

THE EFFECTS OF CARPET DYE ON THE BAGMATI RIVER

By

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ABSTRACT

The objective of this thesis is to determine what, if any, significant effects effluent from the carpet dyeing industry has on the water quality of the Bagmati River in Kathmandu, Nepal. The water quality parameters studied were absorbance, as a color indicator, total chromium, dissolved oxygen (DO) and chemical oxygen demand (COD). Total chromium was measured both in samples from the Bagmati River and in dye samples. All four dyes tested contained chromium. Three of them contained high levels of chromium (1,200 – 2,400ppm). The highest level of chromium measured in any of the river samples was 0.03mg/L (found in two samples). This is below the World Health Organization's (WHO) guideline for chromium in drinking water, 0.05mg/L. This fact does not, however, necessarily indicate that there is not a chromium problem in the Bagmati River. Samples were collected and tested in January 2003, at which time carpet manufacturing was at a low. An increase in carpet production and subsequent increase of dye waste to the Bagmati River could increase chromium in the river to dangerous levels.

There is a noticeable decrease in water quality as the Bagmati River flows through Kathmandu City. This water quality deterioration can be seen by looking at DO and COD levels along the river. Other researchers have theorized that dyes increase COD and therefore, may contribute to the high COD and low DO values in the Bagmati. However, in this study, dyes were not found to add a significant amount of COD.

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1 INTRODUCTION

1.1 NEPAL AND KATHMANDU VALLEY

Nepal is a country with a population of about 24 million people located in Asia between China and India. Only 27% of the population has access to a form of sanitation (such as latrines, septic systems, wastewater treatment plants). Eighty-one percent of Nepal's population has access to safe drinking water¹. It is very important to treat sewage so that it does not affect the sources of drinking water. Nepal does not have access to an ocean, so if water goes untreated in Nepal it is either sent to the surface waters, mostly the rivers that run through the country, or wasted on land. People do use the rivers as a source of drinking water, though in the city this water may be sent to a water treatment plant first. Still, sewage will contaminate drinking water. Sewage released over land can seep through to groundwater and contaminates the groundwater, which is often a source of untreated drinking water. Therefore, to ensure safe drinking water, wastewater treatment is needed.

This paper focuses on Kathmandu Valley. Kathmandu Valley includes three major cities, Kathmandu, the capital city of Nepal, Patan and Bhaktipur, and contains over a million people, about 6% of Nepal's population. While Kathmandu Valley is probably the most advanced part of the country in terms of sanitation, Nepal has the lowest access to sanitation in all of South Asia². It has five treatment plants, but only one is fully functioning. The one functioning treatment plant is Guheshwori Wastewater Treatment Plant located along the Bagmati River. The treatment plant receives its influent from an area of 537 hectares in the Upper Bagmati basin from Gokarna to Pashupati, serving 58,000 people (as of 1996)³. For more information on the Guheshwori Treatment Plant see Amanda Richards' 2003 Master's of Engineering thesis entitled "Effects of Detergent Use on Water Quality in Kathmandu Nepal." Only a small fraction of the wastewater being produced is treated. Another method of treatment being studied in Nepal is constructed wetlands. So far there are four constructed wetlands in Kathmandu Valley

¹ UNDP 2001

² UNDP 2001

and one in Pokhara. For more information on constructed wetlands, see Saik-Choon Poh's 2003 Master's of Engineering thesis entitled "Assessment of Constructed Wetlands". Currently, there are no large industrial wastewater plants in Kathmandu Valley, though some industries are making an effort to treat their effluent by building small treatment plants, such as one in Hetuada south of Kathmandu. Over the past few years, Kathmandu Valley has been experiencing large industrial growth, creating additional industrial waste that can, like domestic sewage, be detrimental to the quality of drinking water. Many companies send their effluent directly to the rivers of Nepal, a practice that may need to be stopped. The effluent from some industries goes to the municipal wastewater treatment plant. This may not be a great disposal method either since municipal wastewater treatment plants are not often designed to deal with some of the components of industrial waste, such as heavy metals. These components could actually be detrimental to the plant and decrease efficiency.

Katmandu's largest manufacturing industry, at present, is the carpet industry. Over the past 10 years, the carpet industry has grown immensely. Many people have moved to Nepal to work in this industry⁴. This has caused an increase in the sewage produced due to the increased population in Kathmandu Valley and also an increase in industrial wastewater. There are approximately 50 wool dyeing companies in Kathmandu Valley approximately 20-25 of them are located along the Bagmati River, the largest river that runs through Kathmandu Valley⁵, and most send their waste to the river. It is likely that the carpet manufacturing industry may contribute significantly to water quality deterioration and is therefore studied in this report.

1.2 RESEARCH OBJECTIVE

The objective of this research is to determine what, if any, significant effects effluents from the carpet dyeing industry in Kathmandu Valley, Nepal has on the Bagmati River.

³ BASP, 2001

⁴ Schrier & Shah, 1995

⁵ Karanjit, 2003

1.3 CARPET MANUFACTURING

Carpet making involves a number of steps; it starts with the wool. For the most part, carpet manufacturers in Nepal import wool from either Tibet or New Zealand⁶.

1.3.1 CARDING

Once the wool is obtained, it is carded; carding is the process of combing and cleaning wool. This is necessary for a good quality carpet. During carding all the wool fibers are separated and any foreign particles, dirt, wax or fat on the wool are removed. Different types and colors of wool are separated to provide a pure bundle of wool. This process can be done by hand or by machine. Often, when carding is done by hand, the wool is washed directly in a river, such as the Bagmati.

1.3.2 SPINNING

The next step in the process is spinning. In this step, similar wool fibers are drawn and twisted together to make yarn of desired thickness. This process also can be done by hand or by machine. Hand-spun yarn is usually better because it is stronger and more elastic. Yarn of five to seven twists per inch is ideal for carpets, rendering the hand-spinning process time-consuming and labor-intensive. It is clear to see why the carpet industry employs so many people. A picture of carded and spun wool can be seen in Figure 1. The bundles of wool in the picture are different colors. The lighter wool is used for dyeing, while the darker wool is more commonly used in carpets in its natural color.

⁶ All of the carpet manufacturers visited while in Nepal informed the author that they use either Tibetan wool or a New Zealand, Tibetan wool blend. This was the same trend seen in the Nepali carpet manufacturers researched on the internet.



Figure 1: Carded and spun wool

1.3.3 WOOL DYEING

The next step in the carpet-manufacturing process is dyeing. Wool can be dyed with either natural or synthetic dyes. Using natural dyes is a traditional Tibetan art and, therefore, some Tibetan carpets produced in Nepal use these traditional natural dyes, but for the most part, synthetic dyes are used. Natural dyes are duller than synthetic dyes and are not as color-fast. Using natural dyes is more complicated, and they make the task of producing consistent color more difficult. Many companies will use natural dyes only upon request. Even when using synthetic dyes, dyeing is a complicated process. It requires much attention and experience to obtain the desired color.

1.3.4 WEAVING

The next step in the process is weaving. Almost all, if not all, of the carpets made in Nepal are woven by hand on vertical looms as shown in Figure 2. The weavers use sketches and graphs to weave the intended design. Knots are woven along the loom at 40 to 125 knots per square inch depending on the intended quality of the carpet (most carpets are either 60, 80 or 100 knots per square inch). Like spinning, weaving is very labor intensive. It can take an experienced weaver a month to weave 4.5m² (48 ft²) of carpet⁷.

⁷ Pioneer Carpet Industries, 2002

1.3.5 TRIMMING, WASHING & FINISHING

The next step in carpet manufacturing is trimming to level carpets. Then, carpets are washed. This is done to remove dirt picked up in the manufacturing process and to restore the original shine of the wool. It also can remove germs. Washing is usually done in a washing plant, not in the surface waters of Nepal, but it is not uncommon for wash water to be released into the Bagmati. After washing, carpets are dried in the sun for 4-5 days and then stretched on all four sides to preserve their shape. The final step is finishing. Carpets receive a final trim by hand to cut them to the right dimensions. At this point, carpets are ready to be sold.



Figure 2: Workers hand-weaving carpet in Kathmandu

1.3.6 POLLUTION-GENERATING PROCESS

The steps in the carpet making process that could emit a significant amount of pollution are the wool dyeing and carpet washing processes. Chemicals used to wash carpets can

get into Nepali surface waters. It is interesting to note that the author's perception of the carpet making process changed after a visit to Nepal. It appeared at first as though one company generally makes carpets from the first step of the process until the finish. Though some companies work in this fashion, in Nepal it appeared as though the majority of carpet manufacturers bought their wool pre-dyed from wool dyeing companies. The author chose to focus on the effluent released by wool dyeing companies as a surface water contaminant.

1.4 CARPET DYEING PROCESS

As stated previously, there are two types of dyes that can be used in the dyeing process, natural dyes and synthetic dyes. Natural dyes can come from vegetables, plant roots and even insects. Common natural dyes are listed in Table 1 below. The most common natural dyes are indigo, madder, which produces a red color, and lakspur (yellow). Notice that the color green is commonly produced from dyeing wool first with lakspur and then with indigo. There is not a natural dye that dyes green, so to get the color green, wool must be dyed twice, first with a yellow dye and then with a blue dye. Also, as stated in the chart below, for a light color, a batch of wool may be dyed using depleted dye from a previously used dye batch. In this way a variety of colors can be created with a limited number of materials.

Table 1: Natural dyes and the colors they produce⁸

Material	Latin Name	Color
Root of the madder plant	Rubia tinctoria	Red to orange
Depleted madder dye (dye baths are re-used so that the dye gets weaker and colors get lighter)	Rubia tinctoria	Salmon
Cochineal (dried insect carapace)	Often from Dactylopius coccus	Bright red to burgundy
Lac (resin secreted by insect)	Often from Coccus laccae	Blue-red to purple-red
Indigo extracted from the indigo plant	Indigofera	Light blue to navy
Larkspur or <i>isparuk</i> (a flowering plant)	Delphinium sulphureum	Pale yellow to yellow-brown
Weld (a flowering herb)	Reseda luteola	Pale yellow to yellow-brown
Oak bark, tree galls	Quercus	Brown
Tannin, oak tree galls		Black
Double-dye of larkspur and indigo	Delphinium sulphureum and Indigofera	Green

The exact method of getting color from the dyeing materials depends on the material being used. Indigo dyes are obtained by boiling the leaves of indigo plants and extracting *indican*. Madder dyes are produced by boiling the dried, chunked root of madder plants, and larkspur dyes are produced by boiling the crushed leaves, stems, and flowers of the larkspur plant.

Vegetable dyes are not used as often as synthetic dyes because they are more expensive and are more complicated to use. Whereas a gram of synthetic dye can produce a great deal of color when diluted, more natural dye is required to produce the same color and this costs more. In addition, synthetic dyes are available in a greater variety of colors. Whereas a few natural dyes may be used to produce every color, synthetic dyes are available in many shades. It does not require as much skill and technique to achieve a

⁸ Jacobsen Rugs, 2003

desired color when using synthetic dyes. Often people will request carpets made from natural dyes, not because the quality is better, but because the natural dyeing tradition is popular or because they want more environmentally friendly carpets.

There are various classes of synthetic dyes such as basic, direct, vat and acid dyes. Basic dyes were the first type of synthetic dye. They were used to dye silk and wool but did not stick well to these fabrics. They are now used, diluted in weak acid, exclusively for dyeing synthetic fibers. Direct dyes are water soluble dyes used mainly for coloring paper, but also for dyeing cotton. Vat dyes are not water-soluble and are used in an alkaline solution. They are used on cotton products that require excellent color-fastness, such as towels and military uniforms.

The type of synthetic dye used on wool, and therefore in the carpet industry, is acid dye. Acid dyes are water-soluble anionic compounds. They are applied to either wool, nylon or silk in an acidic medium (hence the name acid dye). Acid dyes contain at least one sulfonic acid group; these groups can form ionic bonds with the basic amino groups in wool, silk and nylon fibers, resulting in a high affinity of the dye for wool. Acid dyes exhibit little affinity to materials that do not have these functional groups to which they can bond. Many synthetic dyes, including acid dyes, contain heavy metals. These metals are integral to the dye molecule and an essential part of the dye's performance. Seventy percent of synthetic dyes used for wool dyeing contain chromium⁹. Other common heavy metals in acid dyes are cobalt and copper.

Before dyeing, acid dyes are mixed with an acid, commonly acetic acid or sulfuric acid, depending on the type of dye used. While in Nepal, the author had the opportunity to visit Mount Everest Dyeing Company. The company was very cooperative and provided nine samples. Four were samples of dry, powder dyes from Clariant India, Ltd. in various colors, four were samples of liquid dyes, which are powder dyes mixed with acetic acid and one was a sample of the acetic acid used for mixing. Another wool dyeing company visited also buys its dyes from Clariant India, Ltd. Clariant and Ciba

⁹ EPA, 1997

dye manufacturers appear to be the major dye providers for Nepal's carpet industry¹⁰. The Clariant website provides an overview of the types of dyes it offers and instructions for dyeing¹¹. The brands of acid dye that were likely being used by Mount Everest Dyeing Company, as well as other Nepali dyeing companies, were either Sandolan® dyes, which are manufactured in a variety of brands, or Lanasan® dyes. The instructions Clariant gives for dyeing include the ingredients that go into a batch. Ingredients are the dye, acetic acid, sodium acetate crystal (1g/L), Lyogen liquid (1%), a liquid produced by Clariant for addition to its dye batches, and 0-10% Glauber salt. Lyogen and sodium acetate crystals are used as leveling agents to assure that dye is evenly applied to wool fibers. Glauber salt is sodium sulfate, which is used to increase wool color yield. No specific amount of dye to be added is given because it depends on the desired shade. The rest of the batch, the majority of it, consists of acetic acid of 4.5-5.5 pH depending on the brand of dye used. The batch is brought to a boil at 100°C at the rate of 1°C per minute and kept there for 30 minutes to an hour. Then the batch is cooled and the wool is rinsed.

1.5 WATER QUALITY PARAMETERS ASSOCIATED WITH CARPET DYEING

As mentioned previously, it is a common practice to dump industrial waste, including dye waste into Nepali rivers and about half of Kathmandu Valley's wool dyeing companies are located on the Bagmati River. The majority of these send their waste to the river. This could be causing a number of problems for Nepal's surface waters, especially the Bagmati River. The first to mind is the problem of color, but dyes can also cause other problems such as increased chromium levels, decreased dissolved oxygen (DO) levels and an increase in chemical oxygen demand (COD).

Color is generally considered a secondary water quality parameter as it is an aesthetic problem, not a human health problem. Color in bodies of water can be serious when the color is dark and opaque enough that it prevents sunlight from reaching organisms in the

¹⁰ Karanjit, 2003

¹¹ Clariant, 2002

water and therefore, prevent photosynthesis. In this study, absorbance is measured to test for color. Absorbance data will be used to detect the presence of dyes.

Chromium is a primary water quality parameter. Two oxidation states of chromium are most common in nature, trivalent and hexavalent chromium. Trivalent chromium (in reasonable amounts) has not been found harmful to humans; it is actually a nutrient. The daily chromium requirement for adults is approximately 0.5 to 2 μg ¹². On the other hand, long-term exposure to hexavalent chromium can cause unwanted problems, such as ulcers, contact dermatitis (skin infection), genetic mutations and cancer¹³. Because it is much easier to analyze total chromium than chromium in its different oxidation states, guidelines and standards for chromium are given in terms of total chromium. The World Health Organization's guideline for total chromium in drinking water (as well as the US standard for total chromium) is 0.05mg/L. Adhering to this guideline would keep the hexavalent chromium concentration below 0.4 $\mu\text{g}/\text{L}$ ¹⁴. Because water from the Bagmati River is often directly or indirectly (through utensil washing, irrigation, animals that drink from the river) ingested, it is important that chromium levels in the river are not above the WHO's guidelines. Nepal has no chromium standard¹⁵.

The concentration of dissolved oxygen in water is dependent on factors such as water temperature, composition and chemical or biological processes taking place in the water. At 70°F, the saturated level of dissolved oxygen in water is about 9mg/L.

Depletion of dissolved oxygen below this level can result in the microbial reduction of nitrate to nitrite and sulfate to sulfide, giving rise to odor problems. Low DO levels can also result in corrosion of metal pipes. When DO levels are substantially below the saturation level, organisms cannot receive the amount of oxygen they need to live, and organisms in the water will begin to die. Some chemicals require oxygen to degrade. They exert a chemical oxygen demand (COD) on the water. If a chemical causes a high COD, it will decrease the amount of dissolved oxygen in the water. Several sources

¹² WHO, 1996

¹³ WHO, 1996

¹⁴ Blankstein, 2001

¹⁵ Paudel, 1998

maintain that dyes significantly increase COD levels in water^{16,17}. This study investigates whether it is the dyes or the acids with which the dyes are mixed that exert an oxygen demand.

In this study, data on the above-mentioned parameters, color (absorbance), chromium, DO and COD, was collected along the Bagmati River, as this is the river most affected by the carpet industry in Nepal.

1.6 NEPAL'S INDUSTRIAL WATER QUALITY STANDARDS

Nepal has only recently promulgated water quality standards for industrial effluents. In January of 1998 the Ministry of State for Industry, the body that regulates industries, approved tolerance limits for industrial effluents discharged into inland surface water prepared by the Nepal Bureau of Standard and Meteorology (NBSM). There are specific standards for various industries, as well as general standards for those industries and parameters not covered by industry-specific standards. The standards for COD and total chromium for wool processing industries, which includes carpet dyeing, are shown in Table 2. The general industrial standards for effluent COD and total chromium are shown in Table 3.

Table 2: Nepali standards for wool processing industrial effluents

Water Quality Parameter	Tolerance Limit (mg/L)
COD	250
Total Cr	2

Table 3: Nepali standards for general industrial effluents

Water Quality Parameter	Tolerance Limit (mg/L)
COD	250
Total Cr	0.1

¹⁶ Karanjit, 2003

¹⁷ Paudel, 1998

The wool-processing standard for COD is equal to the general industrial standard, but the total chromium standard for wool processing is 20 times greater. This discrepancy between the general industrial and wool processing chromium standards is reasonable from an industrial point of view. Wool processing emits more chromium than most other industries, and therefore it would be more difficult for the wool industry to meet the same chromium standards as other industries. This discrepancy, however, does not make sense from an environmental view. Carpet manufacturing is the biggest industry in Kathmandu Valley. Wool industry specific standards are allowing the largest waste producer to emit the most chromium per unit waste. Nepal's general industrial effluent chromium standard is twice the WHO guideline for chromium in drinking water, but Nepal's wool processing chromium standard is 40 times the WHO drinking water guideline. If all of the carpet industry wastewater emitted into the Bagmati were at the tolerance limit, the combined waste of all carpet manufacturing companies emitting to the Bagmati would need to be diluted at least 40 times for the river to meet chromium drinking water guidelines. This may be feasible, but does not include other sources of chromium, such as tanneries, which are known for their use of chromium.

2 THE BAGMATI RIVER

The Bagmati River originates in Bagdwar in the hills of the Shivupari Protected Watershed and Wildlife Reserve north of Kathmandu Valley. The river is fed by springs in the hills and monsoon rains, as well as tributaries, and it flows southwest through Nepal until it feeds into the Ganges River in India. The Bagmati bears a great deal of significance for the people of Nepal. Not only is it the largest river in Kathmandu Valley, it is of religious significance to the Hindus, associated with the Goddess Ganga and Lord Pashupatinath. The water of the Bagmati is considered to be holy water (“*jal*” in Nepal). Because of the degradation of the Bagmati due to pollution, the river is losing some of its religious significance among believers. The tradition of drinking the water of the Bagmati is no longer commonly practiced.

There are many activities along and uses of the Bagmati River. Water is taken from upstream before the river enters Kathmandu Valley and routed to water treatment plants for drinking water. Water downstream in the Bagmati is also used for drinking water, especially for livestock in the dry season when less water is available from other sources. In Kathmandu Valley the Bagmati River is used for bathing, irrigation, washing vegetables, utensils and clothing, and likely various other purposes. The Bagmati River is not, however, used for fishing because freshwater fish have been completely wiped out in the Kathmandu Valley portion of the Bagmati and the levels of fish are decreasing in the hills south of Kathmandu Valley. Due to the condition of the river in Kathmandu Valley it is not recommended for recreational use, drinking water, or industrial purposes, though it is used for all of the above.

2.1 SAMPLING LOCATIONS

Samples were collected at seven points along the Bagmati River. Sampling methods are discussed later in Chapter 3. These sites listed from upstream to downstream are: Sundarijal, Jorpati, Guheshwori, Pashupatinath, Tilganga, Sundarighat and Chovar. All of the sampling points are displayed on the following map.



Figure 3: Map of the Bagmati River as it runs through Kathmandu Valley

Sundarijal, the sampling site furthest upstream, is located at the point where the Bagmati River flows from the mountains into Kathmandu Valley, about 7 km (4.3 miles) from the source of the river. This point is the farthest upstream and hence is cleanest since the river has not been affected by industrialization or the high population of Kathmandu. The river is clear enough at this point so that the riverbed can be seen from above the water. Nepal was visited in January during its dry season, so the river depth was low. At Sundarijal, the river was only a few feet deep and about ten feet wide. The river is surrounded by boulders and runs rather quickly over large rocks, providing good aeration

for dissolved oxygen levels near saturation. At the point where the sample was taken, it was possible to cross the river over the rocks. Figure 4 and Figure 5 are pictures taken at Sundarijal. There were few houses in the area and there appeared to be no industry. Trash can be seen in the foreground of Figure 4, but none was seen by or in the river.



Figure 4: The boulders surrounding the Bagmati River at Sundarijal



Figure 5: Area of Sundarijal near the Bagmati. Notice it is mostly forested.

In the section of the Bagmati between Sundarijal and Jorpati, there was a noticeable amount of construction on the riverbanks. A picture of the construction can be seen in

Figure 6. This construction, the run-off of which appears to be going to the Bagmati, will likely contribute to water quality deterioration of the river. The next site down the river is Jorpati. Whereas Sundarijal appeared to be a village, Jorpati is more industrialized. The area around Jorpati includes a medical college that sits on the banks of the river. Less than 1 km away is Boudha. The vicinity around Boudha is the site of many wool-dyeing companies, of which two were located by the author. One of these companies, the Mount Everest Dyeing Company, was generous enough to provide dye samples. Unlike the river at Sundarijal, waste can be seen around and in the river. Animal bones were noticed lying on the banks of the river at Jorpati and people were seen defecating in the river. The river at this point is not as clear as at Sundarijal. The river is wider at this point, about 15 feet across. The river appears to be rather shallow here, at least during the dry season when visited by the author, though the exact depth was hard to gauge visually due to the murkiness of the water. Figure 7 is taken from the bridge that crosses the Bagmati at Jorpat, garbage and bones are visible among the sediments.



Figure 6: Construction along the Bagmati River



Figure 7: The Bagmati River from the bridge at Jorpati. Animal bones are noticeable in the foreground.

From Jorpati to Guheshwori, the Bagmati steers away from the main road on which Jorpati lies, and activity along the river becomes sparser. On one side of the river are hills and on the other side is a small community. The only noticeable activity taking place along this stretch of the river is women washing clothes. Major construction was also taking place. Kathmandu's Tribhuvan International Airport is just up a small hill from the river. A study of the possible effects of jet fuel and other airport-related chemicals on the Bagmati River may be relevant in the future. The Guheshwori water sample was taken at the Guheshwori Temple, a Hindu temple just downstream from the Guheshwori Wastewater Treatment Plant. This treatment plant collects wastewater from sewage lines and treats it using an activated sludge process. When there is an overflow of water in the sewerage lines, especially during monsoon season, the plant is unable to treat all the sewage. Because the Nepali government does not want to discharge untreated wastewater into the Bagmati upstream of the Pashupatinath Temple¹⁸, the effluent from the Guheshwori Wastewater Treatment Plant, along with any untreated sewage that may accompany it, is bypassed through a tunnel that discharges into the Bagmati River at Tilganga.

¹⁸ Guheshwori, 2001

The appearance and width of the river at Guheshwori are similar to those at Jorpati. Noticeable activities along the banks of the river by the temple were people picnicking, people bathing and monkeys playing. Figure 8 is a picture of the Bagmati River and the Guheshwori Temple taken from the opposite bank.



Figure 8: The Bagmati River at Guheshwori. A man can be seen bathing in the background

An effort was made to walk downstream along the right bank of the Bagmati from Guheshwori to Pashupatinath, but this was not possible because most of the way was inaccessible either due to the nature of the terrain or because areas were blocked off around Pashupatinath Temple. Pashupatinath Temple is one of the most revered Hindu temples in the world and is also recognized by many Buddhist, some of whom believe Pashupatinath was also the Buddha. A sample was taken from within the Pashupatinath Temple area. In this area there are steps leading down to the river so that Hindus can bathe in the river. At Pashupatinath, the river is still about 15 feet wide. The water is noticeably darker than at Guheshwori, which may be due to the additional amount of waste in the river at this point. Though it has been a tradition to drink from the Bagmati at Pashupatinath, many Hindus will not because of the perceived quality of the water. Pashupatinath is located approximately 20 km (12.5 miles) downstream from the source of the Bagmati.

Further downstream, samples were taken at Tilganga. Just as it was hard to walk from Guheshwori to Pashupatinath, so too was it difficult to walk alongside the river from Pashupatinath to Tilganga because for most of the way the landscape slopes up rather steeply on both sides of the river. However it is possible to access the river at a given point by carefully walking down hill towards the river. The first day Tilganga was visited samples were not collected, but that day a very dark blue liquid was noticed coming out of a pipe just under the bridge that crosses the Bagmati River at Tilganga on the left bank. Not too far from the pipe was a building with people working amidst chunks of blue powder. The next time Tilganga was visited samples were taken. The blue liquid was no longer coming out of the pipe but the water around the pipe was slightly blue tinted due to the blue residue that had been left on the ground around the pipe. That same day a reddish brown liquid was coming out of a pipe on the opposite bank. A sample was taken of this liquid in the river. Tilganga was visited one more day in which blue and then black dye flowed into the river from a pipe on the right bank. A sample was taken of that water as well. Figure 9 is a picture of the left bank of the Bagmati at Tilganga that day showing the black colored liquid discharge. Tilganga is also the point at which the Guheshwori Wastewater Treatment Plant effluent flows into the river. This occurs slightly upstream of where the samples were taken. The tunnel outlet can be seen in Figure 10. The river at this point is noticeably darker and more turbid than upstream and the river smells like sewage, suggesting a higher, significant concentration of sewage, and possibly other waste, in the river. The river remains approximately 15 to 20 feet in width. As in some other areas of the Bagmati, people were seen defecating by the banks of the river. Women were also seen thigh-deep in the river, shoveling sand from the bottom onto the banks.



Figure 9: The left bank of the Bagmati River at Tilganga. The darker water by the river bank is the black liquid discharge the author noticed flowing into the river.



Figure 10: The Guheshwori Wastewater Treatment Plant effluent outlet into the Bagmati River at Tilganga.

Sundarighat is approximately 7 km (4.3 mi) downstream along the Bagmati River from Pashupatinath and 27 km (16.8 mi) from the Bagmati's source. The river is noticeably wider than before and the water is rather stagnant, not allowing for much aeration. Trash can be seen littered throughout the river, as shown in Figure 11. Sundarighat is close to the point where the Bagmati exits Patan. Sundarighat receives all of the pollution from the river upstream. At Sundarighat, the river has not had an opportunity to self-purify through dilution, settling and biological degradation of the pollution, and therefore this area is considered to be the dirtiest section of the Bagmati River. The river is basically an

open sewer at Sundarighat¹⁹; it is used as a public toilet, smells like a sewer, and the water is dark and quite turbid at this point. The river is reportedly biologically dead at Sundarighat²⁰. Patches of black-colored water were seen floating around some of the debris in the river, but none of the samplers were adventurous enough to walk out into the river to collect a sample of this water.

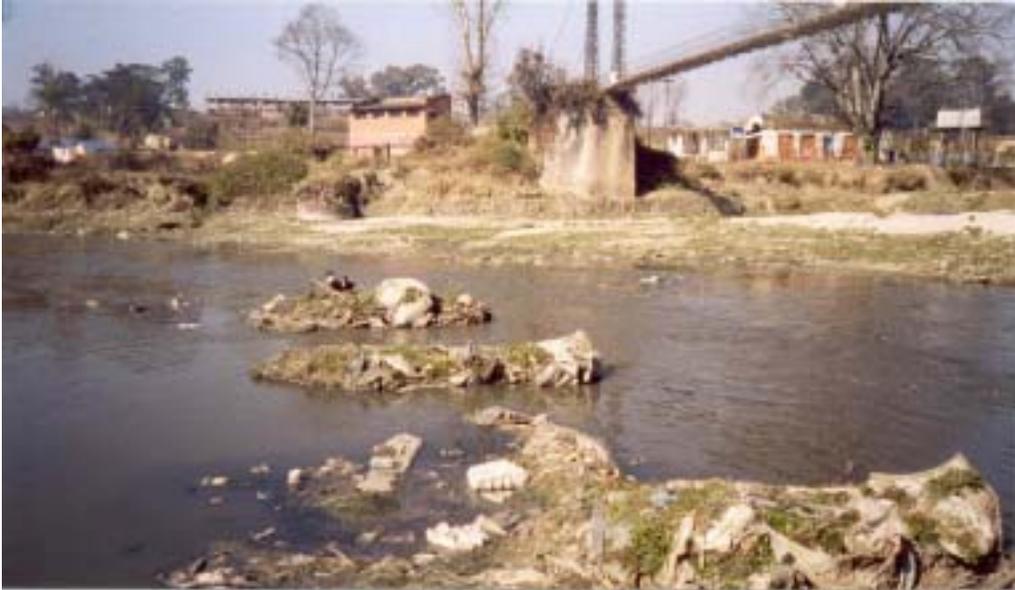


Figure 11: A picture of the Bagmati River at Sundarighat

The last sampling point was at Chovar Gorge, where the Bagmati River exits Kathmandu Valley. At this point the river is much wider and it has been naturally aerated having just past through a large gorge. Chovar is not a crowded, industrialized area, so the river has had a chance to self-purify somewhat by the time it reaches Chovar. Since the waste load is lighter between Sundarighat and Chovar than upstream, cleaner tributaries dilute the waste and biological processes break down the waste. Yet, because the river is in such a bad state prior to Chovar, the river's water quality does not improve significantly by the time the water reaches Chovar.

¹⁹ Sharma & Shrestha, 1996

²⁰ Bottino et. al., 1990

2.2 SOUTH-ASIAN TRANSBOUNDARY MONITORING PROGRAM

Some of the samples analyzed by the author were splits of the samples taken and analyzed by Nepal's Environmental and Public Health Organization (ENPHO) as part of the South-Asian Transboundary Monitoring Program. Split samples came from the following sites: Sundarijal, Pashupatinath, Sundarighat and Chovar. The countries of Nepal, Pakistan, India and Bangladesh are conducting the South-Asian Transboundary Monitoring Program in an effort to monitor and hopefully prevent one country from polluting the surface waters of another country by preventing pollution of the rivers that flow between the two countries. ENPHO is conducting the Nepal part of the study. For this study ENPHO is analyzing samples from two rivers, the Bagmati River and the Narayani River, both of which flow into India. To monitor water quality, ENPHO has been collecting samples from the two rivers at specified points on a monthly basis since April 2002. The six points that ENPHO is monitoring along the Bagmati River are Sundarijal, Pashupatinath, Tilganga, Sundarighat, Chovar and Gaur. These six sites differ from the seven sites sampled by the author only insofar as the author's sites included Jorpati and Guheshwori and did not include Gaur (see Figure 3). Samples were not taken by the author at Gaur because it is 320 km (200 miles) south, near the Indian border. Various water quality characteristics were measured by ENPHO as part of the South-Asian Transboundary Monitoring Program, including temperature, pH, dissolved oxygen (DO), chemical oxygen demand (COD), nitrogen content, phosphorous content, etc. In this study, ENPHO's DO and COD data has been included. Where ENPHO data is used, it has been noted.

3 METHODOLOGY

Various samples were collected in Kathmandu, Nepal. These include samples of the Bagmati River at various locations, samples from the Guheshwori Wastewater Treatment Plant and samples from a dyeing company. There were three types of samples: water samples, dry dye samples and samples prepared at the dyeing company of dry dyes mixed with acetic acid (referred to as liquid dyes). All samples were collected in clean glass bottles to prevent adherence of any relevant chemicals to container walls. Sampling was performed on several occasions and samples collected on any given day were either tested the same day or refrigerated in the meantime (see Appendix A for dates of sample collection and sample testing). There were three kinds of analyses performed while in Nepal: absorbance, chromium, dissolved oxygen (DO) and chemical oxygen demand (COD).

3.1 ABSORBANCE

3.1.1 ABSORBANCE THEORY

A spectrophotometer measures absorbance at a particular wavelength by shining a concentrated beam of light at that wavelength through a sample. The intensity of light that travels through to the other side of the sample is then measured by a detector in line with the beam of light. The spectrophotometer calculates absorbance using the following equation:

$$A = \log\left(\frac{I_0}{I}\right),$$

where A is the absorbance, I_0 is the intensity of light measured from a blank, and I is the intensity measured for a sample. If the light beam is scattered by particles in the sample, the intensity of light received by the detector will decrease. Therefore, absorbance values appear larger when samples are turbid, and it is important to filter samples before measuring absorbance.

Color can be gleaned from a graph of absorbance because what colors molecules do not absorb, they transmit. These transmitted colors constitute the color of a material

illuminated by white light. As will be seen in Chapter 4, many dyes display one broad absorbance peak. In these instances, the color appearance is the color complementary to the color absorbed the most, as shown in Table 4.

Table 4: Colors associated with light wavelengths

Wavelength (nm):	400-450	450-500	500-580	580-600	600-620	620-750
Color Absorbed:	violet	blue	green	yellow	orange	red
Complementary color:	yellow	orange	red	violet	blue	green

3.1.2 ABSORBANCE MEASUREMENTS

Absorbance measurements were performed on the water samples and the liquid dye samples (Samples 1-13 and 18-21). Before testing, samples were vacuum filtered using filter paper and a hand pump connected to a filter flask with side arm. Samples 1-6 were first filtered with filter paper of 1.2 μ m pore size. Those samples that still appeared to be turbid, specifically Samples 2 and 4, were subsequently filtered with 0.45 μ m pore-size filter paper. Later, additional filter paper of 0.45 μ m pore size became available, so Samples 7-13 were all filtered once with the 0.45 μ m pore filter paper. The liquid dyes (Samples 18-21) were not filtered since they were not turbid. Liquid dye samples were diluted before testing so readings would be within the scale of the spectrophotometer. Samples were diluted 50 times; distilled water was added to 1.0mL of each sample to create 50mL of solution.

A Hach DR/2010 portable field spectrophotometer brought from MIT was used.

Absorbance measurements were taken at wavelengths between 400 and 800nm, the range of visible light. Excluding Samples 1-4, samples were measured at wavelengths of 50nm intervals between 400 and 800nm. Samples 1-4 were measured at these wavelengths and at some additional wavelengths to determine whether 50nm intervals would be sufficient to obtain a representative curve. It was decided that 50nm intervals were in fact small enough to achieve a curve of the desired accuracy level. Two 25mL glass sampling

bottles that accompanied the Hach spectrophotometer were used. One was used to hold the sample and the other one was used to hold the blank. In the case of Samples 2-4 the blank was Sample 1 (explained later). For the rest of the samples (1, 5-13 and 18-21) the blank was distilled water. Measurements were conducted one sample at a time. The spectrophotometer would be zeroed at the first wavelength using the blank, and then the sample absorbance measurement would be taken. The spectrophotometer would then be dialed to the next wavelength and the procedure would be repeated once more until all wavelengths were completed. During each reading a cap would be placed over the sampling bottle to block any external light from interfering.

The intended procedure was to use the cleanest Bagmati River sample collected as the blank so that any background color from natural organic matter in the river would be ignored in sample measurements. This technique had to be modified because sampling was conducted on various days and the cleanest river sample collected (the Bagmati at Sundarijal) was not collected until after testing began. In addition, this reasoning was not valid for dye and the dyeing effluent samples. Samples 1-4 were collected on the first day of sampling. The cleanest river sample collected that day was Sample 1 so, in accordance with the original procedure, Sample 1 was used as a blank for Samples 2-4. When the procedure changed and distilled water was used as the blank, absorbance measurements were taken for Sample 1 using distilled water as a blank. So that Samples 2-4 could be compared to all the other samples, the absorbance measurements at each wavelength were added to the respective absorbance measurements for Sample 1, resulting in absorbance measurements similar to what they would be if Samples 2-4 had been tested with a blank of distilled water.

3.2 CHROMIUM MEASUREMENTS

Tests for chromium concentration were performed on the water samples and the dry dye samples. It was necessary to prepare samples before they could be tested. ENPHO's senior chemist, Dr. Narayan Upadaya, prescribed the method for sample preparation. Dry dye samples were prepared by first dissolving one gram of dye in enough distilled

water to create a 100mL solution. Then, 5mL of concentrated nitric acid was added to the solution to release chromium from any chemical complexes it may have been bound in. The solution was heated to a boil until enough liquid evaporated to leave 25mL or less behind. Distilled water was added until the solution was exactly 25mL. During testing, Samples 14, 16 and 17 (red, navy and black dry dye samples, respectively) proved to have too much chromium to be accurately measured so the solutions created from these samples were diluted. The red solution was diluted five fold (5mL to 25mL), the navy solution, 51 fold (1mL to 51mL and the black solution, 50 fold (1mL to 50mL). The chromium levels were still too high to be tested so all three solutions were diluted again, this time 25 fold (1mL to 25mL).

Water samples were prepared by adding 5mL of concentrated nitric acid to 100mL of filtered (using 1.2 μm filter paper) sample. As with the dry dyes, solutions were heated until 25mL or less of solution was left, and then distilled water was added until the solution was exactly 25mL. Nitric acid was added to the solutions and the solutions were heated to break chromium free of any chemical complexes it may have been bound to.

Measurements were performed using a flame atomic absorption spectrophotometer (AAS) at the ENPHO laboratory in Nepal. The AAS was calibrated before each batch of measurements with 1, 5 and 10ppm chromium solutions. Chromium concentrations in mg/L were read from the AAS's computer interface. Actual chromium measurements were calculated from the readings according to the method preparation. All readings for the water samples were divided by four to find the actual chromium measurement. It was necessary to divide the measured concentrations by four because when the water sample solutions were boiled down to 25mL from 105mL (100mL of sample and 5mL of nitric acid), no chromium should have evaporated. Instead it remained behind in solution so that the mass of chromium in the prepared 25mL solution was the same as the mass of chromium that had been in the 100mL water sample. The following equations were used (M_{Cr} refers to the chromium mass and $[\text{Cr}]$ refers to the chromium concentration):

$$M_{Cr} \text{ in } 25\text{mL} = M_{Cr} \text{ in } 100\text{mL}$$

$$[Cr] \text{ in } 25\text{mL} = \frac{M_{Cr}}{25\text{mL}}$$

$$[Cr] \text{ in } 100\text{mL} = \frac{M_{Cr}}{100\text{mL}}$$

$$[Cr] \text{ in } 100\text{mL} = [Cr] \text{ in } 25\text{mL} \times \frac{25\text{mL}}{100\text{mL}} = \frac{[Cr] \text{ in } 25\text{mL}}{4}$$

The AAS chromium readings for the dry dye solutions were first multiplied by the appropriate factor to account for dilutions. Table 5 shows the factors for each solution.

Table 5: Dilution Factors for Dry Dye Solutions

Solution Name	Factor
Red (Sample 14)	x125
Blue (Sample 15)	x1 (no dilutions)
Navy (Sample 16)	x1275
Black (Sample 17)	x1250

After correcting for dilutions, the concentration of chromium in the original dry dye solutions (1g of dry dye in a 100mL solution) was calculated by dividing the calculated chromium levels by four. Then to find the chromium content of the dry dye samples the last calculated chromium concentration was divided by the amount of dry dye added to solution (1g) and multiplied by the volume of the solution (100mL). The equations used are listed below ($[Cr]_0$ is the chromium concentration in the original dye solutions in mg/L, $[Cr]_{AAS}$ is the chromium concentration read by the AAS in mg/L and $Cr(\text{mg})$ is the chromium content in the 1g of dry dyes sampled and $Cr(\text{mg/kg})$ is the chromium concentration of the dry dyes).

$$[\text{Cr}]_0 = \text{dilution factor} \times \frac{[\text{Cr}]_{\text{AAS}}}{4}$$

$$\text{Cr (mg)} = [\text{Cr}]_0 \text{ (mg/L)} \times 100\text{mL} * \frac{1\text{L}}{1000\text{mL}}$$

$$\text{Cr (mg/kg)} = \frac{\text{Cr (mg)}}{1\text{g dye}} * 1000\text{g/kg}$$

3.3 DISSOLVED OXYGEN MEASUREMENTS

Dissolved oxygen (DO) measurements were performed on some of the water samples. Not all of the water samples were tested for DO because some were collected before the lab was set up to do DO testing. DO tests were all conducted the day of sample collection to limit the amount of error incurred. Samples were collected in glass sampling bottles with screw on plastic tops. No head space was left between the samples and the cap. It is understood that this is not the standard method for DO data collection, but it was the only method available²¹. DO test were performed using the Hach DR/2010 Spectrophotometer and High Range Dissolved Oxygen AccuVac Ampuls. Reagent comes vacuum-sealed into these 12mL ampuls. The water sample reacts with the reagent in the ampul and changes color according to the amount of dissolved oxygen in the water sample. The deeper purple the solution appears, the more DO there is in the water sample. The author does not know the exact reaction mechanism that causes this color change, as this information is proprietary. A spectrophotometer is needed to detect the color change. The Hach spectrophotometer has a program that is designed for use with the AccuVac ampuls. To use it, the program number is entered into the spectrophotometer, then the wavelength at which the color change can be detected, 535nm, is dialed. An ampul is filled with sample by breaking the ampul open while it is submerged in the water sample. The ampul is immediately capped and then shaken for 30 seconds. Then the ampul is allowed to sit for 2 minutes and then is shaken again for 30 seconds. A glass vial is filled with water sample (without reagent). This serves as the blank. The spectrophotometer is zeroed with this sample and then the absorbance of the sample-reagent solution in the ampul is measured. The Hach spectrophotometer

²¹See Standard Methods, 20th ed. Part 4500-0 for appropriate sample collection

automatically converts the absorbance measurement to a measurement of DO in mg/L. The range for this method is between 0mg/L and 13mg/L DO with a standard deviation of at least ± 0.20 mg/L.

3.4 CHEMICAL OXYGEN DEMAND TESTING

The author did not have the capability of performing chemical oxygen demand (COD) measurements in Nepal. Dry and liquid dye samples obtained in Nepal from the Mount Everest Dyeing Company were brought back to MIT for COD testing. The dye samples were mixed with water, and the COD of these solutions were determined to find the chemical oxygen demand of the dyes in the water. Three different types of water were used in different trials, distilled, tap and Charles River (Cambridge, Massachusetts) water. Dye samples were mixed with water in a set amount for each trial, and COD measurements were performed immediately afterwards except for in one trial where the solutions were allowed to sit for a day. Hach's High Range Chemical Oxygen Demand Reagent, which contains dichromate, was used. This reagent is appropriate for measuring COD up to 1500 mg/L with an accuracy of ± 18 mg/L. The reagent comes in test tubes with the needed amount of reagent (~ 3.1 mL), ready to use. Two milliliters of solution are added to the test tube and shaken. In addition, 2 mL of distilled water are added to one vial to be used as a blank. Then the vials are placed in the Hach COD Reactor and heated at 150 C for two hours. Heat is required for the dichromate to react with all of the COD in the samples. For the majority of samples, all the COD should react within two hours. After heating, vials are shaken again to insure that the reaction reaches completion and is then allowed to cool.

After cooling, the amount of COD was determined colorimetrically using the Hach DR/2010 Spectrophotometer. During the reaction, the chromium in the dichromate is reduced from hexavalent chromium to trivalent chromium. The Cr^{3+} produced emits a green color, and therefore, the difference in the amount of Cr^{3+} between the sample and the blank can be measured with a spectrophotometer. The equivalent amount of COD can then be calculated. As with DO, the Hach spectrophotometer has a program that is

designed for use with the Hach COD vials. To use, the program number is entered into the spectrophotometer and then the wavelength, 620nm, at which the color change in the vials can be detected is dialed. This is a red visible light wavelength. Absorbance at this wavelength signifies green color in the samples. First the spectrophotometer is zeroed using the blank, and then the COD of the solutions is read. The spectrophotometer displays the amount of COD in mg/L.

4 RESULTS

Thirteen water samples, four dry powdered dye samples and four samples of liquid dyes (dry dyes mixed with acetic acid) were acquired in Kathmandu, Nepal. Each sample was numbered as shown in Table 6 below.

Table 6: Sample Index

Sample Number	Sample Name	Sampling Date
1	Bagmati River at the Guheshwori Temple	1/7/03
2	Guheshwori Wastewater Treatment Plant tunnel outlet effluent (before it enters the Bagmati River)	1/7/03
3	Bagmati River at Tilganga – left bank (blue appearance)	1/7/03
4	Bagmati River at Tilganga – right bank (red appearance)	1/7/03
5	Bagmati River at Sundarijal	1/9/03
6	dyeing effluent from Mt. Everest Dyeing Company – dyeing red	1/9/03
7	Guheshwori Wastewater Treatment Plant influent	1/15/03
8	Guheshwori Wastewater Treatment Plant effluent	1/15/03
9	Bagmati River at Jorpati	1/15/03
10	Bagmati River at Pashupatinath Temple	1/17/03
11	Bagmati River at Tilganga – right bank (black appearance)	1/17/03
12	Bagmati River at Sundarighat	1/17/03
13	Bagmati River at Chovar	1/17/03
14	red powdered dye	1/9/03
15	indigo powdered dye	1/9/03
16	navy powdered dye	1/9/03
17	black powdered dye	1/9/03
18	red liquid dye*	1/9/03
19	yellow liquid dye*	1/9/03
20	blue liquid dye*	1/9/03
21	black liquid dye*	1/9/03

* The liquid dyes are a mixture of powdered and acetic acid in an unknown ratio.

4.1 ABSORBANCE MEASUREMENTS

All of the samples were measured for their absorbance spectrum using a spectrophotometer except for the powder dyes. The reason for measuring their absorbance spectra was to look for hints of dye color in the samples. Figure 12 shows the absorbance spectrum of all of the water samples. The absorbance of the majority of the samples is close to 0 over the visible light range. Organic matter likely contributes to the

absorbance values between 400nm and 450nm, so most of the water samples display maximum values at 400nm. However, a few of the samples did display absorbance peaks at other wavelengths.

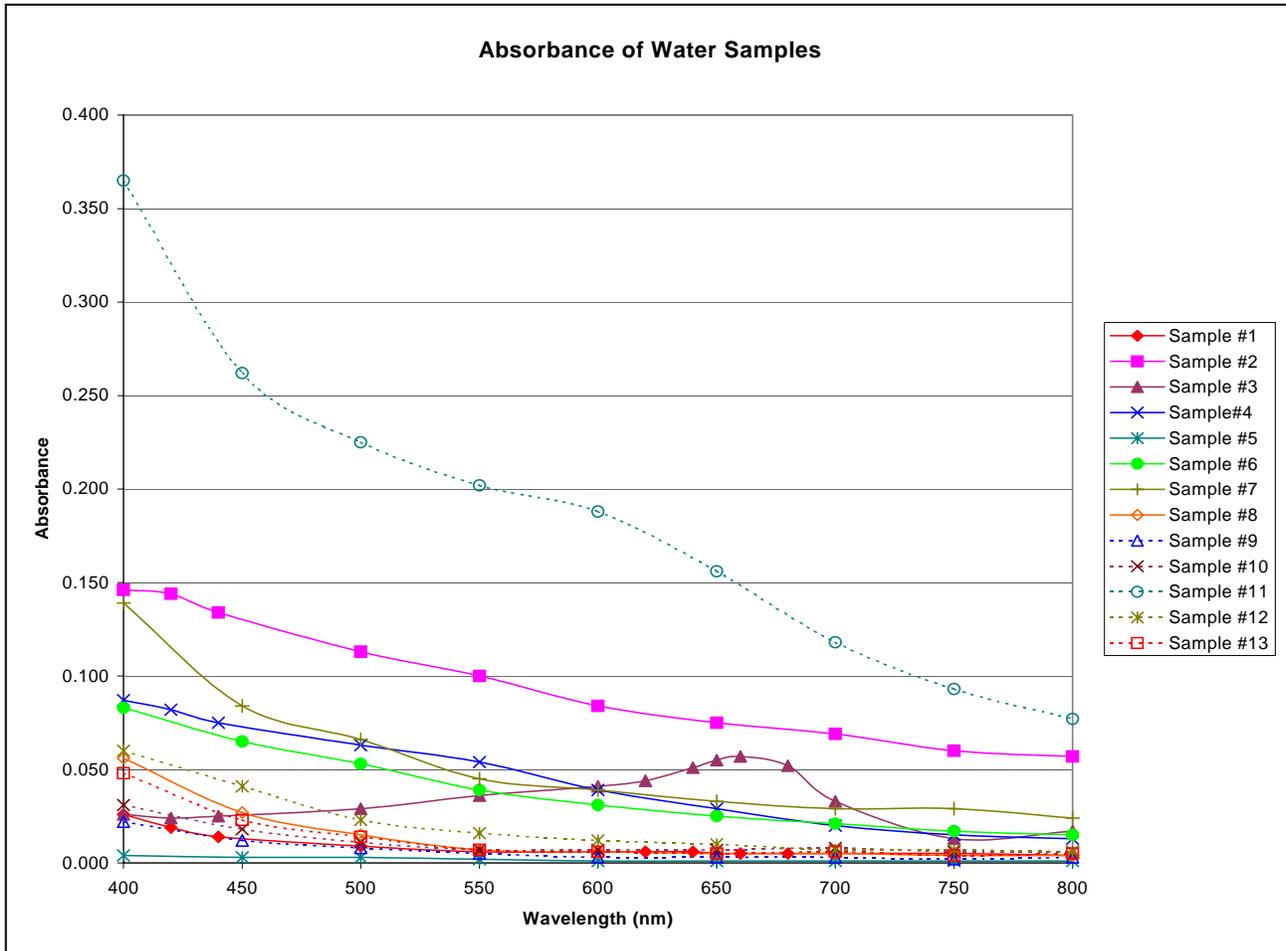


Figure 12: Absorbance of Water Samples

As mentioned in Section 3, all samples were filtered before measurements, yet Samples 2 and 11 appear to absorb an abnormally high amount of light at 800nm, where light absorbance would be expected to be close to zero. It appears that even after filtering there may have been a problem with light scattering in these two samples. Some of the water samples had distinct colors noticeable to the human eye. Those were Sample 3, a sample taken from the left bank of the Bagmati River at Tilganga that appeared blue, Sample 4, a sample taken from the right bank of the Bagmati River at Tilganga that also appeared blue, Sample 11, a sample taken from the right bank of the Bagmati River at

Tilganga that appeared black, and Sample 6, dyeing effluent from the Mount Everest dyeing company that appeared red. Sample 3 shows a definite peak in the orange range, implying it transmits blue light. The absorbance of Sample 3 is plotted on the same graph as the absorbance of Sample 20, the blue liquid dye, below in Figure 13. Although it can be seen that the same dyes were not used (the peaks are at different wavelengths), it can also be seen that the shape of the absorbance curve for Sample 3 resembles the shape of the absorbance curve for Sample 20, except Sample 3 has more background absorbance.

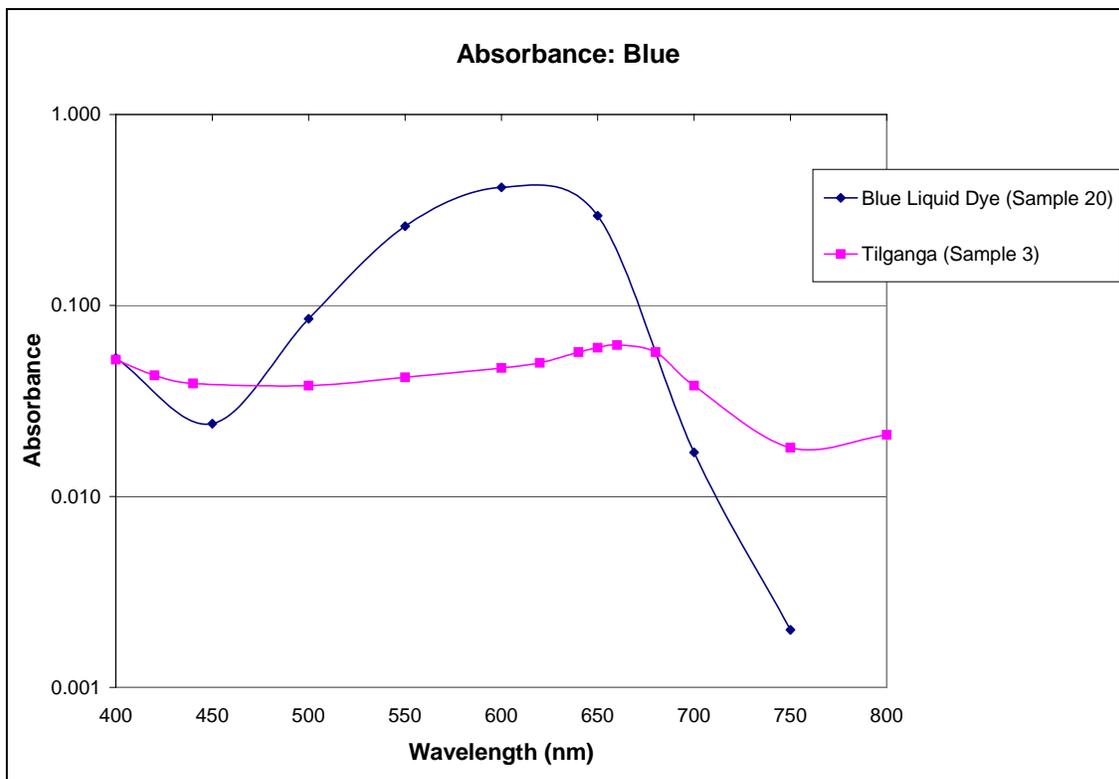


Figure 13: Absorbance graph of Sample 3 and Sample 20. Note that the absorbance scale is a log scale because of the much greater absorption of Sample 20 than Sample 3.

The absorbance peak of Sample 11 closely resembles that of Sample 21, the black liquid dye, as can be seen in Figure 14. Sample 11 appears to contain a lot of background absorbance. After filtration, the sample still appeared somewhat murky and this turbidity may explain why Sample 11 has an absorbance of 0.075 at 800nm, a wavelength at which

most of the other samples have an absorbance of almost zero. For a graph of the absorbance of all the liquid dyes, see Figure 21.

Samples 4 and 6 both have hints of red coloring and their absorbances are plotted below with Sample 18, the red liquid dye. Notice that neither Sample 4 nor Sample 6 has an absorbance peak, but their absorbance curves are not concave in the range of blue-green wavelengths like other, virtually colorless samples, which may account for their slightly red colors.

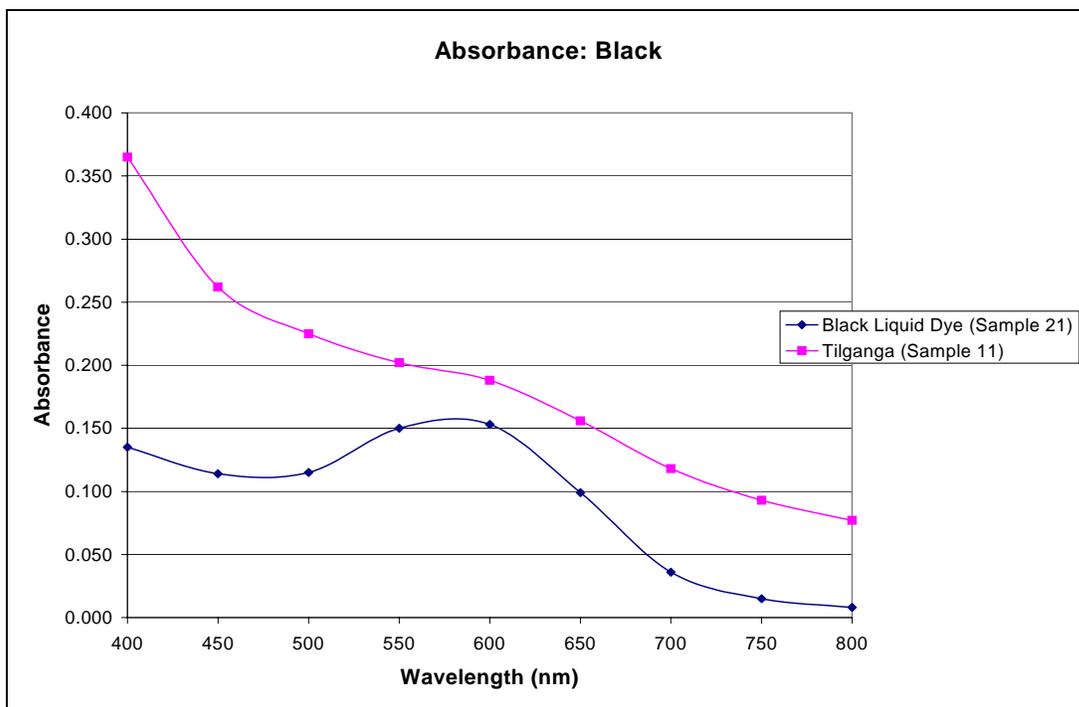


Figure 14: Graph of absorbance of Samples 11 and 21

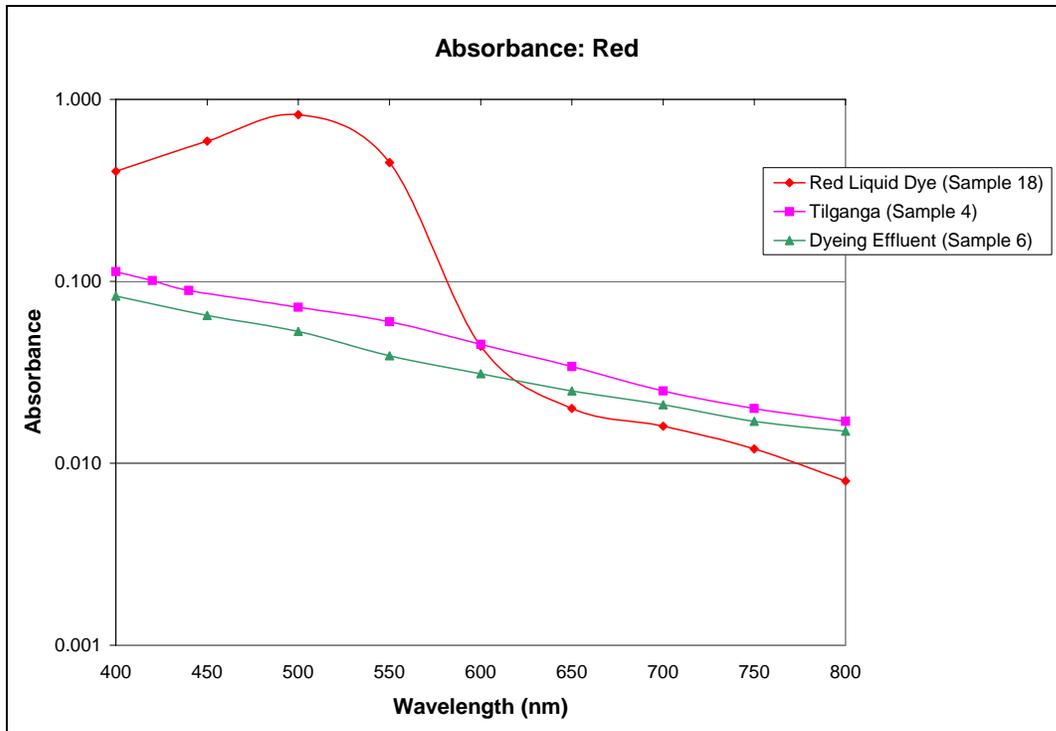


Figure 15: Graph of absorbance of Samples 4, 6 and 18

Most of the absorbance spectra for the water samples do not show peaks. This could be due to the fact that when many colors are added together, individual peaks are evened out, especially when the absorbance is measured at discrete points instead of continuously. Therefore it is probable that there is a build up of colors from dye in the river that appears brown, the color of the river. In support of this idea is Figure 16. The graph in Figure 16 is similar to the graph in Figure 12, except it only shows the absorbance of samples taken from the Bagmati River and Samples 3, 4, and 11, the samples taken at Tilganga, are omitted because these samples appeared to be one specific color. The sampling sites in the legend are listed in order from upstream on the Bagmati to downstream. As can be seen in the graph, all samples have a relatively high absorbance at 400nm, but this rapidly decreases in the range of visible light. This could be the result of both organic matter and dye being present. The overall absorbance in the range of visible light increases from upstream at Sundarijal to downstream at Sundarighat and then, decreases at Chovar. If this absorbance is in fact due to dyes, the absorbances of the samples follow the trend expected. They increase up to Sundarighat, the dirtiest point along the river and decrease at Chovar, where the river is slightly cleaner.

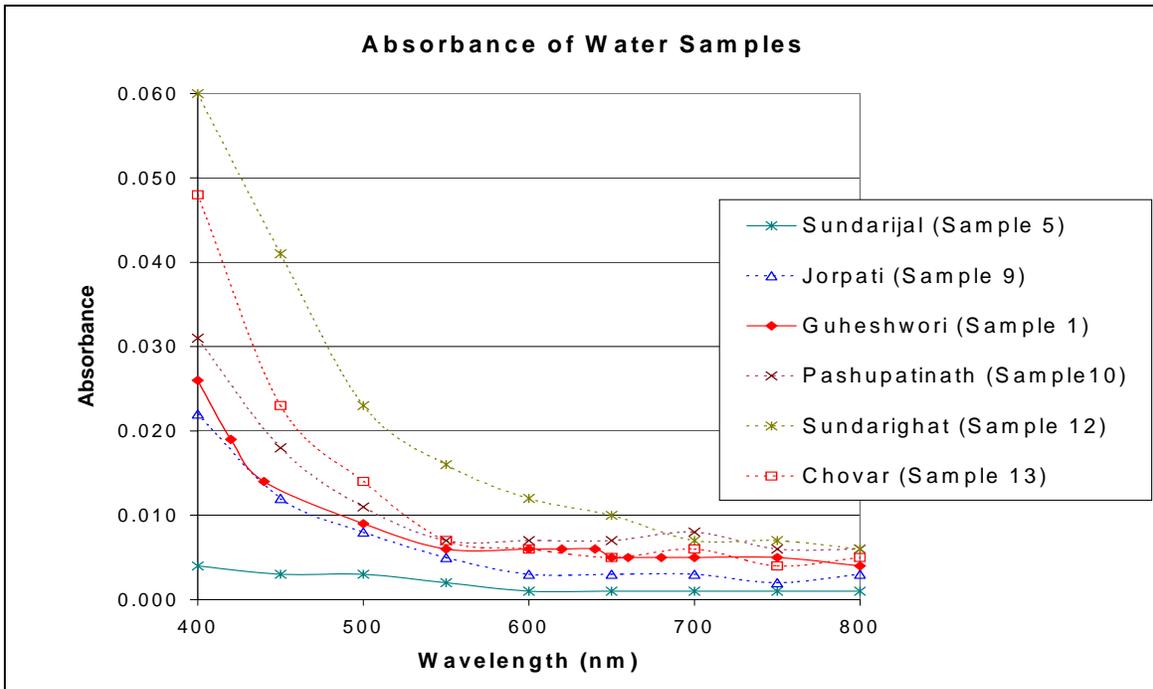


Figure 16: Absorbance of Bagmati River samples with the exception of samples taken at Tilganga

These graphs show that there is, in fact, color present in the river other than that provided from organic matter. There may be other explanations for why these colors are present, but it appears likely that these colors are the result of dyes. Since carpet dyeing is much more prevalent in Kathmandu Valley than any other type of dyeing, such as textiles, it would not be inappropriate to hypothesize that the color noticed is carpet dye. Because carpet dyes contain chromium, which is not as common in textile dyes, chromium measurements were conducted as another method of detecting the presence of dyes.

4.2 CHROMIUM MEASUREMENTS

Total chromium (chromium in all oxidation states) was measured in an atomic absorption spectrophotometer (AAS) for all of the samples except for the liquid dyes (Samples 18-21). The results are displayed in the tables below. Table 7 contains information on the chromium concentration in dyes and Table 8 contains information on the chromium concentration of water samples. Most of the water samples tested contained negligible

amounts of chromium (less than 0.01 mg/L). Those that contain more chromium are listed in Table 9 along with the name of the site from which the sample was taken.

Table 7: Total chromium in dry dye samples

Sample #	Color	Total Cr (mg/kg)
14	red	12,700
15	indigo	55
16	navy	24,000
17	black	24,000

Table 8: Total chromium in water samples

Sample #	Total Cr (mg/L)*
1	< 0.01
2	< 0.01
3	< 0.01
4	< 0.01
5	< 0.01
6	0.05
7	< 0.01
8	< 0.01
9	< 0.01
10	0.01
11	0.03
12	0.02
13	0.03

*Note that 0.01 mg/L is the lower detection limit for the AAS instrument used so values for measurements under 0.01 mg/L cannot be specified.

Table 9: Total chromium concentrations at points along the Bagmati River

Sampling Locations	Total Cr (mg/L)
Pashupatinath (Sample 10)	0.01
Tilganga (Sample 11)	0.03
Sundarighat (Sample 12)	0.02
Chovar (Sample 13)	0.03

As one can see from the total chromium data, the levels of total chromium are quite high in the dry dyes but low in the water samples. Of the dry dyes, navy and black have the highest chromium content and indigo the lowest. Chromium content appears to be dependent on color. Darker, black-based colors contain more chromium since chromium is good at providing a black color, while brighter colors do not contain as much. As mentioned earlier, 70% of acid dyes contain chromium and others often contain cobalt or copper. Because cobalt is commonly used for its bright blue color, the low concentration of chromium in the indigo powdered dye may be due to a high cobalt content.

One could come to the conclusion that because the chromium content of dyes is high and the content in the water is low, not much dye reaches the water, that it is all used in the dyeing process and that the dye that does eventually reach the water is of low chromium content. The samples taken from the Bagmati River at Tilganga would support that reasoning. The samples taken on the left and right banks on January 7, 2003, Samples 3 and 4, both have a chromium content of less than 0.01 mg/L. The sample taken from the right bank of Tilganga on January 17, 2003 has a chromium content of 0.03 mg/l which is less than the World Health Organization's (WHO) chromium limit for drinking water of 0.05 mg/L.

However, broad conclusions cannot be drawn from this single result. The state of the river at Tilganga changed each time it was visited. The first time Tilganga was visited, there was a stream of dark blue liquid exiting from a pipe on the left bank into the river. At that time sampling was not being conducted. When the site was revisited for sampling, liquid was not flowing out of the mentioned afore pipe. Instead the river water

near the pipe had a pale blue tint, and this is where the water from the left bank was obtained. If the blue liquid flowing from the pipes on the first visit did have a high chromium content, these results would not necessarily show it. The sample taken from the right bank that same day appeared to be a pale reddish brown color (as compared with the brown color of the river). It was not discernable whether the red color was the effect of dyes or something else. Therefore a low level of chromium shown by this result does not necessarily imply that there is no problem.

The chromium concentration of Sample 11, the black colored liquid, presumably dye, flowing into the river was quite interesting. Sample 11 was taken from the right bank of the Bagmati River at Tilganga. Its chromium content was measured at 0.03 mg/L, which is interesting because the previous measurements of the Bagmati at Tilganga showed a chromium content of less than 0.01 mg/L. Therefore this black material did affect the chromium content of the river. It is likely that the black material as well as the blue material observed earlier were carpet dyes. Carpet dyeing is prevalent along the Bagmati River, much more so than any other type of dyeing, such as textile dyeing. In addition the chromium content would suggest that it is a carpet dye, since textile dyes do not often contain chromium. Assuming that Sample 11 did, in fact, raise the chromium content of the river by at least 0.02 mg/L, it is possible that twice as much could raise the chromium content another 0.02 mg/L to the WHO's drinking limit of 0.05 mg/L. The Bagmati is not a high volume river, especially in the dry season. Contamination is not as easily diluted.

Sample 9 to Sample 13 were taken progressively downstream along the Bagmati River. Table 9 shows that the samples contain increasingly more chromium from Sample 9 to Sample 13, except for Sample 11, the black sample taken at Tilganga. This suggests that contaminants are continuously being added to the river all the way down to Chovar, the sampling site furthest downstream. It is beyond the scope of this paper to say whether the source of this chromium contamination is carpet dye. However it is possible that it is carpet dye. It could also be due to other sources of chromium, such as the metal working craft industry, which is prevalent in Kathmandu.

Another interesting point is the shade of the dyeing effluent from Mount Everest Dyeing Company, Sample 6. The color of the dyeing effluent was extremely pale. They had been dyeing red at the time we visited and the effluent was barely red. This brings up two points. The first is, why were the dyes emitted into the Bagmati River at Tilganga so dark if dyeing effluent is so pale? If Sample 6 had been emitted into the Bagmati it would have been indistinguishable from the brown water of the river. There are several possibilities. One is that what was being discharged into the Tilganga was not effluent but a discarded batch of dye. Another is that the company emitting dye at Tilganga used cheap dyes. Since cheap dyes do not stick to wool as well, that would require using more dye per batch and more dye would flow into the river as waste. Yet another possibility is that the intensity of the dyeing effluent depends on the intensity of the color being dyed. Another observation regarding Sample 6 is that this dyeing effluent was very pale, but it had a chromium content of 0.05 mg/L, hence noticeable color in the water does not necessarily indicate high chromium levels. In doing dilutions of the liquid dyes for the absorbance test, the author noticed that the color black fades more quickly upon dilution than the other colors, but had the highest chromium content, reinforcing the conclusion that the absence of color does not indicate the absence of chromium.

Chromium levels in the Bagmati were lower than the WHO's guideline for drinking water but this does not necessarily mean that there is not a problem with chromium in the Bagmati River. It is possible that levels are this low because dyeing is in an off-season during the winter and carpet sales are worse this year than in past years²². Also, more chromium may enter the Bagmati than indicated by chromium measurements. Since dye has an affinity for sticking to particles, those particles filtered out from the water samples before chromium measurements were taken may have contained a significant amount of chromium. Chromium could also be removed by settling to the river sediments. In the literature reviewed by the author there was no mention of any studies conducted to measure chromium in the sediments of the Bagmati River. This issue may not have

²² Mahat, 2001

received much attention because many of the researchers studying the Bagmati believe that it does not have a heavy metal problem.

4.3 DISSOLVED OXYGEN (DO) MEASUREMENTS

DO measurements conducted by the author were not carried out according to standard methods due to the unavailability of equipment to do so. Therefore the author's DO measurements are only rough estimates of the true DO in the samples. Appendix B contains the DO measurements obtained by the author. Below, Figure 17 contains DO measurements taken by ENPHO at the five common sampling points between the author and the South-Asian Transboundary Monitoring Program. These measurements were taken by experienced technicians using a Hydrolab Series 4a MiniSonde® MultiProbe with a Series 4a Data Surveyor® Data Logger and are thought to be reliable.

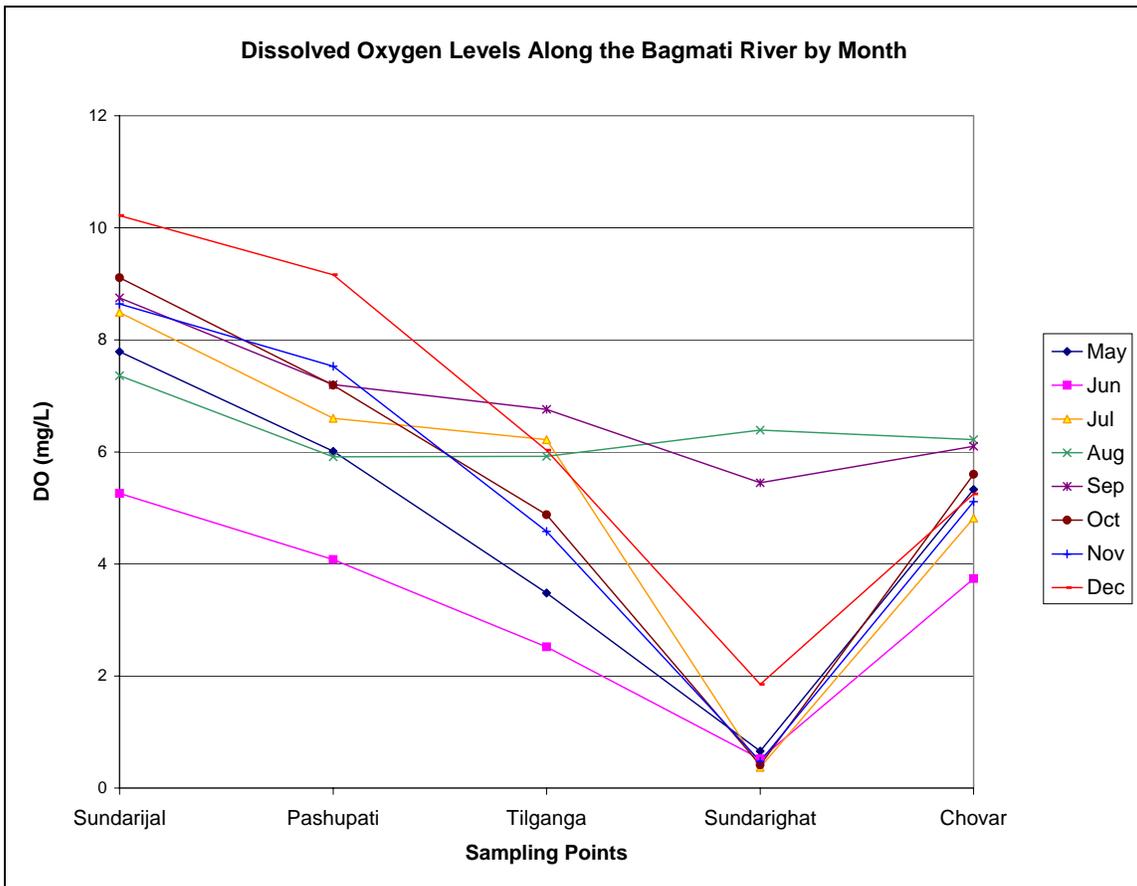


Figure 17: DO measurements at sites along the Bagmati River by month

For most months, DO measurements decrease from Sundarijal to Sundarighat and then increase again at Chovar. DO levels increase at Sundarighat in August and decrease only slightly at Sundarighat in September, instead of decreasing sharply, as in other months. The likely reason for this is that August and September are in the monsoon months, when the volume of the river is much greater, and the river is able to further dilute any pollutants.

4.4 CHEMICAL OXYGEN DEMAND (COD) MEASUREMENTS

As COD measurements could not be taken by the author in Nepal, the data presented below in Figure 18 are those taken by ENPHO for the South-Asian Transboundary Monitoring Program. Figure 18 shows COD levels at the same five sampling points as shown in Figure 17 for the months from April 2002 through December 2002.

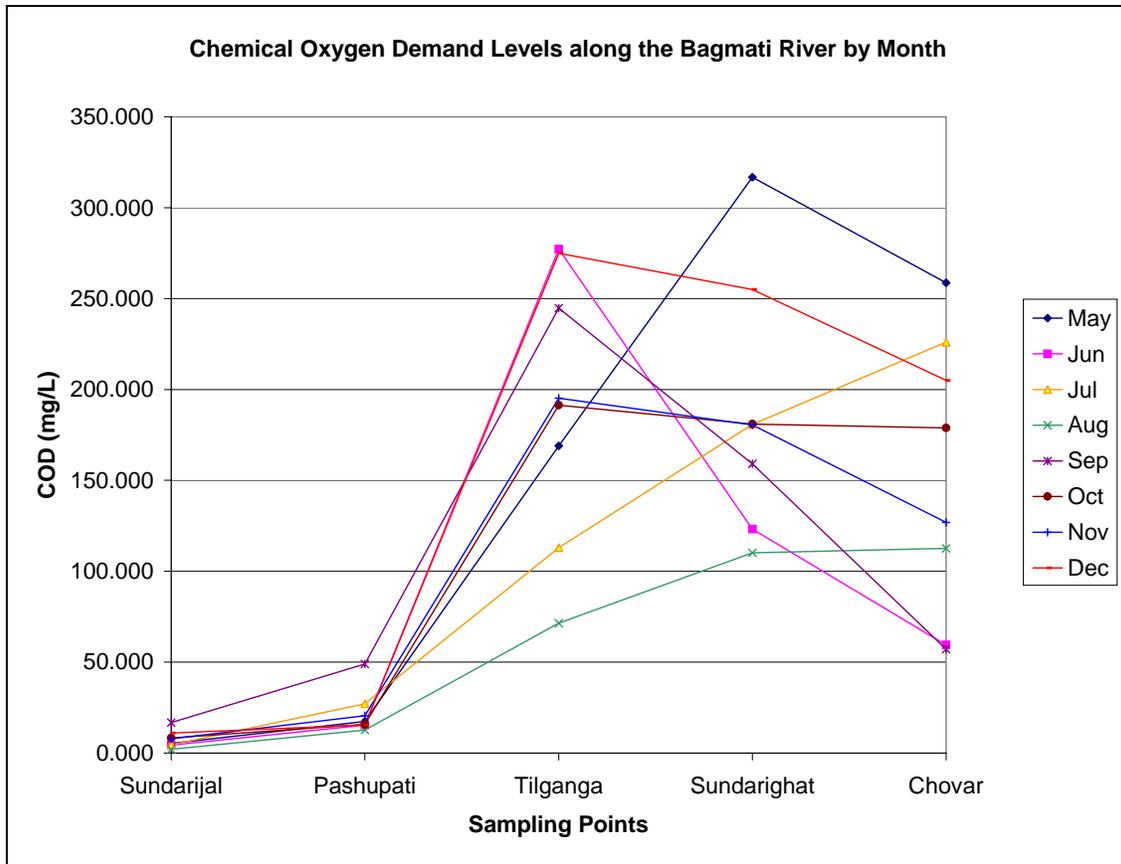


Figure 18: COD levels at points along the Bagmati River by month

COD is quite low at Sundarijal and Pashupatinath, but increases sharply at Tilganga. In most months the COD decreases from Tilganga to Sundarighat, but in some months it increases. In all months the amount of COD decreases from Sundarighat to Chovar. These increases and decreases in COD along the Bagmati River can be the result of a variety of substances in the water. The author had been informed by various sources that carpet dye discharge generates high COD levels in the receiving waters. To assess whether or not dye could be contributing to the chemical oxygen demand of the river, the COD of dyes was tested.

As explained in Chapter 2, the COD of dyes was measured in four rounds of testing. For the results from all four rounds of measurements, see Appendix C. The first round of measurements was performed on solutions that were 0.2% liquid dye. None of the liquid dyes exerted an additional chemical oxygen demand on the water that they were

mixed with. The next round of testing was performed after letting the solutions sit for 24 hours in an effort to observe whether the COD the dyes exerted would increase when given time to decompose in solution. The liquid dyes still did not add COD. For the third round of measurements, 1% liquid dye solutions were prepared. At this concentration the liquid dyes add COD to the water. The levels of COD of these solutions can be seen in Figure 19. COD measurements for some of the samples in Figure 19 were taken twice. In these instances the two measurements are averaged. For the full data set, see Appendix C. From the COD results, it appears that acetic acid is much more dilute in the solutions to which powdered dyes are added to create liquid dyes than in the sample of acetic acid provided by Mount Everest Dyeing Company. The COD of a 1% solution of the provided acetic acid was over 1500mg/L (the upper limit of the readable range for the equipment used).

To test whether the COD exerted by liquid dyes is only a result of the acetic acid they contain, or of both the acetic acid and the dye itself, a fourth round of measurements were taken to document the COD of dry dyes in water solutions. The solutions measured had a dry dye concentration of 25mg/L. In Figure 20, COD levels for dry dye – river water solutions are graphed. All the dry dyes except for the red dye cause an increase in the COD of the Charles River water they were added to, though the increase is small, so dyes and not just acetic acid can exert a COD. The decrease in COD associated with the red dye is also small and could be a matter of precision as it is unlikely that dye would decrease COD.

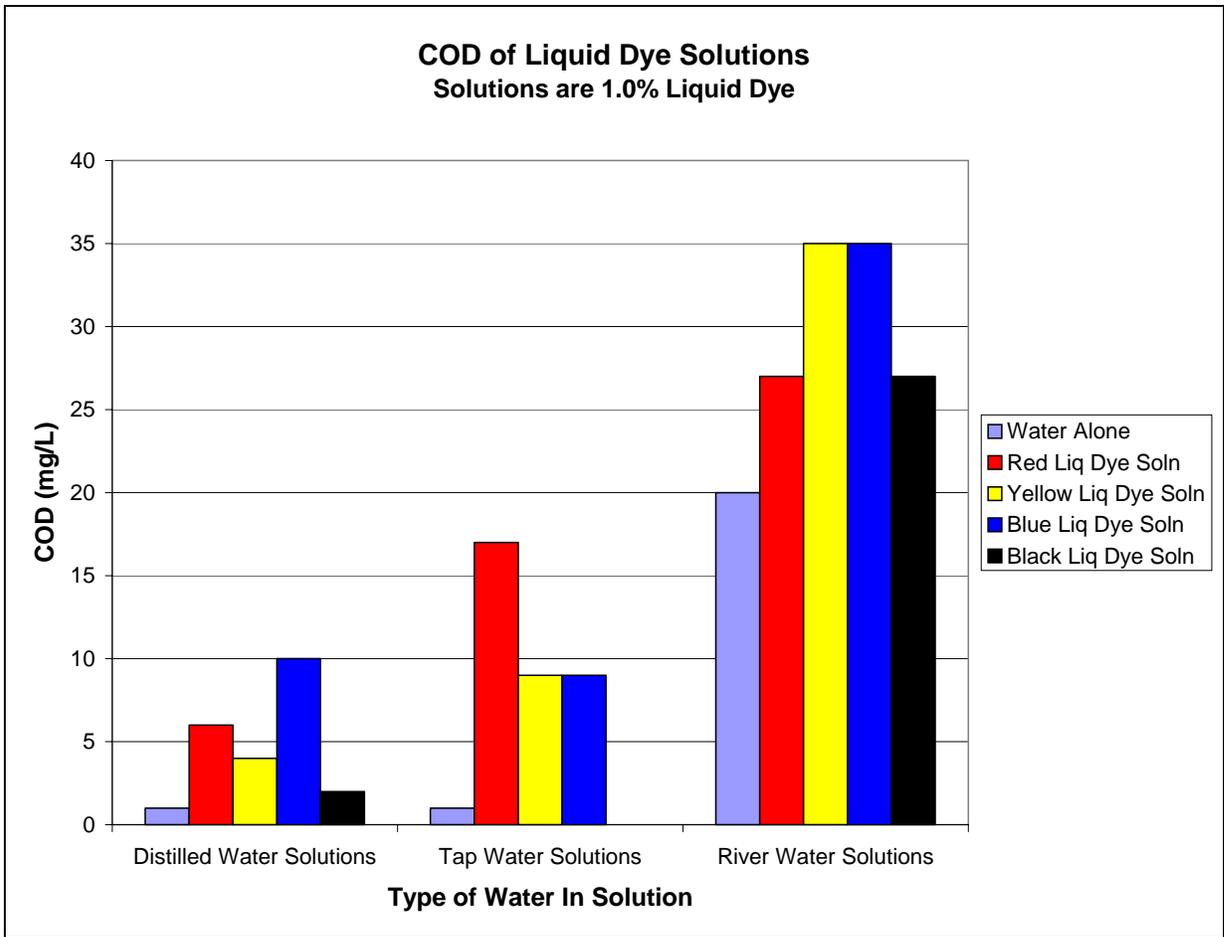


Figure 19: COD levels in 1% liquid dye solutions

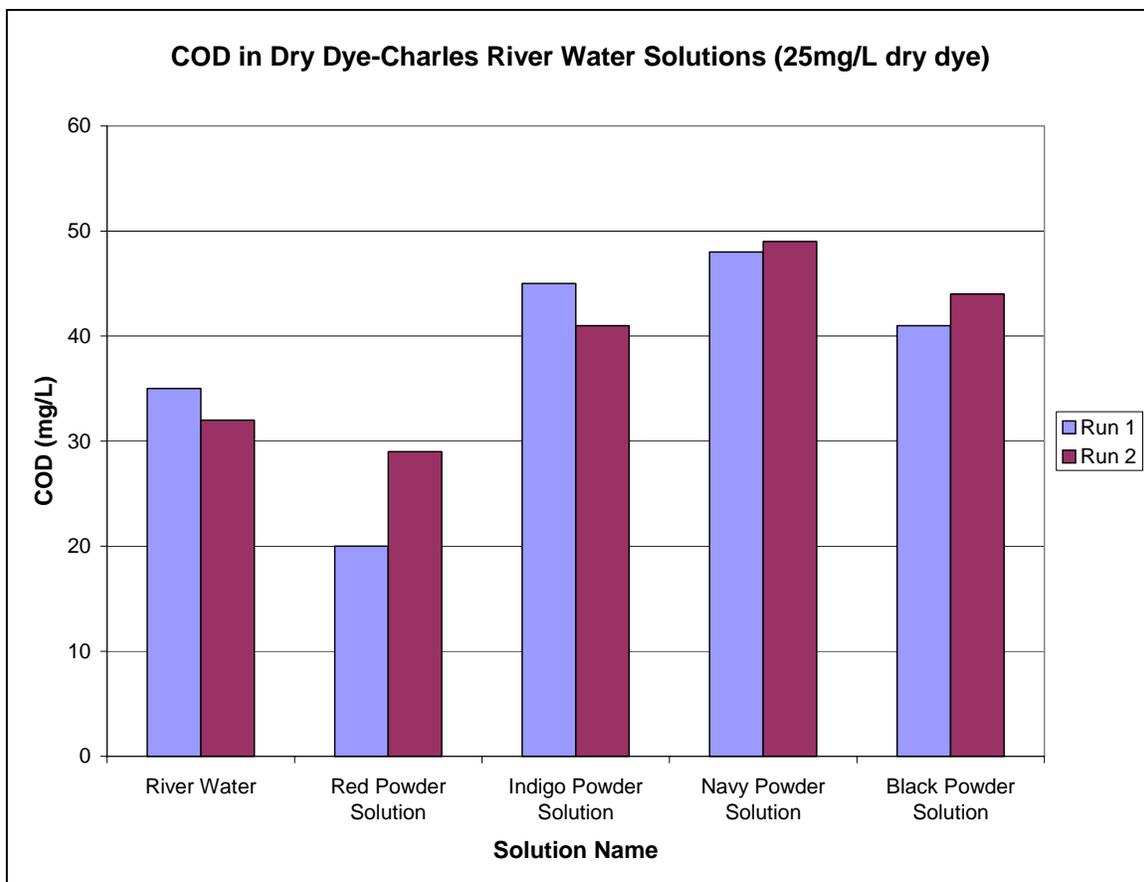


Figure 20: COD level in 25mg/L dry dye solutions

Two points about the accuracy of the COD measurement method used should be noted. The first is that, as stated in the Methodology (Chapter 3), COD was measured using a spectrophotometer, and an increase in absorbance is correlated to an increase in COD. Therefore the color of the dyes in the samples could lead to error in the COD measurements, but it should not. As the dyes are oxidized by dichromate, they lose their color. If the reaction is carried out to completion, as it likely is after being heated for two hours, all of the original dye color should be gone by the time COD is measured.

To find the change in COD that corresponds to a one unit change in absorbance, after measuring the COD of one sample, the author measured the absorbance of that sample at 620nm using the same blank. It was found that a one unit difference in absorbance equates to a 2280 mg/L difference in COD. The absorbance of sample solutions was measured at 620nm before addition to the COD reagent. The absorbance of the red liquid

dye solution was the lowest (as expected from Figure 21) at 0.010, and absorbance of the blue liquid dye solution was the highest (as also expected from Figure 21) at 0.211. Accounting for the fact that 2mL of these solutions were diluted in about 3mL of reagent, the maximum possible effect the color of the dyes could have on the COD measurements was calculated. For the red liquid dye, color could have increased the COD measurement by 9mg/L. For blue liquid dye, color could have increased the measurement by 190mg/L. Looking at the COD measurements in Figure 19, there does not appear to be any correlation between the COD and color as one would expect if color were affecting the COD measurements. The COD measurements of blue dye solutions are much less than 190mg/L, and in one trial, the COD of the red liquid dye was greater than that of the blue dye. Therefore, it can be concluded through chemical reasoning and by viewing the results that dye color does not produce a significant amount of error in the given COD measurements.

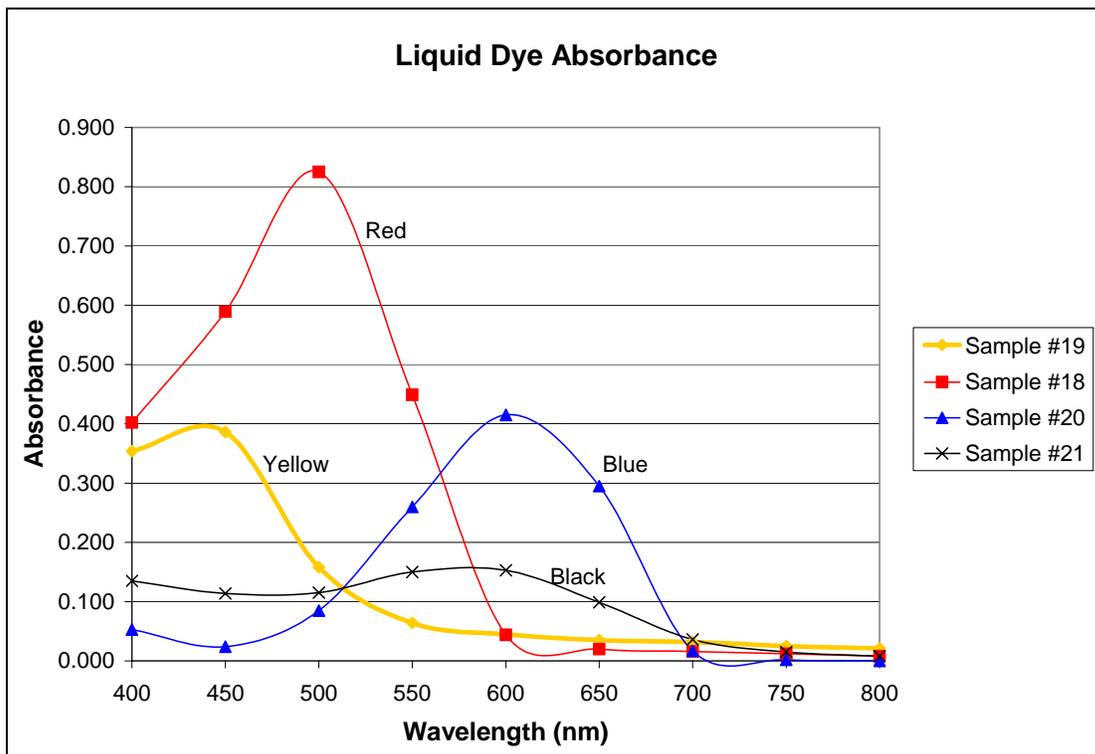
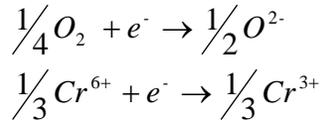


Figure 21: Absorbance of liquid dyes (2% liquid dyes in water)

The second accuracy issue is that chromium in a sample may affect COD measurements. Since COD is calculated from the amount of trivalent chromium produced by the

reduction of dichromate, it is important to account for the chromium already present in the dyes measured for COD. Calculations were performed to find out whether chromium in these dyes would affect COD measurements. COD and chromium measurements for the navy dry dye were used for these calculations since the chromium concentration of the dry dyes is known, and navy dry dye (along with black dry dye) contains the highest concentration, and therefore would cause the most error.

COD measurements are given as the equivalent amount (in mg/L) of O₂ required to oxidize the same amount of dye as oxidized by the dichromate. The half reactions for oxygen and chromium are provided below.



The average COD of the measured navy dry dye solution was 49mg/L. To determine the amount of Cr³⁺ that must be present after dichromate reduction, first the COD must be changed from mg/L O₂ to mmol/L O₂. Then the equivalent concentration of Cr³⁺ in mmol/L, and then in mg/L, can be found. The steps are shown below.

$$\begin{aligned} [O_2] &= \frac{49 \text{ mg } O_2/L}{32 \text{ mg } O_2/\text{mmol } O_2} = 1.5 \text{ mmol } O_2/L \\ [Cr^{3+}] &= 1.5 \text{ mmol } O_2/L * \frac{\frac{1}{4} \text{ mol } O_2}{\frac{1}{3} \text{ mol } Cr^{3+}} = 2.0 \text{ mmol } Cr^{3+} / L \\ Cr^{3+} &= 104 \text{ mg } Cr^{3+} / L \end{aligned}$$

The amount of total chromium already present in the dye is found from the concentration of dye in the dye solution (25mg/L), the percent of dye solution in the dye solution-reagent mixture (40%) and the chromium concentration of the dye (2,400 mg/kg). The calculations are shown below.

$$Cr_T = 25 \text{ mg dye/L} * 0.40 * 2,400 \text{ mg } Cr_T / \text{kg dye} * \frac{1 \text{ kg}}{10^6 \text{ kg}} = 0.024 \text{ mg } Cr_T / L$$

The amount of trivalent chromium produced from dichromate reduction is 104 mg/L. The amount of total chromium contributed by the dye is 0.024 mg/L. Even if all the

chromium in the dye were trivalent chromium, the amount of chromium contributed by dye would not be significant enough to affect COD measurements.

One conclusion that can be drawn from the COD measurements is that dyes do not contribute significantly to the COD demand of the Bagmati. To look at this quantitatively, the blue liquid dye solution used in COD testing can be compared to Sample 3, the water sample collected at Tilganga that appeared blue. This sample displayed an absorbance peak with a maximum absorbance of about 0.06 at 660nm. The blue dye measured displayed an absorbance peak at about 620nm (Figure 21), so its maximum absorbance is about 0.21 (measurement given previously). Relating COD and color, one would expect the COD of the sample taken at Tilganga to be only a fraction of the COD of the blue liquid dye solution, which was only 10mg/L in distilled water. However, COD at Tilganga ranges from 160 mg/L and 280 mg/L in the dry season. Thus, the COD contributed by dye appears to be minor.

Comparing Table 9 (chromium), Figure 16 (absorbance), Figure 17 (DO), and Figure 18 (COD), it can be seen that they follow somewhat similar patterns. In terms of absorbance and DO, water quality becomes increasingly worse from Sundarijal to Sundarighat and then improves slightly at Chovar. Water quality in terms of COD (Figure 18) follows a somewhat similar trend, but for most months the water quality decreases up to Tilganga and then becomes increasingly better at Sundarighat and Chovar. Interestingly, water quality in terms of chromium becomes progressively worse until Tilganga, better at Sundarighat and the worse at Chovar. It should be noted that Sample 11, the sample at Tilganga for which the chromium content was 0.03mg/L, was taken not far from where the black liquid, presumably dye, entered the Bagmati River. The reason why the chromium measurement at Tilganga is higher than that at Sundarighat could be that the sample taken at Tilganga is more concentrated with dye. Chromium is the only water quality parameter that is worse at Chovar than at Sundarighat. This would imply that although the general chemical load on the river starts to let up after Sundarighat, the chromium load does not. Looking at the effects of dyes on the river discussed above, this fact could imply that there are dyeing factory effluent outlets beyond Sundarighat.

5 CONCLUSIONS

Research conducted on the effects of carpet dye on the Bagmati River was preliminary and as such, firm conclusions can not be drawn at this time. Some commentators criticized the carpet industry for causing a great amount of pollution in Nepal. These reports cited chromium as an especially problematic pollutant from the carpet dyeing. Others cited COD as being the only problem associated with carpet dyes. Yet others asserted that the Bagmati does not have a heavy metal pollution problem and that the COD contribution from dyeing was minimal in comparison to that produced by domestic sewerage, rendering the carpet industry rather insignificant in the overall issue of Bagmati River water quality.

Unfortunately, this thesis cannot offer a definitive answer to the question of whether carpet dyeing effluent significantly decreases the water quality of the Bagmati River, but it does provide valuable insight for future studies. The first conclusion that can be drawn from this thesis is that, though many carpet manufactures profiled in the author's search for information claimed to use metal free dyes, one of the main suppliers of dye to Nepal, Clariant, makes no claims of having metal free dyes. In fact, all four of their dyes tested contain chromium, and three of these four dyes contain chromium in significant amounts. Therefore, even though the highest level of chromium found in the Bagmati River, 0.03mg/L, is below the World Health Organization's guideline for chromium in drinking water, an influx in dyeing wastewater to the Bagmati River, especially from wasted dye batches, could easily increase the concentration of chromium in parts of the Bagmati to above the WHO guidelines. Chromium could also be going to the sediments of the Bagmati River. Even if the concentration of chromium in the river appears low, there could be a significant amount in the sediments. Since the Bagmati is rather stagnant in the dry season, chromium can settle to the sediments. When the river flow increases in the monsoon season, chromium in the sediments could be re-suspended in the river, leading to the possibility of high chromium concentrations in the river at the beginning of monsoon season.

Another significant conclusion to be drawn from this thesis is that color intensity does not necessarily correspond to chromium content. Since black absorbs color over a range of wavelengths, but not intensely at any particular wavelengths, the color black fades more quickly upon dilution. Yet, black, in this study and, in general, contains more chromium than most dyes. Therefore the perspective that some Nepalis may have about a stream being free of dyes and their harmful components if it is free of color is not a valid one.

Addressing the topic of chemical oxygen demand, dry dyestuffs do not appear likely to contribute significantly to the high COD at points along the Bagmati River, but the acid (particularly acetic acid) used in conjunction with these dyes does. The amount of acetic acid present in liquid dyes does not add a high COD. The COD of liquid dyes is quite small in comparison to the high COD values measured along the Bagmati. Yet, if acetic acid is wasted in a stronger form to the Bagmati River, it could add a significant amount of COD.

The purpose of this thesis was to determine the effects of carpet dye on the Bagmati River. These effects are an increase in chromium levels and a slight decrease in dissolved oxygen. Just how significantly the quality of the Bagmati River will improve if and when controls are placed on the dyeing industry's effluent remains to be seen.

6 RECOMMENDATIONS

6.1 RECOMMENDATIONS FOR NEPAL

Waste from the wool dyeing industry appears to be problematic but there are some solutions that can help mitigate the effects carpet dyes could have on the waters to which they are discharged, specifically the Bagmati River.

Currently, Nepal has no standards for chromium in drinking water. Nepal instituted standards on industrial effluents, but the chromium limit for carpet industry wastewater is 20 times higher than that for other industries in general. Also, these regulations are not enforced. In a survey conducted by Keshav Mangal Joshi for Nepal's Ministry of Population and Environment (MOPE) in 1999, a year after the standards were approved, eleven out of twelve (~90%) of companies surveyed said that they do not regularly monitor their effluent²³. This number has likely remained the same since there is no enforcement of Nepal's industrial effluent standards. Although there are regulations in place, there is no incentive to adhere to them. First it would be advisable that Nepal develop standards for heavy metals in drinking water and water for other purposes, such as irrigation and recreation. Then, using these standards the Nepali government could estimate a new regulatory limit to be placed on the carpet dyeing industry to ensure pollution stays below the level of the drinking water standards, instead of putting a regulation in place because it is agreeable to Nepal's industries. It is understandable that it will take time to lower the industrial standard for chromium while companies put controls into place, but it is of the author's opinion that eventually Nepal should lower its chromium standard for the carpet industry to the general standard. Consequences are needed to go along with these regulations. When companies are fined for not complying with regulations, they will find it more economically feasible to clean their wastewater.

More progress would probably be made if the responsibility of implementing environmental regulations were given to an agency other than the one that currently holds

the responsibility, the Ministry of Industries (MOI). The main objective of MOI is to promote industrial growth. MOI already feels that industrial growth is being inhibited by environmental regulations²⁴. It would likely be more effective for another agency, such as MOPE, to enforce water quality standards on industrial effluents.

The second recommendation is to use vegetable dyes instead of synthetic dyes. The reasons that vegetable dyes are not used nearly as often as synthetic dyes is because the complicated process requires workers with more experience and is more expensive, but if the carpet dyeing industry switched to vegetable dyes, there would be a market for the carpets produced. The beginning of this process is in the hands of the consumers, who are international. Most of the carpets produced in Nepal are made for export to wealthy Western countries (80% to Germany) where consumers are able to pay more for carpets produced with natural dyes and may be willing to pay more for carpets made using the respected vegetable dyeing process. If companies had their employees trained in the making of vegetable dyes, they would learn the skill. If the government could support those companies that use vegetable dyes, it may not only help the environment, but also Nepal's agriculture industry. The carpet industry would provide jobs to farmers who grow the materials for vegetable dyes, instead of spending much of its money in other countries to import dyes, as Nepal does not have any synthetic dye manufacturers. Using natural dyes would decrease the risk of elevated chromium levels. The only possible drawback the author could envision to this "process substitution" recommendation is that no conclusive tests have been made to determine whether natural dyes exert a significant COD demand. Studies to this effect should be carried out before a mass movement is made to the use of vegetable dyes.

Another recommendation is to use less dye in the dyeing process. As mentioned before, companies that use natural dyes will use the same batch of dye to dye multiple batches of wool, up to three times. This technique is not commonly used with synthetic dyes since the cost of material is less expensive, and it is difficult to dye an exact color when a dye

²³ Joshi, 1999

²⁴ Joshi, 1999

solution is recycled from a previous batch. Better training of dyeing operators would make it easier to recycle dye batches from darker to lighter dyes. Lighter wastewater could even be recycled with the addition of more dye.

Clariant recommends that wool be dyed below boiling²⁵. Wool is often dyed at boiling because in that case a thermometer is not required to be certain that dyeing is occurring at a given temperature. Clariant asserts that when wool is dyed between 80 and 85°C, the quality of the wool is better. It is softer with fewer thread breaks, and the colors are more brilliant. In addition the dyeing time is shorter since the temperature of the batch is increased from room temperature to the final elevated temperature at a constant rate, no matter what the final temperature may be. Dyeing at a lower temperatures also saves energy, a valuable commodity in Nepal, and water, another valuable commodity, since water is not boiled away. This will result in less wastewater and therefore less dye and acid would be wasted to the Bagmati River, assuming that batches are not currently diluted to account for the evaporation of water.

Another recommendation is to obtain control systems. This recommendation may be difficult to implement, as it may be too expensive for the small dyeing companies of Nepal. If the dyeing plants were outfitted with automated control equipment to detect changes in temperature and pH, changes could be dealt with early on instead of after the wool has been dyed too strongly and must be bleached to start over. This is a major pollution problem when a whole batch of dye gets bleached and discharged to the wastewater. Since control technology may be too far-fetched, at a minimum dyeing factories should hire operators that are knowledgeable and trained in the process that will monitor properties such as temperature and pH and detect glitches in the process.

6.2 RECOMMENDATIONS FOR FUTURE STUDENTS

There are a number of different directions in which this research can be taken in the future. One would be to conduct another study of water quality, looking at the same

²⁵ Clariant, 2003

parameters and maybe some new ones, such as cobalt, another heavy metal found carpet dyes. This would be a valuable study because it would show if and how the Bagmati's water quality is changing over time. Using this study as a reference it would be possible to formulate a more efficient research plan for time spent in Nepal, hopefully avoiding some of the drawbacks faced in this study, such as using time in Nepal to determine appropriate sampling sites.

Another valuable parameter to research would be chromium in the sediments of the Bagmati, as this is a virtually untouched subject that could effect Bagmati River water quality. Also it would be useful to measure water quality parameters in the tributaries that flow into the Bagmati to give a more holistic view of the river.

Not as technical, but equally as important would be a thesis that surveys the different carpet dyeing companies in Kathmandu Valley. It would be valuable to the continuation of the presented research to know the number, location, and approximate effluent loads of carpet dyeing companies. This would be of great use in estimating the contribution of dyes to the Bagmati River water quality deterioration. A thesis along this line could also include a survey of which brands of dyes are used so a future study could be conducted to analyze the chemical properties of these dyes.

Another area for future research is in inexpensive but effective treatment of industrial carpet waste. There is a process that has been tested by scientists in other countries that could be a possible mechanism of removing dyes from wastewater called Fenton's reaction. Fenton's reagent, hydrogen peroxide and iron (II), is effective at oxidizing dyes, which removes their color. Methods for removing other constituents of dyeing wastewater, such as chromium, could also be researched.

APPENDIX A

Table 10: Dates of sample collection and testing

Sample Number	Sampling Date	Date of Absorbance Measurements	Date of Total Cr Measurements	Date of DO Measurements	Date of COD Measurements
1	1/7/03	1/8/03	1/14/03	-	-
2	1/7/03	1/8/03	1/14/03	-	-
3	1/7/03	1/8/03	1/14/03	-	-
4	1/7/03	1/8/03	1/14/03	-	-
5	1/9/03	1/10/03	1/14/03	-	-
6	1/9/03	1/10/03	1/14/03	-	-
7	1/15/03	1/16/03	1/16/03	1/15/03	-
8	1/15/03	1/16/03	1/16/03	1/15/03	-
9	1/15/03	1/16/03	1/16/03	1/15/03	-
10	1/17/03	1/21/03	1/22/03	-	-
11	1/17/03	1/21/03	1/22/03	1/17/03	-
12	1/17/03	1/21/03	1/22/03	-	-
13	1/17/03	1/21/03	1/22/03	-	-
14	1/9/03	-	1/10/03	-	4/12/03
15	1/9/03	-	1/10/03	-	4/12/03
16	1/9/03	-	1/10/03	-	4/12/03
17	1/9/03	-	1/10/03	-	4/12/03
18	1/9/03	1/14/03	-	-	4/19/03
19	1/9/03	1/14/03	-	-	4/19/03
20	1/9/03	1/14/03	-	-	4/19/03
21	1/9/03	1/14/03	-	-	4/19/03

APPENDIX B

Table 11: DO measurements performed by the author

Sample Number	DO (mg/L), Test 1	DO (mg/L), Test 2
7	6.5	6.9
8	4.3	4.9
9	0	0
11	0	-

APPENDIX C

This appendix contains the complete set of COD dye data. Four rounds of measurements were performed. In the first round of measurements, 0.31 mL of liquid dye or acetic acid were added to 155mL of water to fill 150mL sampling bottles (leaving no head space). The resulting solutions were 0.20% liquid dye or acetic acid respectively. Distilled water was used as a blank. Below in Table 12 is the label coding used for the samples. Table 13 contains the data from the first round of COD dye testing.

Table 12: Sample name coding

TW - tap water
DW - distilled water
RW - Charles River water
AA - acetic acid
RL - red liquid dye
YL - yellow liquid dye
BluL - blue liquid dye
BkL - black liquid dye
RP - red powder dye
IP - indigo powder dye
NP - navy powder dye
BkP - black powder dye

Table 13: COD levels in 0.20% liquid dye or acetic acid solutions

Sample	COD (mg/L)
TW	0
RW	35
RW-AA	331
RW-RL	10
TW-AA	313
TW-RL	0
TW-YL	0
TW-BluL	0
TW-BkL	0

The solutions prepared in the first round of testing were tested again the next day to determine whether the dyes would exert a higher COD with time. They did not; the results are presented below in Table 14.

Table 14: COD levels in 0.20% liquid dye or acetic acid solutions one day after solution preparation

Sample	COD (mg/L)
TW	0
RW	0
RW-AA	323
RW-RL	5
TW-AA	304
TW-RL	0
TW-YL	0
TW-BluL	0
TW-BkL	0

Data from the third round of testing was presented in Section 4.4. Solutions in this round were 1% liquid dye or acetic acid. Again, distilled water was used as a blank. The results are presented in Table 15.

Table 15: COD levels in 1% liquid dye or acetic acid solutions

Sample	COD (mg/L)
DW(2)	1
DW-AA(1)	>1500
DW-AA(2)	>1500
DW-RL	6
DW-YL	4
DW-BluL	10
DW-BkL	2
TW(1)	2
TW(2)	0
TW-AA(1)	>1500
TW-AA(2)	>1500
TW-RL	17
TW-YL	9
TW-BluL	9
TW-BkL	0
RW(1)	18
RW(2)	21
RW-AA(1)	>1500
RW-AA(2)	>1500
RW-RL(1)	28
RW-RL(2)	26
RW-YL	35
RW-BluL	35
RW-BkL	27

The results of the fourth round of testing were also presented in Section 4.4. In this round solutions of 25mg/L dry dye in Charles River water were prepared and measured for COD. The results are in Table 16 below.

Table 16: COD levels in 25mg/L dry dye solutions

Sample	COD (mg/L)
RW(1)	35
RW(2)	32
RW-RP(1)	20
RW-RP(2)	29
RW-IP(1)	45
RW-IP(2)	41
RW-NP(1)	48
RW-NP(2)	49
RW-BkP(1)	41
RW-BkP(2)	44

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