Sharma, 1996

Pashupatinath, the concentration of DO decreased in all years while the concentrations of BOD and ammonia increased for all years.

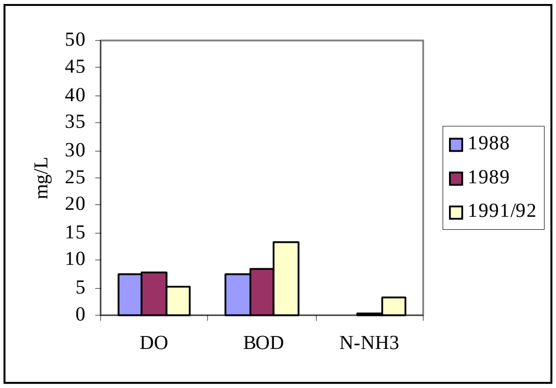

Figure 33: DO, BOD, and ammonia concentrations at Pashupatinath

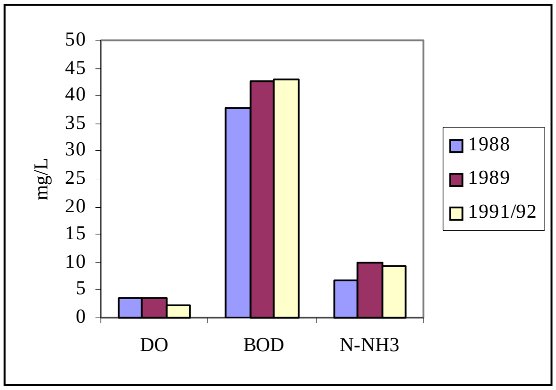

Figure 34: DO, BOD, and ammonia concentrations at Sundarighat

The coliform content of the Bagmati also gives an indication of increasing pollution as the river progresses downstream. Figure 35 shows the total coliform levels for five different sampling stations: Sundarijal, Pashupatinath, Thapathali, Sundarighat, and Chobar. Since the y-axis for this graph is on a log scale, it is obvious that the pollution increases drastically as it moves downstream. Worsening pollution occurs until Sundarighat. After that there are no major sewage discharges and the natural ability of the stream to recover and the dilution effect of some relatively clean tributaries lessen the Bagmati’s total coliform concentration.

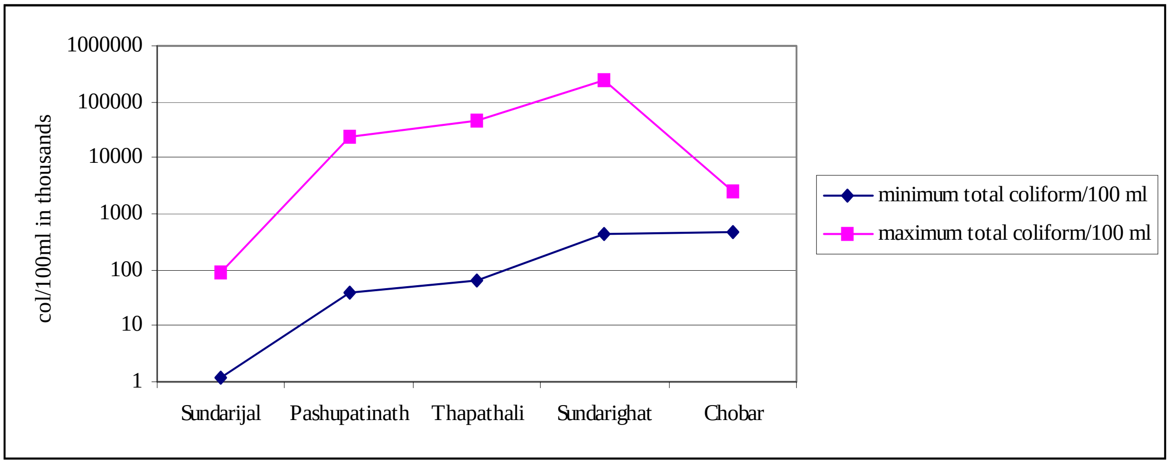

Figure 35: Minimum and maximum number of total coliform at progressive sampling stations.[70]

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[70] Shrestha and Sharma, 1996

As described in the observations, much of the domestic wastewater which is produced in the Kathmandu Valley flows into the streams giving the river the look and smell of raw sewage. The degradation of the Bagmati's water quality and ecology has been increasing due to rapid population growth and the expansion of urban areas in the upper Bagmati sub-basin without adequate wastewater treatment systems.[71] Waste disposal into the river currently exceeds the river's natural capacity to recover.

In addition to domestic wastewater, there are also other sources of pollution into the Bagmati River. It has been estimated that while Kathmandu's industries are not numerous, they discharge 2.1 million cubic meters of wastewater into the river each year.[72] Most of this discharge is from carpet factories. At this time, most of the pollution concern from industries is from BOD loading. However, the total BOD loading by industry into the river system is insignificant compared with domestic waste since estimates show that industrial wastewater accounts for only 7% of all BOD that enters the river. Leachate from solid waste is another source of water pollution.

Stormwater and agricultural runoff are also pollution sources of concern. The first rain of the monsoon causes a high level of pollution on the Bagmati River because of all the wastes that are washed off the streets.[73] Not all the waste that enters the river at the first rain event of the season are chemical or biological. There is also a lot of trash and garbage on the streets and in the gutters that would also get washed into the river. With increasing populations in the Valley there are increased uses of chemical fertilizers used. Fertilizers use has become necessary because intensive farming has caused infertility in the topsoil, so runoff contains fertilizers as well as some pesticides.

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[71] Paudel, 1999

[72] Paudel, 1998

[73] Paudel, 1998

5.4 DISCUSSION AND RECOMMENDATIONS

Along with the changing water quality in the Bagmati over time, there has also been a change in the recommendations put forward to improve water quality on the Bagmati. In 1990, despite water quality problems that lead to water quality characterized as "severely polluted" around the densely populated urban areas of Kathmandu, the recommendation for water quality improvement was that "in order to avoid a further deterioration of the environment proper measures should be adopted as soon as possible."[74] This is based on the fact that the river had lost much of its ability to recover from the wastewater discharges and was still highly polluted far downstream of the city.

By 1996, the recommendations for improving water quality had increased and become more specific and policy oriented. Shrestha and Sharma wanted industries to be encouraged to install wastewater treatment systems and they also wanted to control household sewer connections.[75] They advised that many small community-scale sewage treatment systems would be better than a large central treatment system. To protect the ecology of the river they suggested that the bank be protected, sand a gravel excavation prohibited, water quality monitored, and a green belt maintained. All of these policies and legislation should be supported by specific guidelines for improvement and preservation of the river given by the Ministry of the Environment in conjunction with other Ministries.

These recommendations from Sharma and Shestra in 1996 were much more robust than the recommendations from Pradhananga et al in 1990. Perhaps this is because there was much more data behind the 1996 report or perhaps it was because the water quality in the river had greatly deteriorated in the intervening six years and that made specific recommendations much more urgent. It was interesting to see that in January 2000 some of the recommendations given by this 1996 report had been carried out. As noted in the observations, there were many Gabion blocks lining the banks of the Bagmati north and east of the city. These blocks consist of large metal cages containing small boulders are

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[74] Pradhananga et al, 1990

[75] Shrestha and Sharma, 1996 Shakya and Sharma, 1996

used even in the United States to prevent erosion of riverbanks. These visible indications of governmental effort were an optimistic sign for increased focus on river protection.

The ever-increasing pollution loading onto the river has made some of the more recent recommendations even more specific. In his 1998 and 1999 articles, Arjun Paudel is adamant that specific rules and regulations must be enacted in order to achieve better water quality on the Bagmati. He argues that effluent standards for wastewater discharge and ambient standards for surface water quality are necessary.[76] These standards would help in designing wastewater treatment plants. It would also make penalty enforcement for severe polluters possible. He, like Shrestha and Sharma, would like to see small sewage treatment plants constructed in communities instead of large centralized treatment systems.

The plan for constructing small treatment plants makes sense because with small treatment plants there could be local goals and incentives for improvement. It would also make waste a community issue, not just a central government problem. Further, with the old pipeline infrastructure, treating waste close to its origin would reduce the likelihood of leaks and spills. However, small community treatment systems would have to be combined with a public awareness campaign so people would be familiar with the problems with discharging untreated sewage into the river and the benefits that could be gained by having a cleaner river.

Paudel also raises the moral issues of watershed wide planning since the Bagmati River is a shared natural resources and upstream users have to be sensitive to people downstream.[77] He also shows that the degraded water quality of the Bagmati due to discharges in the Kathmandu area affect the people downstream of Kathmandu. If Kathmandu produces so much pollution that it destroys the Bagmati and makes the water unsafe, it is not only the people of Kathmandu that suffer but also everyone else in the watershed.

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[76] Paudel, 1998

Given the rapidly worsening water quality on the Bagmati River, it seems that a high priority should be given to all these recommendations. The first element of a water quality improvement plan would be to enact legislation that sets effluent and ambient standards and assigns responsibility for a monitoring and enforcement agency that is independent from a water and sewage agency. There are many good reasons for the construction of many small community-based treatment systems as opposed to several large region-wide plants. Building small systems would allow resources to be concentrated in critical areas that produce the most pollution before areas of less pollution. A basin-wide watershed planning would respect the needs of downstream people to not receive the waste of upstream users. And, it would also help target specific problem areas to avoid further degradation and encourage on site industrial wastewater treatment.

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[77] Paudel, 1999

6 CONCLUSION

This paper has highlighted some of the major water quality problems in the drinking water supply and the Bagmati River in the Kathmandu Valley. It was shown that the microbial quality of drinking water varies depending on where it is sampled. Water from wells was microbially contaminated 50% of the time, water from spring or stream sources was always contaminated, water in outflow of Mahamkal, Balaju, and Maharajganj treatment plants was not contaminated, and at least 50% of water at distribution points was microbially contaminated. It was also shown that pollution problems vary seasonally and that drinking water pollution can be directly related to the incidence of waterborne disease. Water quality on the Bagmati was found to be very poor and worsening over time. This was problematical because many people still use the Bagmati River for washing clothing, worship, and other activities. A number of recommendations were explored in this report. These recommendations are summarized in Table 7 below.

TABLE 7: RECOMMENDATIONS FOR DRINKING WATER AND RIVER WATER QUALITY IMPROVEMENT.

	Drinking Water	Bagmati River
Regulatory	• Set water quality standards • Set responsibilities of the water supply agency and the consumer	• Enact rules and regulations on effluent and ambient water quality • Penalize severe polluters
Policy	• Fully funded drinking water quality monitoring program • Disclose water quality problems to the consumer • Train people in hygiene and household treatment • Increase community involvement • Increase drinking water coverage • Redefine the roles of different levels of government • Properly dispose of sewage	• Encourage industry to install waste water treatment systems • Control household sewer connections • Protect stream from erosion and gravel excavation • Basin-scale planning • Educate the community about untreated sewage
Technical	• Link the distribution system to a specific treatment plant • Chlorinate adequately • Develop a rational monitoring plan	• Install Gabion blocks along the banks of the rivers • Focus on small scale, not large scale treatment plants

It is clear that to improve drinking water quality in the Kathmandu Valley regulations, policy, and technical recommendations all need to be implemented. First and foremost, regulations that deal solely with water quality standards and the roles and responsibilities of government water suppliers to consumers need to be specified. Without these regulations water suppliers have no legal responsibility to the people they serve.

Then HMGN needs to formulate and implement a policy that will improve the quality of water delivered to the entire population. It appears from their stated policies that they feel their role must be limited and they will mainly facilitate drinking water improvement projects that are funded and implemented by outside agencies. If this is the case, they should not take their role as facilitator as an excuse to cease involvement in the process. Rather they should have an active role in coordinating the varying resources, directing attention at those places that need the most assistance, and stressing the needs and values particular to the Nepalese people. NGOs and INGOs who are concerned with drinking water quality and supply issues should concentrate on working with HMGN while insuring that the needs of the communities they are working for are met.

Many technical improvements are also necessary. Short-term goals should involve devising and implementing a robust monitoring program operated by an agency independent of the water supply and sanitation agencies (the DWSS and the NWSC) and promoting effective, low cost, sustainable household-level water treatment systems. There also needs to be a long-term sustained effort to improve the drinking water distribution system infrastructure since it appears very likely that the current system leaks and contaminates the drinking water supply with microbial matter. Without an improved system the construction and improvement of drinking water treatment plants is redundant as purified water is recontaminated in the distribution system anyway.

It has also become very necessary to improve water quality conditions on the Bagmati River because contact with the raw sewage is also likely to cause health problems. Recommended solutions to problems on the Bagmati are similar to those for improving drinking water quality. Regulations and policy need to be in place so that people are held accountable for the problems and there is a plan for improvement. Technical recommendations involve improvement of sanitary waste disposal. It is unclear that large wastewater treatment plants would be effective in dealing with the many wastewater discharges. A far better plan seems to be building many smaller treatment plants. This might be more economically feasible and would decrease the likelihood of leaking sewage pipes. It must not be forgotten that the health of the Bagmati River effects the health of many Kathmandu residents. To improve the quality of life of the population it is not enough to correct the problem of drinking water, surface water quality and sanitation must also be addressed.

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APPENDIX: RAW DATA

KATHMANDU VALLEY DRINKING WATER SUPPLY DATA

Sample Number	Location of Well/Water Source	Source Type	Turbidity	H2S/ MPN	P/A	*E. coli*	Comments
18/01	Dathali Public Water Supply, Intake to sedimentation tank - directly from nearby streams; Near Bhaktapur	TP-SS	1	5	N/A	N/A	Dathali Water Supply; System is 13 years old which serves a population of about 10,000 people; Two reservoirs - currently only one is working; The only treatment used is a sedimentation tank; The source is from three nearby streams; Yield is 1.5 L/sec; Area has heavy agricultural, heavy use of fertilizers; crops include wheat, potatoes, mustard, tomatoes, garlic, and cauliflower; During rainy season, water quality declines visually; Algae growth in tank; no cover on sedimentation tank - photosynthesis can occur; no tests ever conducted on this water source
18/02	Dathali Public Water Supply, Sample from sedimentation tank: Near Bhaktapur	TP	0	0	N/A	N/A	
18/03	Dathali Public Water Supply, Water tap in distribution system: Near Bhaktapur	P	0	5	N/A	N/A	
18/04	Kiwachowk Public Water Supply, Water tap near outflow from above ground tank: Near Bhaktapur	P	13	5	N/A	N/A	Kiwachowk Water Supply; Water from 5 or 6 springs is collected and pumped into a large covered above ground tank; Spring source is 3.5 km away near cultivated agricultural lands; no water quality testing ever performed
19/02	Thimi household	TW	12	0	-	-	Tube sticking out of ground with a plunger used to pump water to surface - depth estimated to be consistent with depths of other hand dug wells
19/03	Thimi	P	42.5	0	-	-	Kyung Hee Nepal Health Centre, sink
19/04	Thimi local market	R	3.5	0	+	-	Drinking water
19/05	Thimi	R	8.5	0	+	-	Drinking water, Chandramukhi Cabin Restaurant
19/06	Kirtipur	P	3.5		N/A	N/A	Central laboratory tap water
20/02	Patan	TD	3.5	0	+	+	Durbar Square water spout; used for drinking and bathing; traditional water source
20/03	Patan	R	6.5	0	+	+	Cafe du Temple Restaurant tap water; used for drinking
20/04	Kathmandu	R	5	0	+	-	Kathmandu Guest House tap water; used for drinking; Sonde results showed nitrate concentrations at 14 mg/L
20/05	Kathmandu	R	16	0	+	-	Pilgrim Restaurant and Bar Tap water; used for drinking; filtered at restaurant before use
23/01	Naikap, source of water to system from sump well	TP-SW	6	1	-	-	Naikap treatment system, 762 households, near Balkhu stream (polluted), industrial (automobile, food processing, oil tankers) and agricultural (rice) sites upstream, system provides water 1 - 2 hours per day, Naikap is 5 km from Kathmandu city center, Pump house takes water from 2 sources (1) sump well 2 ft below Balkhu

23/02	Naikap, source of water to system from tube well	TP-TW	9	0	-	-	Stream bed and (2) deep tube well 100 ft. deep in pump house
23/03	Naikap, sample from Balkhu Stream that feeds sump well	TP-SS	15	0	+	+	
23/04	Naikap, sample from treatment system aeration tank, only deep tube well water, tube well and sump well water combine after aeration	TP	9	2	-	-	
23/05	Naikap, after filtration	TP	4.5	N/A	+	+	
23/06	Naikap	TD	7.5	0	+	+	Traditional source, people use this water because they think it is better than the municipally supplied treated water
23/07	Sitapaila	TP-SS	10.5	0	+	+	Stream surface water source, pipeline takes untreated water from stream for water supply
24/01	Kathmandu	R	2	0	-	-	Store in front of Royal Palace, municipal tap water, used for drinking
24/02	Kathmandu	TD	1	0	-	-	Sundhara public water spout used for bathing and drinking, traditional water source
24/03	Kathmandu	R	4	2	+	+	Store near Sundhara
25/01	Kathmandu	R	2.5	0	+	-	Drinking water from a store near Kathmandu Durbar Square
25/02	Kathmandu	TD	3	1	+	+	Naradeni Spout; traditional water source for bathing and drinking
25/03	Kathmandu	TW	4	0	+	-	Hand pump near Kathmandu Durbar Square
26/01	Mitrapark/Cholobol	R	3	0			On the road to Bouddha; store in Mitrapark near Temple, drinking water
26/02	Mitrapark/Cholobol	R	4	0	-	-	On the road to Bouddha, store in Mitrapark on main street
26/03	Mitrapark/Cholobol	TW	5	1	-	-	On the road to Bouddha, hand pump well used for drinking
26/04	Mitrapark/Cholobol	TW	6.5	1	+	+	On the road to Bouddha, hand pump well used for drinking
26/05	Mitrapark/Cholobol	TW	6	5	N/A	N/A	On the road to Bouddha, hand pump well used for drinking
26/06	Mitrapark/Cholobol	TD	10	1	N/A	N/A	On the road to Bouddha, water spout near bus station
TP1	Mahankal	TP-DBW	1.77	N/A	-	-	
TP2	Mahankal	TP	13.3	N/A	-	-	
TP3	Mahankal	TP-SS	0.58	N/A	+	+	
TP4	Mahankal	TP-out	1.24	N/A	-	-	
TP5	Balaju	TP-DBW	6.01	N/A	-	-	
TP6	Balaju	TP-out	1.25	N/A	-	-	

TP7	Maharajganj	TP-out	1.99	N/A	-	-	
* key: HD = hand dug well, P = piped, R = store or restaurant, TD = traditional source, TP = within treatment plant, TP-DBW = deep boring well feeding treatment plant, TP-out = treated water, TP-SS = stream into TP, TP-SW = sump well into TP, TP-TW = tube well into treatment plant, TW = tube well							