Wastewater Treatment in Kathmandu, Nepal

by

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1 Introduction

1.1 Motivation

January 2003 marks the fourth straight year that a group of MIT students and staff have traveled to Nepal to study pressing water quality concerns. In the past, student projects have focused on improvements in drinking water quality, concentrating on household treatment systems such as filtration and/or disinfection approaches, with special attention given to microbial contamination and arsenic. While these projects are ongoing, three students from the class of 2003 elected to form a group with a new water quality focus: wastewater treatment and sanitation.

When it comes to basic sanitation, Nepal lags behind all the other nations of South Asia as well as most other developing countries. It has been estimated that only 27% of the population of Nepal has access to sanitation (Human Development Report, 2003), while the average is 44% among developing countries worldwide (UNICEF, 2003). Nepal's per capita gross domestic product (GDP) is $240 US, and only 0.5% of this (annually $1.20 US per capita) is spent on drinking water and sanitation (Human Development Report, 2003).

In urban areas like the cities within Kathmandu Valley (population 1.3 million) and especially Kathmandu City (population 500,000), the lack of basic sanitation has been devastating to the quality of local streams and rivers, namely the Bagmati and Bishnumati Rivers. Methods of sanitation lacking in much of Kathmandu include adequate wastewater collection and treatment, toilet facilities and solid waste collection and disposal. Agricultural runoff and industrial discharge without pretreatment contribute to the detrimental effects on water quality, not to mention public and environmental health.

1.2 Existing Wastewater Treatment in Kathmandu

Kathmandu Valley currently has five municipal wastewater treatment plants (WWTP): an activated sludge plant at Guheshwori, non-aerated lagoons at Kodku and Dhobighat, and aerated lagoons at Sallaghari and Hanumanghat. Of the five, the only wastewater treatment plant in operation as of January 2003 is the activated sludge system at Guheshwori.

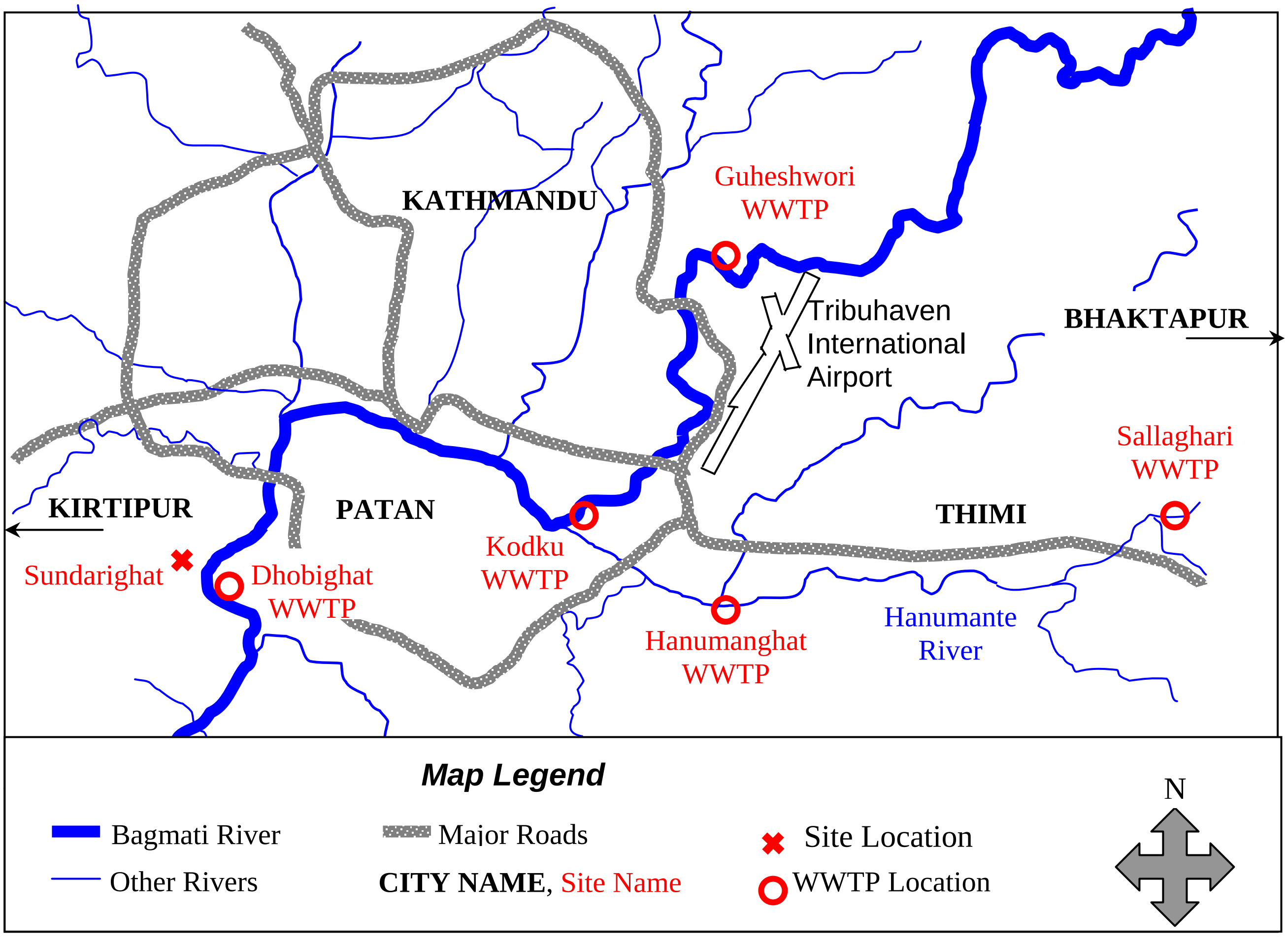

Figure 1: Map of Wastewater Treatment Plants in Kathmandu Valley (ADB, 2000)

The Kodku WWTP lies along the Bagmati River in the city of Patan (Figure 1). The Kodku plant is a non-aerated lagoon facility with a design capacity of 1.1 MLD (ADB , 2000). The 2000 ADB Report lists the plant's status as "partially operational." MIT Nepal Project team member, Tetsuji Arata, observed in January 2003 that the performance of the facility was doubtful, as effluent discharged into the Bagmati River "was bubbling" and smelled "just like that of sewer water" (Arata, 2003).

The Dhobighat facility is positioned downstream from Kodku, in the southwest area of Kathmandu Valley (Figure 1). Designed in 1978, the plant was built with a capacity of 15.4 MLD (ADB , 2000). Today, estimated sewage flow for the area exceeds 120 MLD (Darnal, 2002). In this plant, gravity-driven sewage flows to a sump well at Sundarighat (Figure 1), where it is pumped to the plant at Dhobighat, consisting two non-aerated lagoons and one facultative pond. The pump station at Sundarighat, the pump main and the interceptors along the Bagmati and Bishnumati Rivers are all broken in places, so untreated wastewater drains directly into the Rivers (Darnal, 2002). As of January 2003, this plant was used as a pasture for cattle (Arata, 2003).

Sallaghari and Hanumanghat WWTP's both lie along the Hanumante River in Bhaktapur, upstream from its junction with the Bagmati River near Kodku (Figure 1). These treatment facilities were designed as aerated lagoons, with capacities of 2.0 and 0.5 MLD, respectively (ADB, 2000). The 2000 ADB Report describes both plants as partially operating and in need of rehabilitation.

Tetsuji Arata observes in January 2003 that the aeration systems from both the Sallaghari and Hanumanghat facilities were removed and sold. He describes that the Sallaghari plant originally had two collection mains: a northern main with a pump feed, and a southern one using gravity feed. Since the shutdown of the plant, local farmers have removed the pump from the northern main and plugged the southern main so that inflowing, untreated wastewater could be used for irrigation purposes. Also, the Hanumanghat site is used as a crop field (Arata, 2003).
In addition to the collection systems noted above, Kathmandu Valley contains 43,000 septic tanks. Eight collection vehicles with a capacity of 1.5 m^3/vehicle service the tanks, and the septage is treated using low-energy treatment systems. Upwards of 35 truckloads of sewage a day should be collected, but "septic tank cleaning is generally performed too infrequently" (ADB, 2000). One such low-energy treatment method gaining popularity in Kathmandu and elsewhere is the constructed wetland system, a treatment facility designed to mimic and optimize the natural removal processes of natural wetlands.

Table 1: Operating Status of Wastewater Treatment Facilities in Kathmandu Valley (ABD, 2000 and Arata, 2003)

	Reported Capacity	Status	
Plant	MLD	ADB Report, Feb 2000	MIT Nepal Team, Jan 2003
Guheshwori	17.3	Under Construction	Operating
Hanumanghat	0.5	Partially Operating	Not Operating
Sallaghari	2	Partially Operating	Not Operating
Kodku	1.1	Partially Operating	Partially Operating
Dhobighat	15.4	Not Operating	Not Operating

2 Waste Stream and Bagmati River Characteristics

2.1 Overall

The Bagmati River originates upstream from Kathmandu and flows as the largest and most culturally significant river through the Valley. Upstream from Kathmandu Valley, the overall water quality is very good, but this deteriorates quickly as the river reaches the urban areas within the Valley. Table 2 presents typical water quality data of the Bagmati River at Sundarighat, a very heavily populated section of Kathmandu.

Table 2: Water Quality Parameter of the Bagmati River at Sundarighat (ENPHO, 2003)

	May, 2002	August, 2002	October, 2002	December, 2002
pH	7.0	7.3	6.7	6.5
Turbidity (NTU)	100	>100	75	180
TSS (mg/L)	166	304	92	144
BOD (mg/L)	240	54	50	109
COD (mg/L)	317	110	181	255
TDS (mg/L)	260	120	230	360
DO (mg/L)	0.7	6.4	0.4	1.9
NO_3-N (mg/L)	0.6	3.4	0.6	>10
NH_4-N (mg/L)	18	4	18	20
PO_4-P (mg/L)	1.7	0.3	1.3	1
Fecal Coliform (per 100 mL)	230×10^4	2×10^4	5.6×10^4	1.8×10^4

Values are listed for each parameter during the dry season (May), the monsoon season (August), the post-monsoon season (October) and winter (December) of 2002.

2.2 Contributions of Carpet Industry

Domestic sources contribute the majority of pollution to the Bagmati River and therefore receive the most attention. Industrial waste is often overlooked but can lead to significant pollution problems. Currently, apart from tourism, the largest industry in Nepal is the carpet manufacturing industry, which has grown immensely in the past ten years. The process of carpet manufacturing involves several steps, but those that are potentially the most damaging to the environment are the carpet dyeing and carpet washing steps. The chemicals used in carpet washing can be harmful to the environment and, as influent to wastewater treatment plants, may contribute to foaming problems. This study, however, focuses solely on the carpet dyeing aspect of the industrial waste stream of Kathmandu.

Carpet dyes can either be natural or synthetic. Synthetic dyes are used on a much wider basis because of their relative ease of use and their relatively low cost. Synthetic dyes, however can be detrimental to the environment. Not only do synthetic dyes released into surface waters such as the Bagmati add an aesthetically displeasing color to the water, effluent from the dyeing process contains chromium and can increase the COD of the water its released to.
Samples were collected from sites along the Bagmati and measured for total chromium content. The results are shown in Table 3 below.

Table 3: Chromium measurements at sampling sites along the Bagmati River

Sampling Site (from upstream to downstream)	Total Chromium (mg/L)
Sundarijal	<0.01
Jorpati	<0.01
Guheshwori	<0.01
Pashupati	0.01
Tilganga	0.03
Sundarghat	0.02
Chovar	0.03

Though most of Kathmandu Valley's dyeing companies are reportedly located near Jorpati, the only dyeing effluent outlets noticed while the authors traversed the river were located at Tilganga. This could possibly be the reason for the relatively high amount of chromium at Tilganga.

Mount Everest Dyeing Company of Jorpati, Kathmandu was generous enough to provide the authors nine samples of their dyes. These samples included four samples of dry powder dyes in various colors, four samples of the powdered dyes mixed with acetic acid, here referred to as liquid dyes, and a sample of the acetic acid that is mixed with the powder dyes to make the liquid dyes. In an effort to test the hypothesis proposed by some colleagues in Nepal that synthetic dyes increase COD, each dye was tested for its COD. The COD of the acetic acid was also measured to determine the effect of liquid dyes relative to both powder dyes and the acetic acid that they are added to. Solutions of either 1 % liquid dye or 1 % acetic acid were prepared using distilled, tap, and Charles River (Boston, Massachusetts) water for different trials. The results of the COD measurements are provided in Figure 2, except for the acetic acid results.

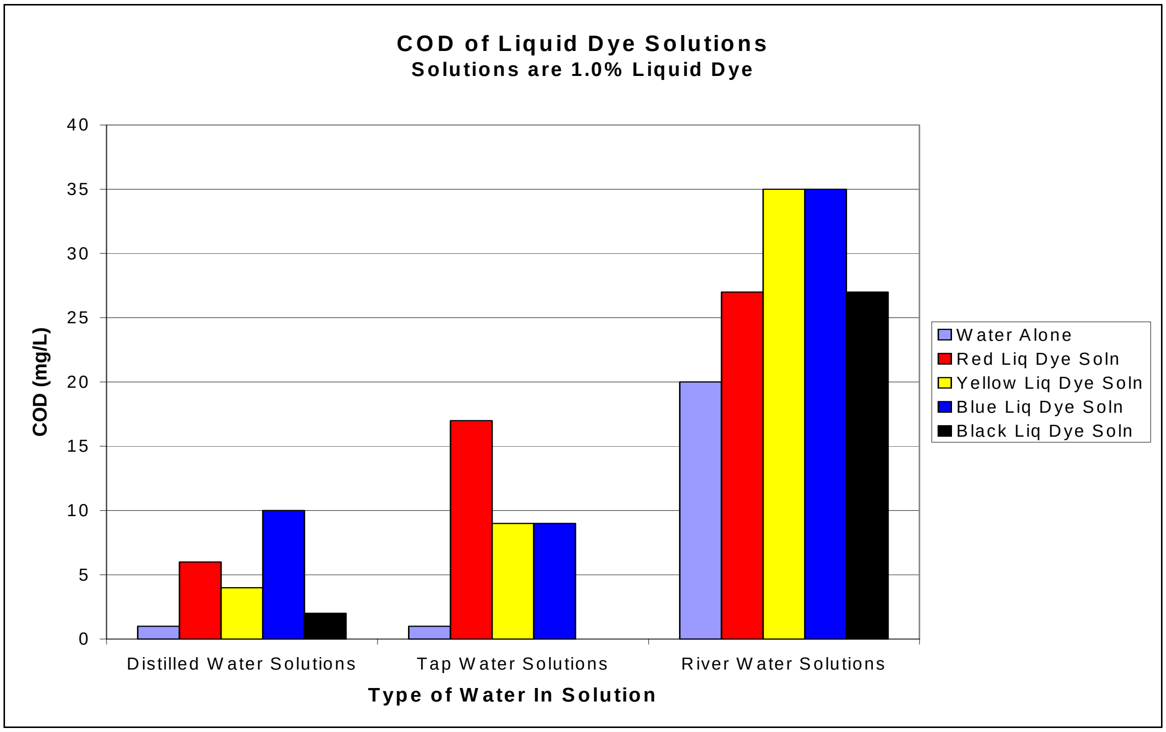

Figure 2: COD levels in 1% liquid dye solutions

The acetic acid COD concentration results are not provided because the acetic acid COD was greater than 1500 mg/L, the maximum detection limit for the apparatus used. Solutions of 25 mg/L dry dye were also prepared and their COD in Charles River water was measured. The results of this test are shown in Figure 3.

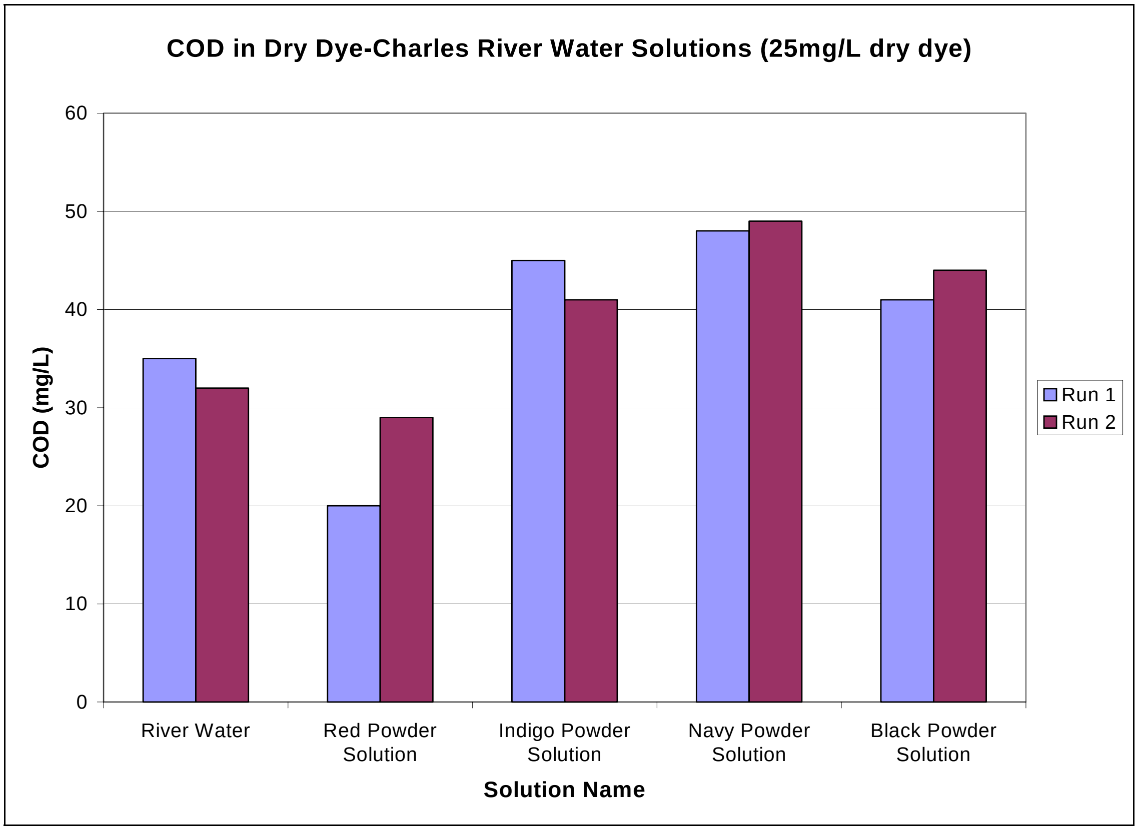

Figure 3: COD levels in 25mg/L dry dye solutions

Like the liquid dyes, the dry dyes only slightly increase the COD of water (the red dry dye actually slightly decreases the COD). It is uncertain why acetic acid would exhibit such a high COD but dry dye mixed with a substantial amount of acetic acid would not. It may be due to a chemical interaction between the acid and dye. Whatever the reason, it appears from these results that the acid used in dyeing, and not the dye itself, causes an increase in COD. Acetic acid may be a significant contributor to the high COD levels seen at Sundarighat.

2.3 Contributions of Detergent Use

As discussed earlier, only 27% of Nepali citizens have access to basic sanitation (Human Development Report, 2003). One can imagine the devastating effects such a situation has on the quality of surface waters flowing through urban areas like Kathamandu. Those without other resources rely on local surface water, namely the Bagmati and Bishnumati Rivers, for bathing, washing clothes and food, and even as a public toilet. These major rivers have become sewage discharge sites for municipal wastewater and industrial dumping grounds for local businesses with no other means of disposal.

Not only are the rivers polluted by human waste; they also serve as receiving waters for foods, health and beauty products and cleaning agents. Consumer products and medicines are becoming ever-increasingly sophisticated and complex in chemical structure, and many constituents of these products are not easily degraded even under optimal water quality conditions. These chemicals retain the properties that make them so useful in consumer products and have the potential to behave in the environment in ways we never intended.

Anionic surfactants, for example, are used widely in products ranging from shampoos to soap and detergents to household cleaners. While even high levels of anionic surfactant are non-toxic, their presence above a certain threshold results in stable foam on water surfaces. In a survey of 18 laundry detergents popular in Kathmandu households, the average detergent contains 6.6 weight percent anionic surfactants and 0.04 weight percent orthophosphates. Of the total anionic surfactants, 8% is recalcitrant under aerobic conditions. In the Bagmati and Bishnumati Rivers, where dissolved oxygen levels fall below aerobic limits at times, the anionic surfactants are expected to be much less labile.

Using the manufacturers' recommendations on the detergent labels, a typical load of wash water is approximately 25 g (1 handful) detergent in 4 L (half bucket) of water. From the anionic surfactant levels reported above, characteristic wash water for one load of laundry contains 6.25 g detergent/L, 413 mg total anionic surfactant/L and 32 mg recalcitrant or "hard" anionic surfactant/L.

The minimum concentration at which anionic surfactants foam depends on both the solvent and the level of pollution. For example, in distilled water, the foaming limit is 5 mg ABS/L. In typical wastewaters, surfactant foaming ceases at levels below 0.5 mg/L. Kathmandu City has a population of approximately 500,000 residents (Finlay, 2001). The average family size in Nepal is 6 people, so Kathmandu City is home to approximately 83,000 families. If one load of laundry is washed per family every week, using 4 L water for a load of laundry, 333 m^3 wash water is generated every week in Kathmandu City, or 5×10^{-4} m^3/s (0.011 MGD).

Flow rates in the Bagmati River are annually at their lowest during the dry season (March to May). At Sundarighat, for example, the River flowed at a rate of less than 1 m^3/s (22.6 MGD) during April 1999 (ADB, 2000). If the worst-case scenario is assumed, such that all of the wastewater generated by laundry washing is discharged into the Bagmati River, the wash water is diluted by a factor of about 2000. In such as case, the resulting total anionic surfactant concentration in the Bagmati River is about 0.2 mg/L, and the hard concentration 0.016 mg/L, both below the limit of foaming.

For total anionic surfactant levels in the River to reach 0.5 mg/L, each family unit would have to wash 2.5 loads of laundry per week during the dry season. The 2000 ADB Report estimates that residents of Kathmandu City use 25 L water/day-person (1,050 L water/week-family). It is entirely possible, then, that families would sacrifice 10 L/week for 2.5 loads of laundry/week.

Using this same analysis, one can estimate the contribution of household detergent use to foaming problems at the Guheshwori WWTP. The Guheshwori treatment plant was designed in 1996 to serve a population of 58,000 and has a treatment capacity of 0.19 m^3/s (4.3 MGD) (Figure 4).

Figure 4: Guheshwori Wastewater Treatment Plant

Once the wastewater is aerated and labile surfactants degrade, 0.08 mg/L ABS remains in the waste stream. For the ABS to cause foaming in the Guheshwori WWTP, 6 loads of laundry/week-family are required. As in the analysis of household detergent in the Bagmati River, it is certainly possible that surfactants exist in high enough concentrations to cause foaming in receiving waters.

Further, the wash water from an average load of laundry contains 2.5 mg/L orthophosphates. If each family in Kathmandu City were to wash 1 load of laundry/week during the dry season and to discharge all their wash water into the Bagmati River, household laundry detergents would contribute 10^{-3} mg phosphates/L to the River. But phosphate levels in the Bagmati River at Sundarighat were as high as 1.6 mg/L during May, 2001 (ENPHO, 2003). Each family in Kathmandu would need to wash 100 loads of laundry per week even to contribute 0.1 mg/L to this 1.6 mg/L phosphates. It is very unlikely, then, that phosphates found in household laundry detergents are major contributors to the high levels of phosphates in the Bagmati River.

The real issue with foaming in the Guheshwori WWTP and in places along the Bagmati River is not a matter of the use of soft and hard surfactants, but an indication of more serious water quality problems, namely poor surface water quality and inadequate wastewater treatment.

3 Treatment Systems

3.1 Activated Sludge Treatment Process

The activated sludge wastewater treatment process is identified by three major characteristics: a biological reactor for the decomposition of degradable organic chemicals, a settling tank for the removal of solids and biomass from the water, and a recycle stream from the settling tank to the reactor to ensure sufficient levels of microorganisms. In operation since January 2001, the wastewater treatment plant at Guheshwori is the first activated sludge treatment plant in Nepal.

This facility provides pre-treatment of wastewater with a mechanical bar rack and a grit chamber. The Guheshwori WWTP lacks primary clarification tanks. This is not unusual in smaller plants, especially when oxidation ditches are used (Harrington, 2003). The bar rack eliminates large objects from the influent, and inorganic particles like sand are removed in the grit chamber. The wastewater at Guheshwori WWTP is biologically treated in two carrouseltype oxidation ditches, each with three aerators. From the oxidation ditches, wastewater flows into two secondary clarifiers for the settling of solids. Up to 2,500 MLSS sludge is pumped from the clarifiers back to the oxidation ditches to be metabolized by microorganisms, and any excess sludge is wasted to one of fourteen drying beds.

At the time of our MIT Nepal Project team visit in January 2003, the sludge drying beds were not being used, nor did they appear to have ever been used. The explanation we were given for this was that all of the sludge from the secondary clarifiers was recycled to the oxidation ditches as RAS (return activated sludge). Any excess solids are likely to leave the Guheshwori WWTP with the effluent as TSS (Harrington, 2003). Table 4 displays design and performances parameters for the Guheshwori Wastewater Treatment Plant. The performance parameters are averages over the first six months of operation at Guheshwori (January 2001- July 2001).

Table 4: Design and Performance Parameters for Guheshwori WWTP (BASP, 2002; Shah, 2002 and Darnal, 2002)

Guheshwori WWTP Design Parameters	
Service Area	5.37 km^2 (3.28 mi^2)
Service Population (1996)	58,000
Projected Population (2021)	198,000
Wastewater Produced	80 L/cap-d
WWTP Footprint	51 m^2 (164 ft^2)
Energy Consumption	2.3 KW-hr/kg BOD
Annual Operating Costs	$167,000 US
Design Flow	0.19 m^3/s (4.3 MGD)
MLSS	3,500 mg/L
F/M	0.34

Guheshwori WWTP Performance			
Parameter	*Influent*	*Effluent*	*Removal*
BOD_5 (mg/L)	270	25	91%
COD (mg/L)	1150	250	78%
TSS (mg/L)	216	100	54%
TKN (mg/L)	48	30	38%
NH_4-N (mg/L)	41.7	22.1	47%
P (mg/L)	6.71	3.2	52%

Advantages of conventional activated sludge treatment systems over some of the alternatives discussed below are a relatively high removal rate of BOD and TSS and capacity to treat a large amount of wastewater in a relatively small area. Performance data for Guheshwori shows a lower TSS removal rate than in typical activated sludge WWTP's, however. One explanation for this could be the full recycle of sludge from the secondary clarifiers back to the oxidation ditches.

In addition, the use of conventional activated sludge in developing nations has come under much criticism in recent years (Harleman, 2001). The major disadvantage of activated sludge systems are high operating costs associated with large energy needs. Nepal has few exploitable fossil fuel sources, so electricity production efforts have been primarily focused on hydroelectric plants. Even this source is largely untapped, so electricity remains very expensive.

3.2 Constructed Wetlands as an Alternative Technology in Nepal

Due to the failure of the large treatment plants, small and decentralized treatment systems such as constructed wetlands are in high demand. Environment and Public Health Organization (ENPHO) introduced the use of constructed wetlands for wastewater treatment in Nepal as an alternative to conventional wastewater treatment technologies. ENPHO's aim was to produce a sustainable and feasible wastewater treatment system based on the natural ecosystem in this impoverished country. It would be more appropriate if such plants could be installed at a community scale around the valley and maintained by such communities.

The first ENPHO-designed constructed wetland system with a two staged sub-surface flow was for Dhulikhel Hospital. It was built under the leadership of Dr. Roshan R. Shrestha of ENPHO in 1997 to treat domestic wastewater (Shrestha, 1999). Due to the success of the Dhulikhel Hospital system, four more sub-surface constructed wetland systems have been built in and around Kathmandu in the past few years (Shrestha, 2001). The Kathmandu metropolitan city (KMC) established its own septage treatment plant based on this technology. The Malpi International School, located near Panauti, has adopted a similar system to treat household wastewater before discharging the water in De Rosie River. The Sushma Koirala Hospital at Sankhu and Kathmandu University at Banepa also have their own constructed wetland to treat their domestic wastewater.

There are several additional constructed wetland systems that are in design phase in Nepal. The Pokhara Sub-Metropolitan City's system that is under construction will be the largest constructed wetland system in Asia. The system is designed to treat 100 m^3 of septage and 40 m^3 of landfill leachate per day. The technology introduced and designed by ENPHO, is getting popular and gradually becoming adapted within Nepal.

3.3 Treatment Efficiency of Dhulikhel Hospital's Constructed System

The system has shown high treatment efficiency since its operation began in 1997 to 2000 (Table 5).

Table 5: Summary Statistics of Inlet and Outlet Concentrations and Mean Removal Rates of Dhulikhel Hospital Constructed Wetland System (1997 to 2000) (Shrestha, 2001)

Month	Q (m^3/day)	TSS IN (mg/L)	TSS OUT (mg/L)	NH_4-N IN (mg/L)	NH_4-N OUT (mg/L)	PO_4-P IN (mg/L)	PO_4-P OUT (mg/L)	BOD_4 IN (mg/L)	BOD_4 OUT (mg/L)	COD IN (mg/L)	COD OUT (mg/L)	*E.coli* IN (col/mL)	E.coli. OUT (col/mL)
Nos. of Reading	13	12	12	12	11	12	12	13	13	13	11	11	11
Minimum	7	26	0.3	17	0.04	2.2	0.6	31	0	63	4	39000	3
Maximum	40	230	6.7	52	5.4	26	18	210	10	1048	40	8E+08	987
Average	20	83	2.3	33	1.6	8	4	110	3	325	20	1E+08	148
Median	11	41	1.8	19	0.04	2	0.7	41	4	79	18	1E+05	38
Std. Deviation	11	58	1.9	12	2.2	7	5.8	63	3	273	14	2E+08	307
Elimination (%)			97		95		47		97		94		99.99

During that interval of time, it was observed that the major pollutants such as total suspended solids (TSS), organic pollutants, and ammonia-nitrogen had a removal percentage of more than 95%, while the removal percentage of *E. coli* was even higher at 99.99% (Shrestha, 2001).

Although the system was initially designed for 20 m^3/day of wastewater, since 2000 it now treats 30 to 40 m^3/day. The removal efficiencies for total suspended solids (TSS), 5-day biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) were not significantly affected by the increase in hydraulic loading in 1999 and 2000, (Figure 5).

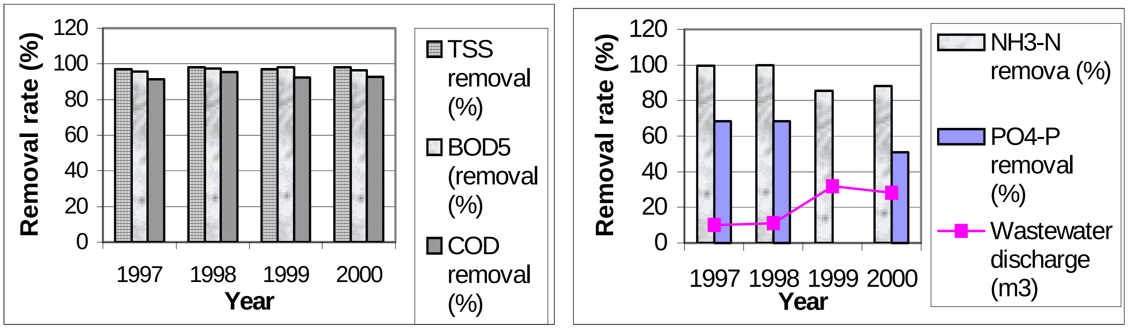

Figure 5: Concentration reduction of Dhulikhel Hospital Constructed Wetland System at Different Time Interval

However, the removal efficiencies of ammonia, phosphorus and pathogens were reduced with the increase in hydraulic load and time interval. It was reported that due to the loss of drainage capacity at the upper layer of the vertical flow bed and decrease in hydraulic loading interval caused the reduction of oxygen flowing into the vertical flow bed. This reduced the ammonia removal efficiency (Shrestha, 2001). During the trip to Dhulikhel Hospital, the author noticed that the wetland system was in poor condition. It was observed by the author that the horizontal flow and vertical flow bed were full of sludge (Figure 6).

Figure 6: Sludge Affected Areas in the Wetland System

The main reason for the sludge accumulation in the wetlands might be the increase in flowrate above the design flow, which prevents the sludge from settling in the tanks before discharging into the wetlands. The condition of sludge accumulation in the vertical flow bed was more serious, as ponding of wastewater affected almost 90 percent of the surface of the bed, while only 20% of the surface area of the horizontal bed was affected (Figure 7).

Figure 7: Ponding Effects on the Vertical Flow Bed (Left) and Horizontal Flow Bed (Right) at Dhulikhel Hospital Due to Sludge Accumulation

The reeds in the wetlands looked unhealthy as the growth was not thick and the reeds were withered. The average height of the reeds was only 0.3 meter in the horizontal flow bed and 0.5 meter on the vertical flow bed compared to reed growth of 2 to 3 meters in the other wetland systems. These problems suggested that the wetland system was not maintained regularly.
The removal efficiencies for TSS, BOD_5 and COD from July 2002 to January, 2003 are shown in Table 6.

Table 6: Summary Results of Inlet and Outlet Concentrations and Mean Removal Rates of Dhulikhel Hospital Constructed Wetland System (Jul 2002 to Jan 2003) (ENPHO)

Date	Parameters											
	BOD(mg/l)			COD(mg/l)			TSS(mg/l)			PO_4 (mg/l)		
	In	Out	% Removal	In	Out	% Removal	In	Out	% Removal	In	Out	% Removal
12-Jul-02	62.0	1.5	98	122.4	20.0	84	66.0	3.0	96	3.94	3.27	17
24-Sep-02	84.0	5.4	94	130.6	23.3	82	106.0	5.0	95	2.5	1.0	60
15-Nov-02	72.0	1.9	97	97.6	22.0	78	46.0	5.0	89	2.8	1.5	45
14-Jan-03	349.0	14.3	96	680.0	49.5	93	380.0	24.7	94	8.6	4.9	42
Average Removal %			96			84			93			41

The elimination rates of the respective pollutants were compared to those shown in Table 5 and the removal efficiencies of these pollutants were noted to be significantly reduced (Table 7).

Table 7:Comparison of Average Removal % for Dhulikhel Hospital Constructed Wetland System

Date	%Average Removal			
	BOD_5 (mg/l)	**COD (mg/l)**	**TSS (mg/l)**	**PO_4 (mg/l)**
1997-2000	97	94	97	47
2002-2003	96	84	93	41

It was observed that the removal efficiencies of these pollutants in this wetlands system fluctuate as the influent and effluent discharge was higher in the day than the night (Poh, 2003). It was also noted in his report that the distribution of different parcels of water remained in the system longer during the night flow period than the day flow period (The hours selected for the day and night flow periods were 8:00 A.M to 8:00 P.M and 8:00 P.M to 8:00 A.M respectively). Thus, for a given reaction rate coefficient ($k_{r)}$, a greater pollutant removal is achieved during the low flow period because the residence time is higher. Therefore a more stringent sampling method is needed to determine the mean daily removal efficiencies of pollutants.

Table 8 describes the minimum level of effluent quality attainable by secondary treatment in terms of the parameters set by the Environmental Protection Agency (EPA) in the U.S.

Table 8: Minimum Level of Effluent Quality Attainable Through Application of Secondary or Equivalent Treatment (EPA, 2003).

Date	Minimum Level of Effluent Quality Attainable		
	BOD_5 (mg/l)	**COD (mg/l)**	**TSS (mg/l)**
30-Day Average	30	25	30
7-Day Average	45	40	45

Since all requirements for each parameter shall have a 30-day average percent removal not less than 85 percent, a more rigorous sampling data is needed for the wetlands system at Dhulikhel Hospital to meet the standards as the recent data provided, is taken only once a month.

3.4 Alternative Treatment Options

3.4.1 Chemically Enhanced Primary Treatment (CEPT)

From current knowledge of the wastewater problem in Kathmandu, CEPT appears to be a viable treatment option. CEPT is more cost-effective than traditional biological treatment (primary treatment plus activated sludge) (Harleman, 2001). Construction costs of CEPT plants are on average 60% of the construction costs of a traditional biological treatment plant, though cost will vary on location and condition. Annual operating costs for CEPT plants are also less expensive. Though chemical costs for CEPT may be high, they are more than off set by the high energy cost for biological treatment. This is a bonus in Nepal, where energy can be scarce.

CEPT plants are more robust than biological plants; they can operate under a wider range of conditions. Industrial influent often has adverse affects on the microorganisms used in biological treatment leading to plant upsets. Heavy metals, such as chromium can precipitated out as hydroxides and sulfides with the appropriate chemical addition. Chemical treatment is not as susceptible to system upsets based on the influent to treatment plants. CEPT plants can also handle higher influent rates than biological treatment plants, such as Guheshwori, because they require less residence time.

The basic flowsheet for a CEPT plant is shown in Figure 8.

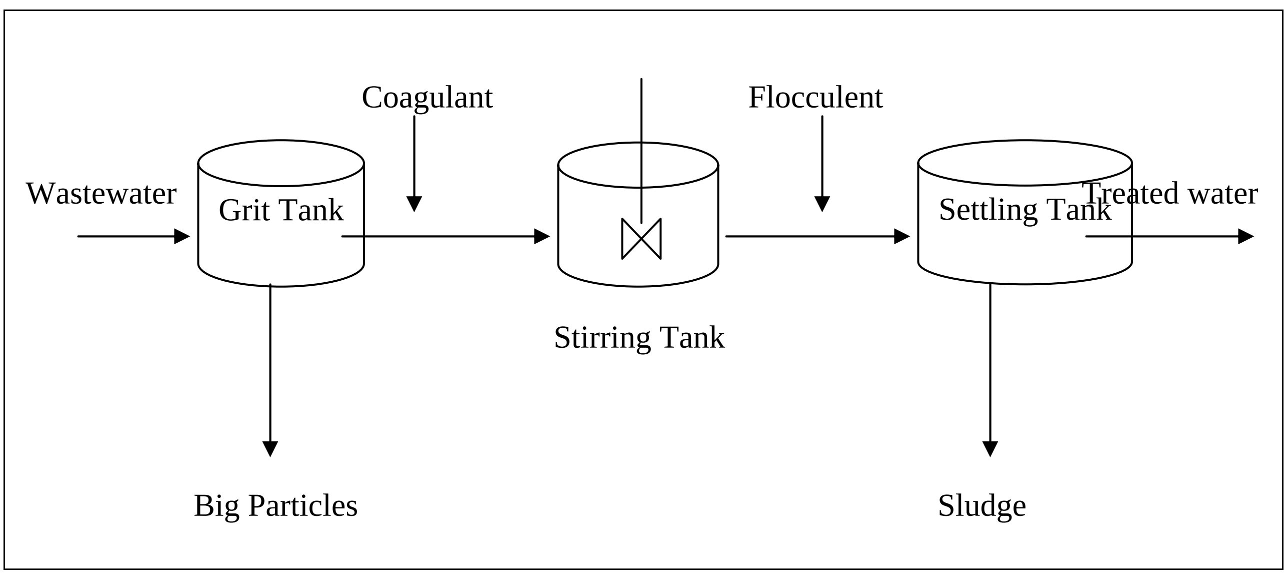

Figure 8: Flowsheet For a Typical CEPT Plant

Wastewater enters the first tank, where big particles are allowed to settle out. Next, a coagulant is added, often an iron complex. The coagulant attaches to suspended solids in the stirring tank, forming denser particles. A flocculent, an anionic polymer is then added, allowing coagulated solids to combine to form even larger particles. These particles are allowed to settle and form a sludge, which is separated from treated water. Jar test and coliform test must be performed to analyze how effective CEPT could be at removing debilitating parasites found in wastewater.

3.4.2 Advanced Integrated Pond System (AIPS)

Another alternative wastewater treatment system gaining popularity in developing and fully developed nations alike is the advanced integrated pond system (AIPS). AIPS is suitable in situations of normal wastewater flow as well as highly variable flow rates and organic loadings, especially in cases of limited industrial pre-treatment and in the presence of toxic organics and heavy metals (Swanson, 2002).

This treatment system consists of an anaerobic pit beneath an oxygenated, aerobic reactor. The wastewater enters into the deep anaerobic reactor, where heavy solids settle to form a thick anaerobic sludge blanket. Some organics are removed as the wastewater passes through the dense sludge toward the aerobic reactor. Decomposition in the anaerobic pit releases gases into the aerobic zone, which are either absorbed by the water or emitted to the atmosphere.

The aerobic section contains bacteria and algae for the further decomposition of soluble organic materials in the wastewater. The oxygen levels in the aerobic zone are controlled with horizontal surface aerators as well as natural aeration and algal photosynthesis. The aerators are positioned such to create a circular flow on the pond surface to inhibit seasonal turnover within the pond and to minimize odors.

A non-aerated pit exists to the side of the aerobic zone. This section of the treatment system serves as a settling tank, where solids are removed by gravity. The solids in both the non-aerated zone and the anaerobic zone remain until they are fully decomposed. This is possible, since the pits are very deep. The advantage of such a design is that no sludge needs to be removed or wasted (Swanson, 2002).

Other highlights of the AIPS are energy efficiency and low construction costs. Table 9 displays operating and construction cost savings for AIPS over other conventional treatment systems.

Table 9: AIPS Cost Savings, as percentage of costs associated with other treatment systems (Swanson, 2002)

AIPS Cost Savings

	Construction Costs	**Operation Costs**
% of Oxidation Ditch cost	29	33
% of Trickling Filter cost	25	33
% of Activated Sludge cost	22	29
% of Stabilization Pond cost	71	77

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