Evaluation of Textile Treatment and Treatment Alternatives for the Village of Jasol in Rajasthan, India

A collaboration of the
Jal Bhagirathi Foundation and the Northwestern University Global and Ecological Health Engineering Certificate Program

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Executive Summary

In the Thar Desert of Rajasthan, India, the textile industry is being forced to reevaluate its water intensive practices following increased public pressure and legal actions against the industry. Public concern is largely due to the exhaustion of regional groundwater resources and the degradation of water quality in the Luni River Basin. A recent verdict from the Rajasthan High Court mandates a zero discharge policy for effluent into the basin, a decision that has left the industrialists looking for economically viable solutions to keep the industry alive through water recycling and the Pollution Control Board struggling to keep up with enforcement requirements. While some community leaders have advocated for a diversification of the industrial activities in the district, the fact remains that the textile industry will remain the short-term lifeblood of the regional economy, and the immediate partial shutdown that has resulted from the court decree will continue to dampen progress. On the other hand, this verdict provides an opportunity to make substantial improvements related to management, regulation, and monitoring. With our research, we aim to evaluate the efficacy of the proposed treatment scheme to achieve a closed loop water treatment system for textile plants and to recommend viable alternatives, specifically near the village of Jasol. Due to its relatively small size and strong community organization, Jasol serves as a perfect test site for innovative textile wastewater treatment. We hope that our recommendations can be successfully tested and applied in Jasol, and then replicated throughout Rajasthan and India.

This paper presents the full scope of environmental, socioeconomic, and political issues at hand within the textile industry in hopes of finding a powerful solution to the present environmental problems. We describe the current treatment process for textile wastewater effluent, which has been designed using a standard conventional treatment that to our knowledge was never properly tested for the unique characteristics of the effluent. Based on these observations and analysis of monitoring data, we concluded that the existing treatment process fails to remove TDS and color. We also analyze the efficacy of the newly added tertiary treatment and the planned reverse osmosis (RO) plant addition and believe that based on color alone, the tertiary filters would be exhausted rapidly and the RO membranes will foul earlier than expected. There are uncertainties surrounding the sizing of the system and its ability to accommodate the entire flow from the industry. Finally, we found inconsistencies in monitoring that limit effective management of the treatment train.

Improvements such as better piping of effluent and improved optimization through data collection at the Jasol Common Effluent Treatment Plant (CETP) are presented as ways to enhance the existing treatment train. We also present an alternative, relatively low-cost, low-maintenance, ecologically based treatment train that we believe would be better suited to the industrial capabilities of the region. This treatment would begin with standard pretreatment and primary treatment, utilize a constructed subsurface wetland for secondary treatment, and end with an industrial-scale solar distillation process to remove the excess salts in the water. With this report, future researchers can pilot test this treatment for textile effluent and thereby, create a viable plan for closed loop water processing. Successful implementation of our recommendations could significantly affect the way that industry leaders think about environmental management, as our alternative sustainable designs are not only suited for the available resources in Rajasthan, but would enhance the environmental quality and long term economic growth in the region.

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Acronyms

AFRI	Arid Forest Research Institute
ASP	Activated Sludge Process
AWWA	American Water Works Association
BARC	Bhabha Atomic Research Centre
BOD	Bio-Chemical Oxygen Demand
CETP	Common Effluent Treatment Plant
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
EPA	Environmental Protection Act
EPR	Environmental Policy and Research
FSD	Foundation for Sustainable Development
HDPE	High-Density Polyethylene
INR	Indian National Rupee
JBF	Jal Bhagirathi Foundation
MED	Multi-Effect Distillation
MLD	Million Liters per Day
MLSS	Mixed Liquor Suspended Solids
MSE	Multistage Flash Evaporation
MSF	Multistage Flash Distillation
NGO	Non-governmental Organization
NITRA	National Indian Textile Research Association
NOC	No Objection Certificate
PCB	Pollution Control Board
RFD	Ready for Dyeing
RO	Reverse Osmosis
RPCB	Rajasthan State Pollution Control Board
SBR	Sequencing Batch Reactor
SFCW	Subsurface Flow Constructed Wetland
SME	Small and Medium Enterprises
SRT	Solids Retention Time
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
VC	Vapor Compression
VSS	Volatile Suspended Solids

Introduction

On the 17th and 24th of February, 2012, the Rajasthan High Court issued two court orders. These orders placed a zero discharge requirement on local industries and mandated a reduction to 40% of their original capacity unless they could effectively create a closed loop water system. The High Court requires that industries no longer freely release effluent, but rather mitigate and reuse wastewater. Presently, treatment is carried out in Common Effluent Treatment Plants (CETPs) where small and medium enterprises (SMEs) can share resources and capital to treat wastewater for limited reuse or plantation (irrigation) purposes. In the past, wastewater has bypassed these facilities and discharged directly into the Luni River, a 530 km seasonally flowing river known for its high levels of natural salt. Textile effluent contains high levels of suspended solids, sulfates, and dyes, among many other impurities, which complicate treatment and make water reuse difficult.

Due to the zero discharge requirement, the nearly 1,800 industry units in the Luni River Basin need treatment process improvements in order to create a closed loop water system. This report focuses on the village of Jasol, which is home to roughly 86 textile units connected to a CETP. Due to the small size of the CETP and strong community organization, this location is a suitable test site for improving treatment. The initial objective of this research was to analyze the present treatment situation and the planned improvements in order to determine if they will render an effluent that can be recycled to create a closed-loop process. We then propose improvements to the present treatment process that could be implemented to greatly enhance the present treatment train. Finally, we present an alternative inexpensive, energy efficient, and ecological-based treatment system that may be better suited for the Thar Desert's harsh environment and the heavy contamination of the textile effluent. By utilizing some or all of these best practices, CETPs across Rajasthan could treat water to a higher quality, avoiding environmental release of contaminants by returning a greater percentage of wastewater to textile industrial units.

Background

The Luni River is a seasonal river, flowing only during and after the monsoon, located in Rajasthan, India. In this region, the water depletion rate is very high and the groundwater is polluted due to industrial expansion (Singhal and Goyal, 2011). The major industry is textile dyeing and printing, which is extremely water intensive. The industries usually acquire water by local wells, which aggravate the already decreasing water table in the Marwar Desert region. A general decline in rainfall and the construction of dams upstream has contributed to the extreme water scarcity in the surrounding area.

Jasol is a small village in the Barmer district of Rajasthan located on the bank of the Luni River. It is accessible by road and is located across the river from Balotra, a major center of textile processing which can be accessed by rail. The Luni River Basin is shown in Figure 1 below. As of 2010, 86 small and medium textile factories have been registered in the Jasol area and are processing primarily cotton, but also polyester and blended fabrics (National Productivity Council, 2010). The Jasol textile industries generally utilize jigger machines which pass stretched fabric along a series of rollers through a reactive dye bath. Leaders of the Jasol Industrial Association have said this process uses roughly 40 percent less water than the previous Ready for Dyeing (RFD) and washing operations for dyeing and printing, which were mainly carried out in open tanks. The collective effluent of the facilities has been measured at just less than 6.5 million liters per day (MLD).

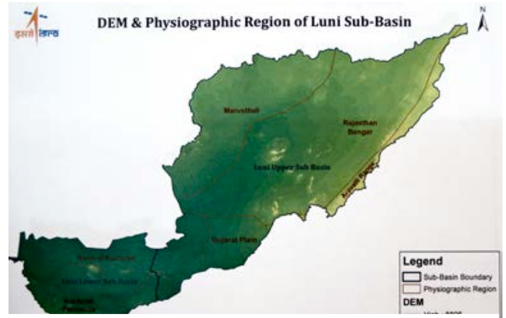


Figure 1: The Luni River Basin

Stakeholders

The future of textile production and effluent treatment in the Luni Basin relies on the actions and opinions of a wide variety of stakeholders. These individuals can be divided into three main groups: industry, government, and community.


Figure 2: Jasol Industrial Association leaders demonstrating how their treatment train works

During our site visits, the textile industry owners expressed a desire to improve their effluent treatment quality, but felt that the court order did not provide adequate time to properly design and implement an effective solution. The Jasol industrial leaders acknowledged the past industrial impact on the environment but did not know how to improve the production process or treatment trains. Industrialists often cited a lack of general education as well as training in pollution control measures as a hindrance in developing improvements. Textile owners expressed concerns about the financial burden the court order imposes and the effect that reducing production to 40% of their original capacity has on the financial sustainability of their industry. The industrialists are responsible for the maintenance and management of the CETPs. The managers of these plants defended the quality of treatment and highlighted the successful aspects of the treatment plants as seen in Figure 2. These leaders also stressed the hardships the court order placed on industry by demanding immediate operational changes at the CETP. An additional group of individuals that is included among the industrial stakeholders is the textile workers. This group consists of mainly unskilled laborers who are entirely reliant on the wages provided by the textile industry. The 60 percent work reduction has decreased the availability of work and has been linked to migration of laborers out of the region. According to the community advocate, over 6,000 migrant workers left the area after the court order came into effect. The remaining textile workers are financially dependent on the industry and are therefore invested in its continued operation.

Government stakeholders include policy makers at the local, state, and national level, as well as civil servants overseeing the pollution of the textile industry. Policy makers are tasked with balancing economic development against environmental protection. They determine effluent production limits and decide what subsidies industries will receive to implement treatment processes. The state government of Rajasthan is responsible for issuing permits and monitoring effluent treatment. The state is also responsible for providing safe drinking water and managing the ground water table. The High Court has played an important role in supporting the zero discharge requirements but does so without the capabilities of ensuring enforcement. Civil servants also play an important role in carrying out pollution prevention and industrial policy. Pollution Control Board (PCB) staff must issue compliance certificates to the industries and CETPs before they can become operational. For this organization, the task of certification and inspection is difficult due to inadequate staff size for overseeing the hundreds of industries in the area. The PCB has not been able to regularly check industries and effluent quality for compliance with the Environmental Protection Act (EPA).

The community stakeholders consist of groups and individuals who may not directly benefit financially from the textile units, but are still impacted by the industry in some way. Consumers rely on the industry for clothing and other textiles and therefore have an interest in its viability of the industry. Conversely, residents in the vicinity of the textile units are concerned about the negative effect of textile effluent on their land and drinking water quality. According to some reports, ground water has been contaminated to unsafe levels up to 125 kilometers away from the Luni River. Additionally, because of heavy extraction for industrial and agricultural use, the water table has decreased significantly. As a result of contamination and decreased availability, residents need to use tankers to bring in potable water. This poses an economic hardship on community members and limits development. Additionally, farmers and landowners like those shown in Figure 3 have seen their land devalued by the textile pollution and are overwhelmingly in support of the court order for zero discharge. The soil quality is degraded after exposure to contaminated groundwater, and farmers can no longer use wells for irrigation. As a result, the land can only support one crop per year during the monsoon rains. Community leaders,

Figure 3: A group of farmers discussing land degradation in Jasol

Non-governmental Organizations (NGOs) and academics aim to educate the community and industrial leaders on environmental protection and effluent treatment options. This group of intellectuals and leaders feels that they must adopt a solution that allows industries to continue without further polluting the environment. Within Jasol, this community group has been organized into a Jal Sabha led by the Rawal of the village, Kishan Singh Jasol.

Socioeconomic and Political Factors

The issues surrounding textile wastewater pollution and treatment in Jasol are not exclusively the result of technological shortcomings. Social, economic, and political factors all play a key role in the success of treatment. While this project focuses on technical solutions for wastewater treatment, the factors that impact implementation are described in this section to identify potential barriers to successful effluent treatment and process change.

The Marwar desert region has traditionally harbored small villages and subsistence farmers. The textile industry developed in the mid 1970s, bringing new development and labor opportunities to the region. Industrial units within Jasol are not diversified and textile manufacturing is the only major contribution to industrial development. The owners of industrial units have become prominent members of the community with a large influence over political and social institutions. For farmers and land owners in the region this has been challenging, creating conflict in the community about the extent to which pollution can take place. A group consisting of both large and small farmers within the Luni River Basin, expressed a divide between the motivations of the industrialists and the best interests of the entire community. As the land quality continues to be diminished due to polluted groundwater, farmers collect less profit and family members are forced to migrate and find new trades and livelihoods to make ends meet. Until recently, the many stakeholders within Jasol acted separately. This has changed with the creation of Jal Sabha with members from a cross-section of community leaders.

Political and economic factors have slowed progress toward more complete treatment of textile effluents. In the past, the government has overlooked pollution concerns in an effort to promote economic growth. Today, pollution control measures are written in the law, but the PCB lacks the human capacity and oversight capabilities to ensure compliance. One office of roughly six people oversees close to 1000 textile facilities, making regular checks nearly impossible in the Jasol and Balotra area. With the recent court order, the PCB has been forced to increase its regulation of textile effluent but has not received an increase in staff or other resources. Within the government, responsibility for management of water resources is also divided among many offices at multiple levels of government. As a result of this fragmented responsibility over areas such as pollution, river management, groundwater maintenance, and drinking water, the general public has difficulty soliciting information and petitioning government bodies. In addition to the lack of transparency, this process is also ineffective in ensuring quality environmental health.

Government subsidies have aided the installation of treatment facilities in the Luni River Basin, but consistent information about the exact percentage and the timeliness of payment by the government has not been received. Reports from various parties have indicated that subsidies can range from 25 to 75 percent of initial capital cost. Industrialists have indicated that the bureaucratic nature of the Indian government has made the process of collecting these subsidies lengthy and uncertain. Without these subsidizes, the large capital costs associated with installing and operating an efficient CETP has made regulatory compliance difficult for the small-scale cottage industries in Jasol.

Characterization of Industrial Process in Jasol

Textile Production Process

The major activity of the industries in Jasol is wet processing of cotton and polyester fabric. The three largest industrial facilities process polyester, blended fabric, and cotton, while the rest of the units solely process cotton fabric. Grey fabric purchased from the market or given by clients for job work is the major raw material for conversion to dyed and printed product. Some textile facilities carry RFD and washing operations like singeing, de-sizing, scouring, mercerizing, and bleaching whereas others are engaged in one or more dyeing, printing, and finishing processes (NITRA, 2008).

Figure 4 below shows the typical steps involved in the processing of textile in a cotton mill, while diagrams showing the typical dyeing processes for various types of fabrics are included in Appendix A. Industrial units that process pure cotton fabric begin with a singeing operation to remove protruding fibers. Singeing machines use petrol and air to burn off protruding fibers before the fabric is passed through a de-sizing bath. De-sizing uses acid or enzymes to remove starches, gums, polyvinyl acetate (PVA), and other materials rendered water-soluble during sizing (strengthening in preparation for weaving) to make the fabric suitable for dyeing and further processing. Next, the fabric is subject to scouring to remove natural impurities such as greases, waxes, fats, and proteins using caustic soda, soda ash, wetting agent, and sequestering agent around 100˚C. After scouring, the fabric undergoes bleaching with sodium hypochlorite solution or hydrogen peroxide to remove natural coloring agents. The scoured fabric is soaked for 30 minutes, then washed and subjected to neutralization before drying. Mercerization with 23% caustic soda followed by hot and cold washing is used to improve luster and enhance dyeing. Excess alkali is neutralized by acid treatment, and the fabric is considered to be RFD. Many classes of dyes, such as reactive, sulfur, vat, and naphthol can be used with the addition of auxiliary chemicals in jiggers for the dyeing process, but reactive dyes are primarily used at the Jasol industries that process cotton. Dyeing is followed by washing to remove excess dyes and salts, and various finishing operations to complete the processing.

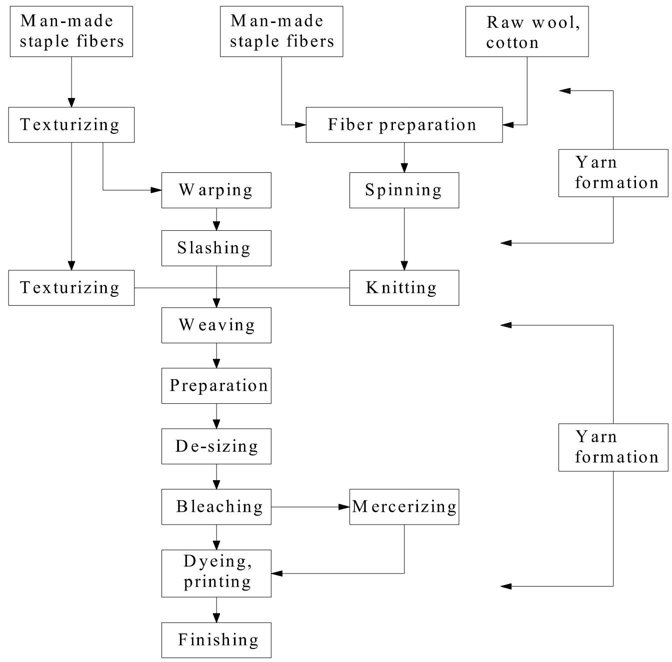


Figure 4: Typical steps involved in processing textile in a cotton mill (Babu, et al., 2007)

Polyester fabric is synthetic and does not need to undergo de-sizing to remove impurities. However, the dyeing process is different because polyester is hydrophobic. Scouring and bleaching take place concurrently to remove tint, spinning oil, and stains, followed by washing, neutralization, drying, and stentering (stretching to impart an elastic finish) at around 210˚C. Jet dyeing machines operating at 130-135˚C carry out the dyeing process with a bath comprised of disperse dyes, acetic acid, dispersing and leveling agent, and water. The machine is washed and cooled to room temperature, and is subjected to reductive cleaning with sodium hydrosulfite when using dark and heavy dark shades. Washing, neutralization, and finishing operations on a stenter complete the polyester wet processing. Polyester-viscose fabric is processed in a similar manner to polyester fabric, but must also be subjected to a dyeing process similar to cotton dyeing to fix color to the viscose component.

If screen or hand block printing of fabrics is required, there is a water requirement for blanket and screen washing. Pigment printing occurs at elevated temperature followed by drying and finishing operations, whereas discharge printing involves steaming, hot and cold washing, drying, and finishing operations on a stenter (NITRA, 2008).

Water Consumption and Effluent Generation

According to the National Indian Textile Research Association (NITRA), specific water consumption ranges from 70-100 L/kg of cotton fabric processed and 25-70 L/kg of synthetic fabric processed. Steam generation, water treatment reject and backwash, wet processing (RFD, dyeing, printing and finishing, intermediate washing, machine cleaning, etc.), cooling (for process machines, cooling tower, etc.), humidification (for spinning), and domestic uses comprise the major water-consuming activities of the textile industry. Table 1 is adapted from a 2011 report by the West Bengal Pollution Control Board, and details water consumption and effluent generation at various steps of textile processing.

Table 1: Water consumption and effluent generation in different wet processing stages in textile industries (L/100kg)

	Activities	*Water consumption*		*Effluent*
		Variation	*Average*	*Variation*
1	*Sizing/slashing*	*50-820*	*435*	*50-80*
2	*Desizing*	*250-2100*	*1175*	*250-2100*
3	*Kiering/scouring*	*2000-4500*	*3250*	*2000-4500*
4	*Bleaching*			
	a. Yarn (Hypochlorite)	*2400-4800*	*3600*	*2250-4600*
	b. Yarn (Hydrogen Peroxide)	*2400-3200*	*2800*	*2250-3050*
	c. Cloth (Hypochlorite)	*4000-4800*	*4400*	*3800-4600*
	d. Cloth (Hydrogen Peroxide)	*1700-3200*	*2450*	*1700-3200*
5	*Mercerising*	*3600-17600*	*10600*	*3500-17500*
6	*Dyeing*			
	a. Yarn (Light and Medium shades)	*3600-4800*	*4200*	*3500-4700*
	b. Yarn (Dark shades)	*4800-6400*	*5600*	*4700-6300*
	c. Yarn (Very Dark shade)	*6600-8800*	*7700*	*6500-8700*
	d. Cloth (Light and Medium shades)	*7800-9600*	*8700*	*7700-9500*
	e. Cloth (Dark shade)	*10400-12800*	*11600*	*10300-12700*
	f. Cloth (Very Dark shade)	*14300-17600*	*15950*	*14200-17500*

Source: Data compiled from Manivasakam (1995) and MSE Study (1998)

Water for the textile process was traditionally collected from deep bore wells on site, but the High Court Order has restricted the collection of groundwater for industrial processes in this manner. However, some industry units may be continuing this method of water collection illegally. Leaders of the Jasol Industrial Association have indicated that the groundwater under the Jasol cluster of facilities contains 20,000 mg/L total dissolved solids (TDS), and as a result, the facility owners must truck 20,000 L tankers of water from 5 to 20 kilometers away to satisfy their water requirements. The extraction of this water from existing bore wells is regulated, and reportedly contains 300 to 6,000 mg/L TDS. Water can be acceptable for use in different textile processes depending on the TDS content. The largest textile facility in Jasol (Kothari) reports spending 1,500 INR per day to truck in 1 tanker of 300 mg/L TDS water for its boiler feed process, as well as 6,000 to 7,000 INR to truck in 6 to 7 tankers of 6,000 mg/L TDS (a workable and generally desirable solids content) water for its dyeing process, according to the plant manager. Thus, the cost is roughly equivalent to 240,000 INR per month to satisfy the water requirement for the single facility.

The desired influent water characteristics for the wet processing of grey fabric vary in TDS content, temperature, and pH, depending on the type of fabric processed (and thus, the type of dye used). Reactive dyes are primarily used for cotton fabric processing, while disperse dyes are used for synthetic fabric processing in order to optimize the exhaustion, fixation, and colorfastness of the dyes applied in the process.

Reactive dyes were inspired by the esterification of cellulose in 1895 with benzoyl chloride, and were introduced to the market in 1956. They form a covalent bond between the dye and fiber and demonstrate improved fastness properties, especially for cellulosic fibers. The use of reactive dyes simplifies the dyeing procedure because there is no need for a redox reaction to fasten the color to the fiber (Venkataraman, 1972). The basic components of reactive dyes are shown below in Figure 5.

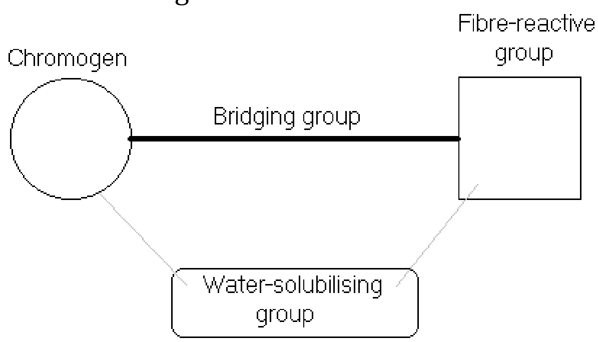


Figure 5 - Basic components of reactive dyes
(http://www.chm.bris.ac.uk/webprojects2002/price/reactive.htm)

The color-causing chromogen is usually classified as a carbonyl or phthalocyanine, as azo dyes have mostly been phased out. An ionic group, often a sulphonate salt, acts as a water-solubilizing group. An amino group (-NH-) acts as a bridging group to link the chromogen and fibre-reactive group, which reacts via nucleophilic substitution to aromatics or nucleophilic addition to alkenes of cellulose polymer (fiber) hydroxyl (OH-) functional groups that result from deprotonation under alkali conditions (University of Bristol, 2002).

Procion dyes that are used at the cottage industries can be applied at room temperature. Disperse dyes on the other hand are water insoluble and are finely ground in the presence of a dispersing agent. They are sold as a paste or powder, which can be used to dye synthetic fibers under high temperature and pressure (Burch, 2003).

Wet processing of textile substrates cause the process effluent to contain large quantities of dyestuffs, inorganic and organic chemicals, detergents, soaps, and finishing chemicals. The effluent also contains waxes, proteins, pigment, and added impurities such as spinning oils, sizing chemicals and oil stains which are removed from grey fabric during de-sizing, scouring and bleaching operations. Thus, the effluent generally contains high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) load. As the industries in Jasol vary in size and process operations, the quality of effluent released to the CETP can vary as well. Table 2 shows an example of the characteristics of untreated common effluent sent to the CETP from the Jasol processing industries and effluent quality after the secondary clarifier (water samples analyzed by NITRA in 2008).

Table 2: Characteristics of untreated and treated effluent (NITRA, 2008)

Sample parameters	Before grit chamber	After secondary clarifier
pH	8.13	8.63
Total Solids (mg/L)	24457	25029
TDS (mg/L)	23544	24857
TSS (mg/L)	913	172
COD (mg/L)	1105.7	184.96
BOD (mg/L) (3 days, 27˚C)	414.7	8.67
Oil and Grease (mg/L)	39	7.5

These data suggest that after secondary treatment, the total suspended solids (TSS), COD, BOD and oil and grease are greatly reduced, but not TDS. However, the data we observed varied greatly depending on who analyzed CETP water samples.

Various Characterizations of Textile Effluent

To assess and compare the quality of water at the various inlets and outlets of the Jasol CETP, samples were collected and tested by the lab technician at the JBF laboratory in October 2012. Table 3 shows the determined characteristics for samples taken at the end of the various steps in the treatment process.

Table 3: Composition of treatment plant effluent at various steps of mid-sized textile factory, Jasol

Sample parameters	Equalization Tank	Primary Clarifier	Secondary Clarifier	Tertiary Treatment
Color (Hazen Unit)	5	1	1	1
pH	9.89	9.20	7.68	8.05
Alkalinity (mg/L)	566	540	720	610
Hardness (mg/L)	264	120	182	138
TDS (mg/L)	13300	9300	9500	4800
TSS (mg/L)	480	90	92	60
BOD (mg/L)	0.047	0.076	0.193	0.197
COD (mg/L)	93.33	106	112	117.33
DO (mg/L)	4.8	8	12.4	12.7
Turbidity (NTU)	16.2	8.4	8.8	4.3
Fluoride (mg/L)	0.034	0.289	0.186	0.238
Chloride (mg/L)	659.79	439.86	511.84	235.93
Sulfide (mg/L)	38.4	28.8	4.8	9.6
Conductivity (mS)	43.7	21.6	64.6	90.5
Nitrate (mg/L)	80	25	22.5	32.5
Phosphate (mg/L)	6.8	0.9	7.2	0.2

These data are strikingly different from the data in Table 2, and suggest that BOD is very low throughout the treatment process but also inexplicably increases (as does COD) following tertiary treatment. Additionally, though it was not the intended purpose of the tertiary treatment addition, TDS appear to be lowered to the point that the effluent may be reused for the dyeing process. This leads us to believe that the Jasol CETP must implement more reliable monitoring to assure consistent data collection.

Monitoring

Internal Monitoring

The plant conducts internal monitoring on a regular basis. Daily analysis data was obtained from the CETP for July 8 through July 10, 2012. The result of the internal analysis is shown below in Table 4.

Table 4: CETP self monitoring data, July 8-10, 2012

Date	Sample	pH	COD	BOD	MLSS	TSS	VSS
July 8, 2012	Inlet	13.0	3164	-	-	3960	-
	Primary Clarifier	7.5	1382	412	-	310	-
	SBR 1	7.5	210	29	6540	-	3940
	SBR 2	7.5	224	26	10620	-	5820
July 9, 2012	Inlet	12.5	2986	-	-	-	-
	Primary Clarifier	7.5	1464	382	-	-	-
	SBR 1	7.5	234	30	6420	-	3250
	SBR 2	7.5	245	29	9740	-	5020
July 10, 2012	Inlet	12.0	2882	-	-	3980	-
	Primary Clarifier	7.5	1472	318	-	650	-
	SBR 1	7.5	248	25	6860	-	4180
	SBR 2	7.5	240	26	12360	-	5260

In addition to the data shown above, an employee estimated the TDS value at the end of the process to be about 8000. Note that mixed liquor suspended solids (MLSS), and volatile suspended solids (VSS) were included in the internal monitoring record, but not TDS. MLSS is the combination of raw or unsettled wastewater and activated sludge within an aeration tank, and is the concentration of suspended solids during the activated sludge process (ASP). It is important to monitor MLSS to ensure that there is a sufficient quantity of active biomass available to consume the applied quantity of organic pollutant at any time. MLSS is responsible for removing the BOD makeup of a large portion of the solids that are retained in the ASP. VSS is a water quality measure obtained from the loss on ignition of TSS. Overall, the internal data in Table 4 tell us that by the end of secondary treatment, pH is neutralized, and COD, BOD, and TSS are greatly reduced. However, we did not obtain any internal data on TDS, so we cannot tell whether or not the Jasol CETP believes it is effectively reducing the salt content of the effluent that it processes.

External Monitoring

The PCB is responsible for monitoring the Jasol CETP by collecting monthly reports from the treatment plant. These reports monitor compliance with internally generated standards, which are provided below in Table 5. The PCB also conducts random checks of the facility. As of July 2012, the most recent PCB audit of the facility was conducted in October 2010. The audit was conducted by the Rajasthan Pollution Control Board (RPCB) Lab Incharge. The parameters tested are shown in Table 6 below.

Table 5: PCB Textile Effluent Standards
(http://cpcb.nic.in/Industry-Specific-Standards/Effluent/500.pdf)

Parameter	Concentration not to exceed, milligram per litre (mg/l), except pH
pH	5.5 – 9.0
Total suspended solids	100
Bio-chemical oxygen demand (BOD)	30
Chemical oxygen demand (COD)	250
Total residual chlorine	1
Oil and grease	10
Total chromium as Cr	2
Sulphide as S	2
Phenolic compounds as C_6H_5OH	1

Table 6: State monitoring data, October 2010 (source: Jasol CETP records)

Parameter	CETP Inlet Result	CETP Outlet Result
pH	8.24	8.91
TSS (mg/L)	2056	94
COD (mg/L)	1558	226
BOD, 3 days at 27˚C (mg/L)	790	24
Oil and Grease (mg/L)	26	8
TDS (mg/L)	25020	25160

The sample used for the data above was collected by the Balotra PCB on October 21, 2010, received on October 22, 2010, and analyzed on October 28, 2010. According to this analysis, the Jasol CETP was in compliance with the PCB standards in October 2010. Again, TSS, COD, and BOD are sufficiently abated while TDS is not affected by secondary treatment.

In order to consider the possibility of a closed loop industrial treatment system, it is useful to compare the TDS content before and after treatment at the CETP, as the salt content is the main characteristic of the effluent other than color that makes it unsuitable for reuse in the dyeing process. Table 7 shows a comparison of TDS data collected and estimated by different parties: NITRA in 2008, Balotra PCB in 2010, and JBF and the Jasol CETP in 2012.

Table 7: Comparison of TDS content before grit chamber and after secondary clarifier at Jasol CETP

TDS (mg/L) Measured by	CETP Inlet	After Secondary Clarifier
NITRA, 2008	23544	24857
Balotra PCB, 2010	25020	25160
JBF, 2012	13300	9500
Jasol CETP, 2012	-	-
CETP Employee Estimate	-	8000

As the internal CETP data log is missing information about TDS content, and JBF's sample data indicate much lower TDS values than NITRA and PCB, it is rather difficult to analyze whether the current treatment process is adequately removing the salts that make the common effluent unfit for industrial reuse. While it is possible that the operation and management of the CETP has improved since 2008 and 2010 when NITRA and PCB took the reported measurements, and though it seems that the addition of the pilot-scale tertiary treatment has helped reduce TDS (see Table 3), it is difficult to confirm the validity of JBF's lab test data without a reference point or more robust set of records. In particular, JBF's observed values for BOD appear to be extremely low compared to what would be expected at the CETP, as confirmed by the NITRA data (Table 2), the CETP internal data (Table 4) and the Balotra PCB data (Table 6), which show BOD values in the hundreds being reduced to a BOD value below 100 by the end of the treatment process. Additionally, as we observed that the color of the water was murky brown until it went through the tertiary treatment train, it is difficult to comprehend measurements that show that the primary clarifier reduced the color of the water to 1 Hazen unit. Thus, these data indicate that monitoring is inconsistent and that TDS removal is not achieved. It is imperative that the internal and external monitoring and recordkeeping systems that the CETP and PCB use are robust and accurate to allow for useful analysis. Additionally, if the Jasol CETP hopes to attain the mandated zero discharge treatment system, it will be even more important to carefully monitor and record the TDS content of the wastewater at every step of the treatment process.

Current Treatment Process: Common Effluent Treatment Plant

There are 86 registered textile industries in Jasol (National Productivity Council, 2010). These SME facilities each produce about 10,000 meters of dyed cotton cloth every day according to industry leaders in Jasol. The local industrialists stated the water usage for each meter of cloth falls between 1 and 2 liters at small industries (e.g., Figure 6) completing bleaching and dyeing processes. At larger industries, such as Kothari Textile Factory, the water usage is higher, usually 6 liters per meter of cloth. The larger facilities complete more water intensive activities, such as washing and finishing with steam, as they have the capacity and demand a higher quality of fabric. Figure 6 and Figure 7 below contrast the scale and automation of a small-scale and larger textile factory.

Figure 6: Small-scale cottage textile factory

Figure 7: Larger textile production factory

The combined wastewater discharge of the Jasol textile industry is approximately 6.3 million liters per day (MLD). It is not considered economically viable for each cottage facility to treat its own wastewater on site. In order to minimize environmental damage as well as treatment cost, the industrial association has collaborated with the central and state governments to form a CETP in Jasol. The CETP scheme is common in India; plants across the country service more than 10,000 polluting industries. In 2005, there were 88 CETPs in India, with a combined capacity of 560 MLD. Figure 8 shows the plant manager giving a tour of the Jasol CETP.

Figure 8: Touring the Jasol CETP

CETP construction is supported by the government of India. Industrialists receive financial assistance for the initial capital cost of the plant. Up to 50% of the total cost is covered by the government. The state government covers 25%, and the central government matches the amount offered by the state. After the initial planning and implementation phase, the government allows the industrialists to operate and maintain the CETP. Inspections by the Central Pollution Control Board (CPCB) have revealed that many CETPs are not meeting the norms and standards set by the government due to improper operation and maintenance (Sengupta et al., 2005).

The CETP design in Jasol follows a standard CETP design for primary, secondary, and tertiary treatment. The plant at Jasol has two separate treatment trains with a combined capacity of 6.5 MLD on a 9 to 10 acre property. The plant was originally constructed for primary and secondary treatment at a capacity of 2.5 MLD. A recent expansion of the plant added a 4 MLD treatment train that includes primary, secondary, and tertiary treatment. An overview of the Jasol CETP is shown in Figure 9 below.

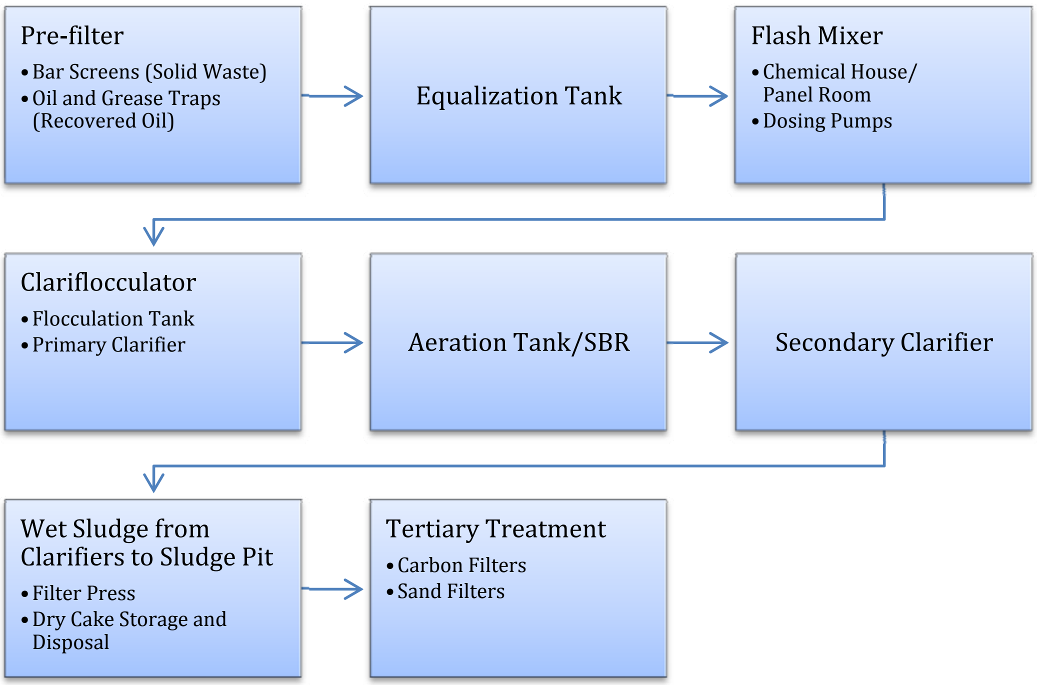


Figure 9: Overview of CETP treatment train (source: Performance of CETPs, pg 40)

Pre-treatment and Primary Treatment

Wastewater flows from the textile industries to the Jasol CETP through pipelines and open gutters. During pre-treatment, the industrial effluent passes through a grit filter or bar screen to remove large objects before entering the equalization tank. In the equalization tank, the effluent is mixed for two to three hours to stabilize and homogenize the flow before it moves to the flash mixer. Diffusers at the bottom of the tank prevent settling. The diffusers operate at all hours with intermittent 15 minute breaks. During a visit to the Jasol CETP, the equalization tank water was observed standing still with a red-brown color at the surface. Once the diffusers were turned on a few seconds later, a dark green color rose from the bottom of the tank and the surface bubbled (see Figure 10).

Figure 10: Equalization tank just after aerators are switched on

After the effluent is homogenized in the equalization tank, it is sent to the flash mixer where ferrous sulfate, lime, and polyelectrolyte are added to neutralize pH, remove COD and color, and coagulate the particles within the flow (see Figure 11 below). Jar tests are conducted every two to three days to determine the appropriate chemical dosage. There is no set residence time in the flash mixer.

Figure 11: Addition of chemicals in flash mixer

After the addition of chemicals, the effluent is transported to the clariflocculator (primary clarifier) shown in Figure 12. After settling, the clarified water is directed to the secondary treatment process. The settled sludge is removed into a second tank, dried, and disposed of in the nearby Balotra Waste Management site operated by Ramky Ltd. This site is described further in the sludge management section.

Figure 12: Clariflocculator

Secondary Treatment

The Sequencing Batch Reactor (SBR) shown in Figure 13 contains aerobic nitrifying bacteria that convert organic matter in the effluent into coagulated suspended mass that settles out in a secondary clarifier. The SBR is seeded with bacteria by adding environmentally available cow dung, and is aerated with diffusers.

Figure 13: Sequencing Batch Reactor

After processing in the SBR, water is moved to the secondary clarifier where the sludge settles and is removed, evaporated, and disposed of in the nearby Balotra Waste Management site. The internal monitoring data shown in Table 4 suggests that secondary treatment is responsible for the majority of the BOD and COD removal, while the JBF data in Table 3 shows an apparent degradation of water quality between the last step and this step.

Addition of Tertiary Treatment

The Jasol CETP has implemented a sand and activated carbon filter system (see Figure 14) as tertiary treatment for the 4 MLD capacity expansion, which in the future may also be added to the original 2.5 MLD segment of the plant. The goal of this additional treatment is to make the water suitable for non-critical industrial uses such as screen washing. However, it will not satisfy the zero discharge mandate or the desire to make a closed loop industrial process. The characteristics of the water at the end of this process can be found in Table 3, which shows an overall decrease in TDS, TSS, turbidity and chloride. These data were collected by JBF and should be confirmed internally and by the PCB during their routine monitoring inspections. The sand and carbon filters discharge water into an open trough that will feed a new pipeline (see Figure 15), which will supply the industries with water for non-critical uses. Different industrialists estimate the percentage of wastewater to be recycled will be between 20 to 80 percent of the plant capacity, depending on the efficacy of the treatment and future non-critical water usage requirements.

Figure 14: Tertiary treatment with sand and carbon filters

Figure 15: Recycled water pipeline being constructed at Kothari Textile Facility

Planned Reverse Osmosis Upgrade at Jasol CETP

The desire of the Jasol Industrial Association and the Jal Sabha to improve environmental conditions and increase water recycling has led to plans for a reverse osmosis (RO) addition to the Jasol CETP. Following the sand and activated carbon filters, the RO plant is intended to reduce the salt content of the wastewater to a level that allows for the water to be recycled for critical industrial processing. The reject water from the RO process could be evaporated and placed in the dumping site in order to comply with the zero discharge court order. Based on the timeline given in July 2012, the project is expected to be completed in early 2013. Without an operational RO system in place, it will be difficult to predict the success that the upgrade can achieve in terms of the quantity of treated effluent that can be directed back to the industries. However, NITRA has estimated in its RO feasibility study for Jasol a capital cost of 73.53 million INR and recurring costs of about 65 INR/m^3 water recovered, and even these may be low estimates considering the high likelihood of membrane fouling and high energy requirement to maintain sufficient pressure gradients across the RO membrane. If the RO system is installed, there will be an opportunity to couple the process with solar distillation to evaporate water from the reject stream mixed with waste stream water according to the design capability of an industrial-scale solar distillation system described near the end of this report.

Typical Applications of Reverse Osmosis

RO is used around the world for drinking water and wastewater purification. The quality of the water depends on the membrane characteristics, such as pore size and surface area, as well as temperature and operating pressure. In Los Angeles, California, wastewater from storm drains is processed using RO and recycled for landscape irrigation and industrial cooling towers. The food industry uses RO to make concentrates like whey protein powder and fruit juice or milk concentrate. For effluent treatment and desalination, traditional treatment in an effluent treatment plant is required before RO.

There are several other options for desalination presently utilized around the world, including membrane solutions such as Effect Distillation (ED) and thermal based solutions such as Multistage Flash Evaporation (MSE), Multi-Effect Distillation (MED), Multistage Flash Distillation (MSF), and Vapor Compression (VC). Eighty percent of desalination plants are located in the Middle East, a water scarce area. India also has 175 desalination plants; the first one was built in Andaman in 1946. There are several Indian companies that design and manufacture desalination systems including Babha Atomic Research Centre (BARC), which constructed a 1.8 MLD capacity desalination plant in Tamil Nadu in 2008 and has several small-scale projects in rural Rajasthan. Thermax, Ltd. is another company that specializes in wastewater treatment and recycling. They design zero water discharge systems, including RO with energy recovery (Shah, 2011).

Sludge Management

About 150 tons of sludge is produced by the Jasol CETP each month. This is similar to the amount discharged at the Manickapurampudur CETP in Tamil Nadu (the 1.6 MLD plant emits 1000 to 1500 kg/day depending on the effluent quality), where a train of RO and other filtration techniques has replaced the traditional treatment method entirely.

The landfill for various industrial wastes, including textile waste, is located approximately ten kilometers from the Jasol CETP. Sludge is transported by open trucks to the Balotra Waste Management site. The sludge is then tested by the facility to determine if further treatment is necessary. The dried sludge is placed on top of two high-density polyethylene (HDPE) liners with separate leachate management systems. The top of the landfill is partially covered by HDPE and the remaining waste is sprayed three times throughout the day to minimize dust around the facility. The HDPE aims to minimize rain penetration into the waste.

Maintenance and Costs

Initial Investment

According to the National Productivity Council, the initial cost of the 2.5 MLD CETP in Jasol was 28.9 million INR. The industrialists have also contributed 50 million INR for the recently constructed 4 MLD upgrade, and they expect that the government will contribute the remaining half of the cost. The industrialists applied three years ago for a government subsidy, and are hopeful that the funds will be received. The addition of 6 MLD capacity RO technology will cost about 240 million INR.

Operation

According to the Jasol CETP operator, total operation cost is currently one million INR each month. The plant operates for eight months each year, making the annual cost of the CETP eight million INR. The plant generally does not operate during the monsoon season in late summer and early fall because industries typically do not operate during this time. Additionally, there are several festivals in the early fall during which workers have extended holidays. The major costs at the plant are:

1. Electrical (300,000 INR/month)
2. Staff and labor (200,000 INR/month)
3. Chemicals, water, repairs, transport, and other (remaining 500,000 INR/month)

The local industries share the burden of these costs. Each industry is charged 60 INR by the CETP for each bale of cloth they produce. A bale is about 100 kilograms of fabric, or 700 to 800 meters of cloth. Assuming that a medium sized facility produces 10,000 meters of cloth (13-14 bales per day), the monthly CETP fee is roughly 24,000 INR.

Problems and Setbacks

Facility Size

The original 2.5 MLD capacity Jasol CETP is dramatically undersized for the current effluent flow of over 6 MLD. Since the construction of the Jasol CETP, industry in Jasol has expanded. Until the recent opening of the 4 MLD upgrade, the CETP was not able to process all of the effluent from the surrounding industries. At nearby CETPs, such as the facility in Jodhpur, any extra effluent bypasses the plant and enters the environment without treatment (according to one source from the Jodhpur PCB). Additionally, there were some questions about the sizing of the tertiary treatment and the new RO system. Some industry leaders stated that the tertiary treatment was sized for a 4 MLD flow while others mentioned a capacity that could meet the full effluent flow of 6.5 MLD. Understanding the capacity of the facility will be important to ensuring proper operation and high quality treated effluent.

If the industry continues to grow in Jasol, effluent flow in excess of plant capacity could pose problems for the CETP. With the new zero discharge policy in place, bypassing the plant is not legally acceptable. Currently, Jasol textile production has decreased to 40 percent to accommodate the zero discharge policy. Once the effluent is able to be recycled (after the

RO assembly is added in February, 2013) industries will be able to reuse up to 4 MLD, allowing them to increase production while still meeting the zero discharge requirement.

Difficulty of Treatment of Reactive Dyes

The most commonly used dyes are reactive dyes and disperse dyes. Reactive dyes are used for cotton fabric processing, while disperse dyes are used for synthetic fabric processing in order to optimize the exhaustion, fixation, and colorfastness of the dyes applied in the process.

Reactive dyes contain reactive groups capable of forming covalent bonds between a carbon or phosphorus atom of the dye ion or molecule and oxygen, nitrogen, or sulfur atom of a hydroxyl, amino, or mercapto group of the textile substrate. The major properties that make reactive dyes favorable for dyeing cellulosic fabrics are high wet fastness, brilliance and variety of hue, and versatility of application. However, hydrolysis also invariably occurs, and thus dyes are included in the makeup of textile effluent.

Reactive dyeing effluents are not easily removed by conventional treatment methods such as biological treatment, chemical precipitation, and evaporation due to low biodegradability, high effluent salt content, and significant cost and energy requirements for treatment. The salt and colored effluent must still be separated in order to have proper treatment of effluent (Mbolekwa, 2007).

Management and Maintenance Cost

Consistent and timely upkeep of CETP equipment has not been verified by site visits. In past reports, the CPCB has found many CETPs throughout India to be in noncompliance due to improper maintenance and operation. Lack of maintenance and technical staff increases the risk of infrastructure failure and operational mismanagement. These problems faced by CETPs across the country allow water to pass through the plant without meeting the norms and standards of the CPCB.

One potential source of unintended pollution is the effluent piping system. Effluent is transported from the industries to the CETP either by pipelines or a system of open gutters. Open gutters can allow excess rainwater or other comparatively clean water to enter the waste management system, contributing to capacity overflow at the CETP. Other debris and waste may enter the stream via the open channel that the CETP is not designed to address. Open gutters present an additional risk to local residents, animals, and plants by allowing access to the wastewater stream.

Regulatory Enforcement and Oversight

Due to the added costs associated with treatment, few industries proactively pursue full treatment without outside pressure. Traditionally, proper government inspection ensures compliance with regulations. Unfortunately, regulatory oversight is not widespread in the

Luni River Basin due to lack of resources and politically influential industries. The PCB, the main governmental agency responsible for regulating the industries, is significantly understaffed. The Balotra PCB, responsible for supervising industry in the Barmer and Jalore districts, has 3 junior scientists and 3 environmental engineers responsible for the management of about 1000 industrial units. This office is responsible for inspecting all facilities and CETPs and issuing No Objection Certificates (NOCs) to individual industries. The PCB offices in Jaipur and Jodhpur, while slightly larger, appear to have similar staffing issues that make regular enforcement difficult. Additionally, the PCB in Balotra lacks a testing facility and appeared to have limited technological resources that could assist them in tracking the textile industries' pollution mitigation efforts.

While the lack of resources makes the physical supervision of industry units difficult, the political climate of the area adds additional roadblocks to enforcement. Industrialists hold significant influence over the politics and the community in Jasol and have been able to utilize that influence to continue production without full wastewater treatment. As the largest suppliers of jobs in the area, the industrial units maintain their influence even though the court order and the publicity that followed have bolstered the necessity of the PCB to regulate pollution mitigation in the area.

Strategies for Improved Effluent Management

While we will present an ecologically based treatment alternative that we feel presents a viable sustainable solution to the difficulties in treating the textile effluent later in this report, we have also identified other methods for improving the overall effluent treatment in the region. These recommendations are based upon observations made while onsite and should be further researched before final implementation.

Improved Wastewater Flow to CETP

The transport of effluent to and from the treatment plant could be greatly improved. In Jasol, textile wastewater is transported by way of open ditch to the CETP. This leads to infiltration into the surrounding groundwater, open access to animals and humans, and exposure to air, water, and further pollution. As a result, the textile industry is introducing a new sources of contamination such as into the CETP treatment process and further complicating their treatment objectives. This likely produces an economic cost as well. The treated effluent appeared to be transported from the CETP by way of a pipe system that was being installed during our time onsite, which is a substantial improvement from the open gutter system for influent. We recommend that the Jasol CETP begin using a closed gutter or pipeline system to transport both incoming and exiting effluent. This will limit exposure to the surrounding community and better maintain water quality. Leak detection programs and water conservation plans should also be developed with system water audits conducted to track losses through the distribution system. With some adaptation to the different settings in Rajasthan, the American Water Works Association (AWWA) M36 manual on water auditing provides a reputable basis for calculating water loss without the need for intensive monitoring (M36 2009).

Another improvement to the system would be the establishment of a centralized industrial area where all textile plants could be located within Jasol. While other textile cities in the region, including Balotra, have moved to this model, Jasol's textile plants are still dispersed throughout the village. This complicates collection, increases costs due to maintaining piping and creates isolation among textile units. By collocating in a textile park, centralized collection and distribution could be organized and the transport to the CETP could be done more efficiently. Treated water could also be returned to the plants in a timely manner increasing the viability of a closed loop treatment system. This would also improve the oversight of the PCB. With the limited resources they have, placing all the industrial units in the same vicinity would limit the time they spend traveling and would provide them a better opportunity to identify violations and ensure measures are taken to ensure compliance into the future.

Potential Changes to the CETP Process

There are many relatively simple changes that could be made on site at the Jasol CETP and would result in improvements of efficiency and efficacy of the treatment. In particular, stricter monitoring of water parameters at the CETP would allow for simple adjustments at each step, such as varying chemical dosing, bacteria seeding, and retention times. The following adjustments would also help ensure compliance with the PCB standards for textile industry effluents shown in Table 5. First, if pH is found to be higher than desired in the equalization tank, it should be neutralized by adding an acid such as sulfuric or hydrochloric acid. This step could be completed during primary treatment. Next, using pilot scale tests to seed the SBR with microbial communities already adapted to textile wastes could enhance rates and extent of organic degradation in secondary treatment. In addition, better oversight and documented management of the SBR should be used to optimize the secondary treatment process. This depends in large part on proper selection and periodic monitoring of the Solids Retention Time (SRT), the ratio of solids in the system and solids wasted per day.

While measures to ensure efficiency at the CETP may save the management money and will help preserve environmental quality, the PCB must play a crucial role in incentivizing these adjustments by strictly enforcing their published standards. From our visit to the Rajasthan CPCB, it is evident that there is a need for a larger regulatory workforce. The officers with whom we met stated that more officers are needed to appropriately monitor the vast number of industries in the Jalore and Barmer districts. There is also admittedly a need for increased environmental education and accountability throughout the industry, though this is naturally becoming more of a concern as pressures such as environmental regulation and resource degradation become imminent.

Opportunities for Reduction and Reuse

Reduction and reuse measures within the dyeing process have the potential to alleviate the demands placed on the CETP. Most industrial units we observed have moved to jiggers for dyeing which is a great step toward reducing water use as compared to a dye tank system (Hasanbeigi, 2012). For those facilities that have not made the switch to this water saving system, doing so would reduce water consumption by 30 to 40%. Another measure that could reduce water needs and encourage reuse is switching to custom dyes that have been carefully designed to be optimized for the water conditions of the region. By identifying and utilizing dyes with the best exhaustion properties for the water substrate in the region, units could reuse the dyes for a greater period of time and decrease water demands. Along the same lines, but requiring a huge leap in technology in order to be applicable to the developing region, would be the use of super critical carbon dioxide as the dyeing medium instead of water. This would require a setup to maintain temperature above 31°C and pressure above 73 atm likely increasing costs for these cottage industries, but the process leaves only carbon dioxide and dye as waste products. These two products can be easily separated and recycled while the overall dyeing process is accelerated due to the high diffusivity of the super critical fluid (van der Kraan *et al.*, 2007).

Another interesting opportunity for reuse of wastewater is crop cultivation. The Arid Forest Research Institute (AFRI) has published a promising study on the utilization of textile industrial effluent for raising various seedlings in the desert. The results suggest that treated effluent from textile facilities can be effectively used to boost up establishment and growth of Neem (*Azadirachta indica*) in the arid zone. Additionally, gypsum and wood ash, which are readily available in the area, were confirmed to have beneficial effects in terms of sodicity-salinity amelioration and fertilizer effects (Singh, et al., 2009). This concept will hopefully be adapted to a planned plantation site located near the Jasol CETP, although the leaders of the Industrial Association were not able to reveal any specific information about the plantation.

The final measure that could be used to encourage reuse of the dyes is the return to natural organic dyes. While this would not reduce the amount of water the industry would use, the organic dyes can be more easily treated and removed, increasing the possibilities for recycling of effluent. With a better quality treated effluent, the water could be used in applications beyond screen cleaning and washing, not to mention these dyes are severely less harmful to the environment should they be released into the surrounding land and water systems. With these measures, the Jasol textile industry has the chance to reduce their water demand and decrease their environmental impact.

Management of Groundwater Consumption

With the decreasing water table, better management of groundwater consumption will also have to take place. Textile plants have been digging bore wells in order to have a free source of groundwater. The first step in this process should be the cessation of both legal and illegal bore wells in the area for industrial use. This heavy use of groundwater creates a battle between community members and industrialists over a scarce and precious resource in the area. Industrialists should be asked to buy their water at a reasonable market rate, creating incentives for efficiency. It may also be worth implementing alternative pricing schemes that provide water rebates for prioritizing recycling and reuse and for utilizing less polluting dyes that are plant based and can be easily removed. Finally, the industries could be charged for their water usage rather than charged for use of the CETP. This would encourage a reduction in the upfront water usage while not creating a barrier for using the CETP. Revenue generated from water extraction could be used for operation cost of the CETP. These alternatives provide a variety of ways for improving the water management policies in the area and could create lasting water quality changes in a region that has finally begun to value this scarce resource.

Effluent Treatment Design Alternatives

Due to the difficulties in successfully meeting treatment goals using the conventional methods described, the first phases of designing a low-cost, low-maintenance system are proposed in this section. The most promising alternative treatment train is presented and entails the primary treatment already in existence at the CETP followed by a constructed subsurface wetland and solar still.

Wetland Treatment

Wetlands are simply classified as lands with saturated soil conditions and related vegetation (EPA, 1993). This type of environmental system leads to high levels of microbial activity, uptake of nutrients, and both anaerobic and aerobic activity. Marshes, bogs, and swamps are all naturally occurring examples of such a land type. Known for their robust water filtration abilities, environmental engineers have been studying these natural systems and their application for wastewater treatment for some time. A "constructed wetland," a designed wetland specifically built for the purpose of pollution control and waste management, can be engineered with either a free water surface or a subsurface flow of effluent (EPA, 1993). Free water surface wetlands typically consist of a basin or channel, soil, vegetation, and water at a relatively shallow depth flowing through the system. The water is exposed to atmosphere and water moves horizontally. Subsurface Flow Constructed Wetlands (SFCWs) consist of a porous media (usually rock or gravel) in a bed. The roots of the vegetation are contained in this porous media but the water level in the bed will remain below the top of the rock or gravel. This design is favored in a situation where evaporation is of concern. Water effluent flow in a subsurface wetland can be can be horizontal or vertical depending on the complexity of design. A typical horizontal design is shown in Figure 16 below. Both designs use gravity as a means for transporting water through the system and therefore require very little energy input.

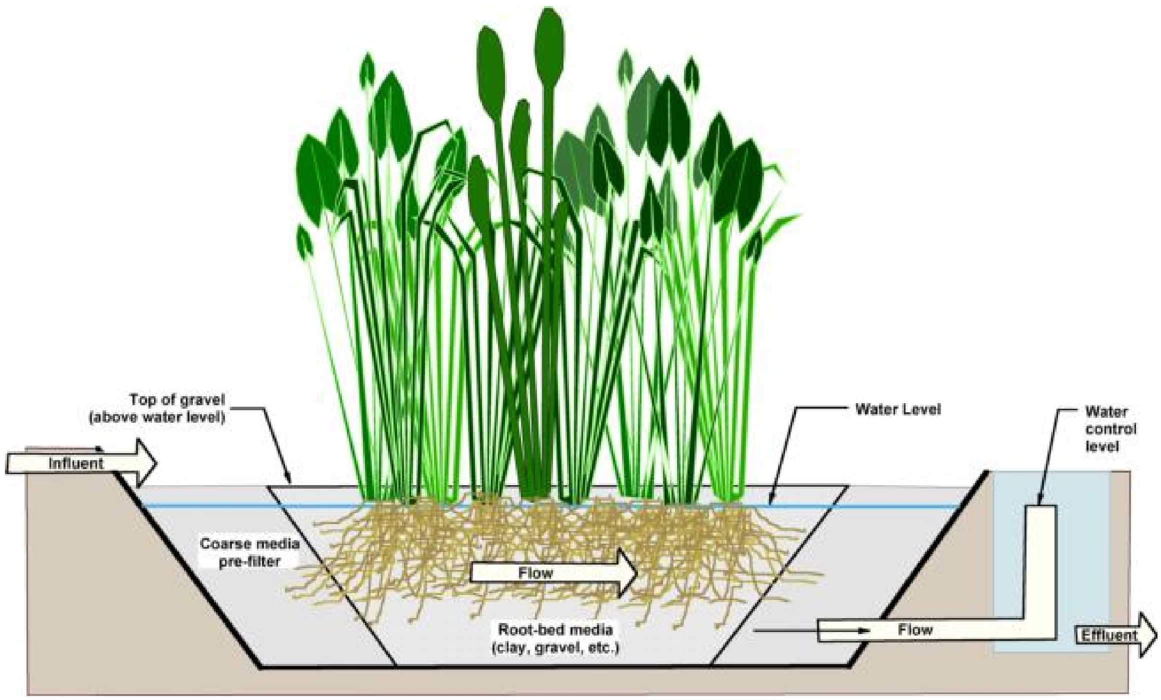


Figure 16: A typical horizontal subsurface flow constructed wetland

According to the United States Environmental Protection Agency, a SFCW has several advantages to a free water surface system. Water contained below the surface has little risk for odors, exposure, or insect vectors. Also when water flows through the media, it is thought that pollutants and waste are more available to vegetation roots than in a free surface setup. The most beneficial aspect of a subsurface wetland, especially for this arid region, may be the limited evaporation that takes place while water is flowing through the system (EPA, 1993). For these reasons, a subsurface constructed wetland design will serve as the basis for our ecologically based treatment alternative.

SFCWs have been extensively studied for wastewater treatment all over the world, building the basis for a wetland treatment design applicable to Jasol. Kickuth *et al.* demonstrated the use of wetlands for filtering water to a depth of about 0.6m in 1977 (Kickuth 1977). Seidel researched the use of a series of beds containing cattails, bulrush, and reeds and showed that a vertical flow through the bed had great performance in removing BOD, TSS, nitrogen, phosphorus and other organics (Seidel, 1977). In 1985, Gersberg *et al.* used large-scale continuous flow experiments to prove that BOD and TSS correlated with depth of roots and plant variety (Gersberg, 1985). With this foundation, subsurface constructed wetlands have been proposed, researched, designed, and implemented around the world for treatment of a variety of different waste streams.

While examples of wastewater treatment through SFCW are readily available, these must be applied to the uniquely harsh arid conditions in the Thar Desert. One of the biggest questions surrounding the use of SFCW treatment in place of secondary treatment within Rajasthan is the question of high temperatures and the impacts this would have on plant growth. Studying constructed wetlands in subtropical and arid Australia, Greenway found that by using a diversity of plant types, treatment was effective in effluent polishing and wetlands could be used in replacement of secondary treatment (Greenway, 2005). This same study found that treatment produced water of high enough quality for irrigation purposes. Presently, effluent in Jasol is being used for "plantations" and this treatment (coupled with solar distillation described below) could produce a supply of high quality effluent for this purpose or for the more desired reuse within textile facilities. Cerezo *et al.* also found success in using a multi-staged constructed wetland for treating urban wastewater in a semiarid region in Spain (Cerezo, 2001). Their treatment design was able to remove upwards of 90% of suspended solids, 90% of BOD, and 87% of COD. Numerous other examples can be found of successful testing of SFCWs as a replacement for secondary treatment in high temperature conditions.

As we have stated previously in this report, reactive textile dyes are difficult to treat through conventional treatment systems; however, the literature shows some success in utilizing wetlands for treatment of dye-rich effluent. Pilot designs tested by Slovenian researchers Bulc and Ojstrsek produced color removal of up to 70%, 84% COD removal, 66% BOD removal, 52% Total nitrogen removal, and 93% removal of TSS (Bulc and Ojstrsek, 2008). Similarly, a study conducted in Tanzania on treatment of effluent from small-scale tie-and-dye facilities found that engineered wetlands could reduce color by 72-77% while reducing COD by 68-73%. This study was important because it showed the importance of the type of vegetation in the success of effluent treatment with localized coco yam plants performing 7.6% better than more traditional cattails in treatment. This difference in efficiency depending on the type of vegetation, especially when cattails are widely accepted as effective vegetation for constructed wetlands, creates the need for individualized pilot testing of native plant types in Rajasthan for the treatment design. Some possible plant species are described below.

Treatment using a constructed wetland could also enhance the quality of life in the community and lead to new economic opportunities. Zurita *et al.* demonstrated the use of ornamental species for domestic wastewater treatment in Mexico. This work demonstrated not only the ability of these plants to survive a 12-month period while removing 80% BOD, 72.2% NH_4, 50% total P, and 82% TSS, but also the ability to find economic value in the vegetation. The researchers made the case that these ornamental plants (*Z. aethiopica, A. andreanum, S reginae,* and *A. Agapanthus*) could then be sold on the open market for decorative purposes. This would help alleviate economic costs and provide a means of disposing of the biomass, beautifying the community, and producing jobs within the Luni Basin Region.

Treatment wetlands could be a viable replacement to secondary treatment because they are robust in their treatment capabilities removing color, organics and suspended solids, require less technical knowledge and less maintenance, and can help enrich the environment of Jasol.

Designing a Subsurface Flow Constructed Wetland for Jasol Textile Effluent

While we are unable to produce a final design for the SFCW design based off the present point in our research, we are able to make certain design suggestions that could be utilized as a next step for pilot testing this process. Based off preliminary calculations, we found that in order to treat the complete effluent load of 6.5 MLD, a constructed subsurface wetland of 6.29 hectares (0.063 km^2) would be needed. To view these calculations, please refer to Appendix C. While this may seem like a large area, we are confident in the ability to produce such a system in the region as other projects have produced larger constructed wetlands projects in the past. In Jasol, land availability is not an issue as there are numerous unused parcels of land along the Luni that could be purchased for the treatment sit.

Construction of this secondary treatment will require a number of steps. First, earth will need to be excavated from the site area down to a depth of approximately 0.6 meters. A liner or geotextile barrier will then be placed on the bed of the wetland to ensure that polluted effluent does not infiltrate into the groundwater. Gravel and sand of different sizes will then be placed in the bed in layers as the wetland medium. At this point, vegetation can be planted and allowed to acclimate to the new environment. Figures 17 through 20 demonstrate selected steps in the construction of a subsurface flow constructed wetland in Bathalapalli, India ("Constructed Wetlands," 2012).

Figure 17: Laying a liner in the soon to be wetland bed

Figure 18: Filling the site with gravel and water distribution piping

Figure 19: Planting the vegetation

Figure 20: The Bathalapalli, India Subsurface Flow Constructed Wetland six months after construction

As shown in these figures, relatively low cost techniques can be used to implement this secondary treatment and once constructed, plant vegetation should flourish with little need for maintenance. Identification of plant species within the system will be critical to ensuring the success of the wetland. Cattails and reeds are predominantly used vegetation in constructed wetlands but that is not to say these will provide the best treatment in the arid environment of Rajasthan. Native plants should be tested first because they are already adapted to the conditions thereby improving the sustainability of the system. Through conversations with representatives from the Arid Forest Research Institute, we believe the desert shrubs *prosipis juliflora* and *prosipis cineraria* may be successful in exhibiting high treatment efficiency. *Prosipis juliflora* is known for its aggressive root growth and is frequently found in the region while *prosipis cineraria* has shallower roots but was referred to as the "king tree of desert" by one Institute researcher. Additional suggestions for pilot testing include *azadirachta indica* (neem), a variety of reeds, and ornamental kale. While this is far from an exhaustive list of potential wetland species for use in the treatment train, this list provides a starting point for performing the critical step of pilot testing these vegetation types, and combinations of vegetation types, for use in the full scale treatment system.

With quality ecological engineering, validated pilot testing, and efficient operations and maintenance, a SFCW system has the ability to improve effluent quality for reuse and recycling while decreasing necessary oversight and technical expertise as compared to traditional secondary treatment. Based off previous studies on wetlands treatment, we would expect the design for Jasol to meet the BOD and COD removal rates presently being achieved at the CETP while decreasing color by a minimum of 70% and TSS by a minimum of 80%.

Solar Distillation

While wetlands are robust in their treatment capabilities, they do lack the ability to uptake salts at the rate needed for the effluent to have an acceptable level of TDS. A solar still appears to be the most promising alternative to the more expensive RO being considered to meet the criteria for TDS removal.

Solar distillation techniques have been recorded as early as the fourth century B.C. when Aristotle described evaporation followed by condensation as a way of transforming unclean water into potable water. In 1872, the first modern solar still was built, supplying animals with 20,000 liters of drinking water per day and lasting for nearly forty years. Oil-fired large-scale community stills are currently considered cost effective (Tiwari et al., 2003).

Solar stills have been researched in the southwestern United States and other arid regions in South America and Africa. Stills are mostly used for drinking water treatment where they have been shown to remove salinity, bacteria, pesticides, iron, manganese, fluoride, and heavy metals (Hansen et al., 2004). Reverse osmosis effectively decreases salinity, but may be too expensive for underdeveloped regions.

Solar stills provide a safe, low cost method for clean water production in sunny, rural locations. Several researchers have estimated the cost of solar still water production. Estimates range from $2.40 to $20 per cubic meter (Ghoneyem et al., 1997 and Madani et al., 1995). Solar distillation avoids the high initial investment and high energy and maintenance costs of RO. There are many solar still designs available. The most commonly used is the single-slope solar still (Aboabboud et al., 1996). With proper engineering, materials sourcing, and quality construction, a solar still has the capability of delivering the same quality of water as RO without the high energy costs.

Solar Still Technology

In basic solar distillation, water is placed in a large, flat container (as shown in Figure 21) and covered with a transparent piece of glass or plastic film. The transparent cover is set at an angle, so that as the sun warms and evaporates the water, condensation gathers underneath the glass. This condensation then rolls down the slanted surface into a gutter that drains into a clean collection bottle. The evaporated and condensed water is pure, leaving behind harmful microbes, salt, and other contaminants. The system is easy to use and maintain, and provides treatment that is sufficient for a small family.

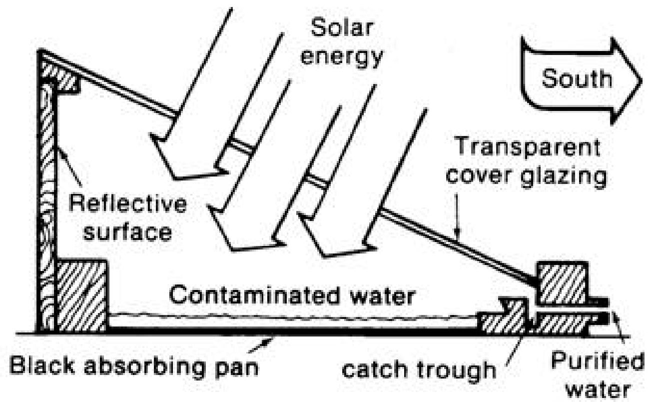


Figure 21: Example solar distillation device (http://theenergylibrary.com/node/11694)

Still designs may be considered active or passive systems. Active systems have thermal energy applied to the basin to increase evaporation and sometimes also have a cooling system for the condenser plate. If no external source of thermal energy is applied, the system is considered passive. There are many types of passive distillers, including the single-slope solar still with passive condenser, double condensing chamber solar still (Tiwari et al., 1997), vertical solar still (Kiatsiriroat, 1989), conical solar still (Tleimat and Howe, 1967), inverted absorber solar still (Suneja and Tiwari, 1999), and multi-wick solar still (Tiwari, 1984).

Many researchers have studied ways to improve the production volume of various still designs. Creating an asymmetrical still with mirrored walls allows more radiation to be reflected which increases the heat of the basin and increases the output volume. Decreasing the water depth has also been shown to increase output volume. In addition, adding dark dye to the water allows it to capture more solar energy and increases the output volume (Al-Hayeka et al., 2004). Adding more insulation to the basin and painting the basin black have also been shown to increase the yield from a solar distiller. The literature shows that the most economical design is a fiber reinforced plastic conventional solar still (Tiwari et al., 2003).

Some research has been done to determine the water quality of single basin solar stills, showing that the still is successful in removing non-volatile compounds from the water (Hansen et al., 2004). There has not been any analysis on the quality of water from solar distillers using water from Rajasthan. This analysis could prove to be very beneficial, as Rajasthan is an area that greatly needs this technology.

Example Solar Still

A study by mechanical engineering researchers from Northeastern University summarizes the following design guidelines for a successful solar still design (Coffrin, 2008):

- The water depth of the solar still should be maintained at 2 cm for optimal water purification
- An asymmetrical design is most inexpensive and most efficient
- The optimal angle of the glass for regions near the equator is roughly 23˚
- The largest temperature difference possible between the glass and water will lead to increased water production
- The greatest absorptivity possible for the basin will lead to the maximum water output
- Minimizing heat loss is a key to increased production

In addition to the guidelines above, the highest output solar distillation system that is most appropriate for the required scale of water treatment at the CETP is a "multiple effect" wicking system (Coffrin, 2008). This system shall be designed in such a way that evaporated water from one surface condenses on the bottom of another surface and subsequently transfers thermal energy to the second surface which also contains evaporating water. An enclosed inclined wicking system supplies a constant feed of water through the still. The saturated wick allows for some of the feed water to be vaporized for condensate and the rest of the feed water runs out of the distiller as hot water that can be reused for multiple purposes within the dyeing facilities. The multiple effect wicking system shown in Figure 22 is simple and cost effective, but does not convert all of the feed to distilled water. This could actually be beneficial because it would allow for blending to match the optimized TDS parameters for dyeing.

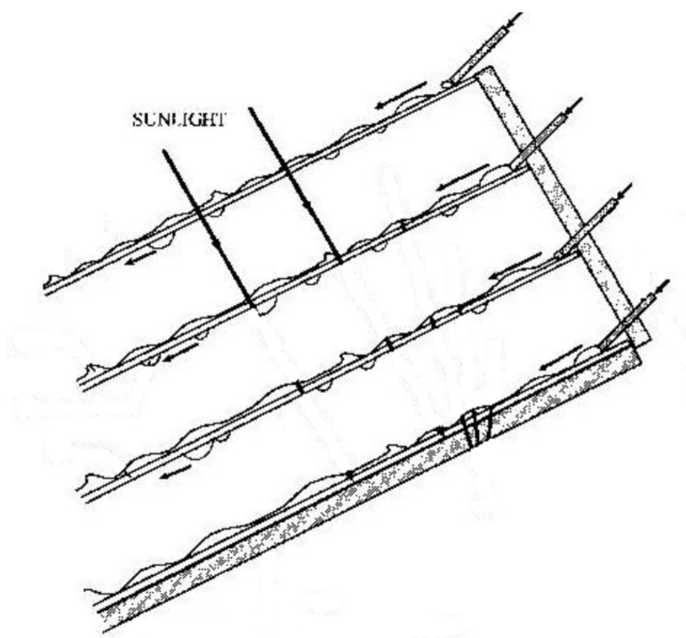


Figure 22: Multiple effect wicking system

Figure 23 shows a small still design that could be scaled up to meet the needs of the treatment process at the CETP. The design is intended to produce 7.5 or more liters per day of distilled water by using a glass area of $1m^2$. The calculations included in Appendix D show that a 927m x 927m square ($0.86km^2$) multiple effect still would more than accommodate the entire 6.5 MLD planned capacity of the Jasol CETP, and in all likelihood, a much smaller still design would be desirable as the water could be blended for recycling. The cost per square meter is estimated as $\$90/m^2$, and would likely decrease with larger scale. Thus it is very difficult to estimate the cost of a system that would be placed at the Jasol CETP without detailed research customized to the sustainability goals of the CETP and textile industry in the region. This design should be cost competitive with RO when looking at full life cycle costs including construction, maintenance, and filter costs.

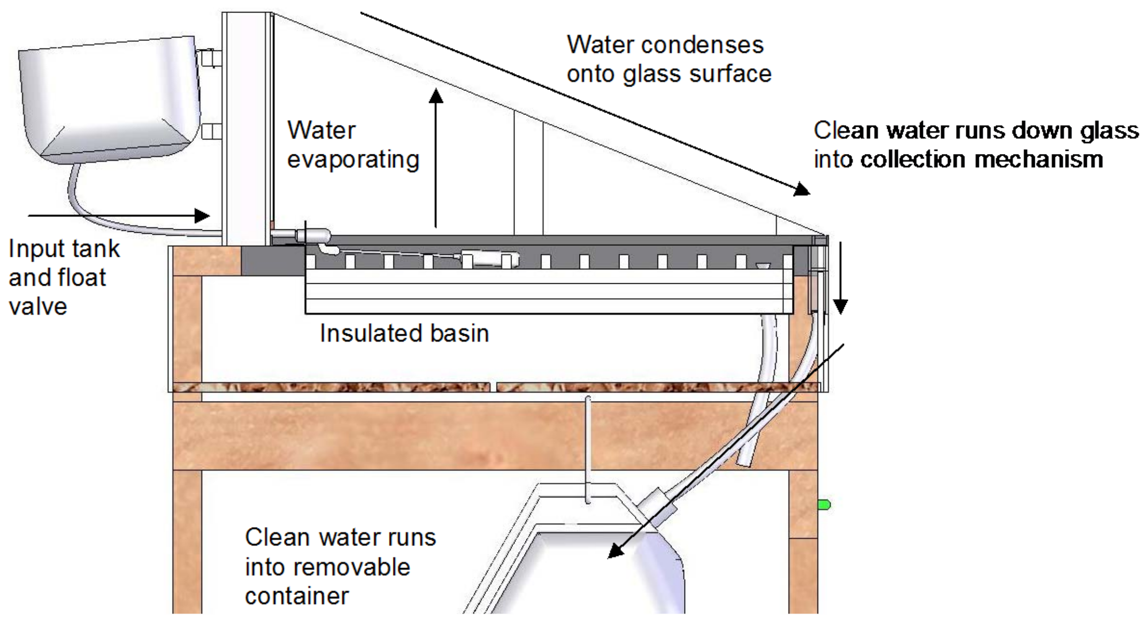
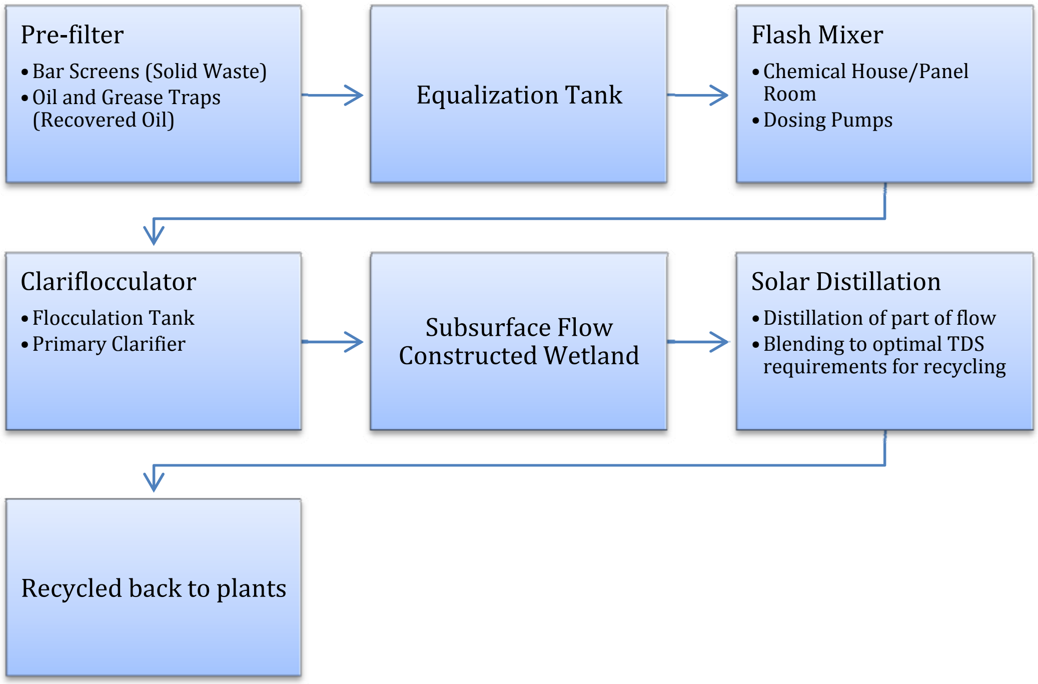


Figure 23: Overview of solar still design to be scaled up

Because Rajasthan has an abundance of renewable solar energy and land area, it is a natural location for the development and implementation of solar distillation technology. Solar stills purify water to the point that it could be directly reused in the industrial process, or mixed with slightly lower quality water before reuse to achieve the desired influent quality standards while also recycling a more abundant quantity of previous wastewater. They utilize abundant readily available solar energy in the form of heat as opposed to the alternative energy-dependent RO technology being considered. Alternatively, the pure water could be sold as a commodity at a nominal price comparable to the rates set by local municipal water treatment plants and distributors. Overall, this technology has an economic benefit for the textile industry and/or the CETP, as well as a significant environmental benefit and thus social benefit in the regions where it may be implemented.

Suggested Treatment Train



Conclusions

As a community whose two biggest industries, agriculture and textile production, have been placed at odds, Jasol faces a complicated problem when dealing with the environmental impacts of industrial textile activity. Many stakeholders in the region have expressed concerns over the pollution of the Luni river system and surrounding groundwater, while another group of community members considers the loss of the textile industry a critical blow to the livelihood of the region. Both of these groups understand the dangers of the lowering water table and the need to limit groundwater extraction.

Based on the data and your observations, the existing treatment process fails to remove TDS and color. Based on color alone, we suspect that the GAC would be exhausted rapidly and the RO membranes will foul earlier than expected. Testing and consistent data collection should be the first step in verifying this observation. In addition, there are uncertainties surrounding the sizing of the system and its ability to accommodate the entire flow from the industry or allow for any growth in the future. For these reasons, we identified a number of ways to improve and potentially redesign the existing treatment process using an ecologically based treatment train. Low hanging fruit such as more careful and frequent data collection and managerial oversight could be immediately implemented at lower cost than other changes. Improved data collection is imperative prior to any modifications the treatment train as water and effluent quality data are needed for tailoring a treatment to the Jasol industrial textile effluent. A wetlands/solar distillation process, while a more drastic departure from what is presently in place, may better match the conditions of the Thar Desert, decrease the need for constant maintenance and oversight, and almost eliminate the impact waste effluent would have on the Luni River. This system could potentially treat the wastewater to a quality that would be suitable for reuse in the textile industry and create a closed loop treatment system. While other treatments such as reverse osmosis may achieve the same goal, they require a higher degree of technical expertise and management and would result in greater recurring costs associated with energy use and membrane replacement. It is our belief that through improved effluent treatment, creation of a closed loop system, and eventual remediation of the river basin, the Luni River can become a vibrant and healthy water system in a community where the development and growth of the critical textile industry supports environmental goals.

Future Work

While we are optimistic about the viability of an ecologically based treatment train, further research on both solar distillation and subsurface wetlands will need to be conducted in the arid zone. Subsurface wetlands have had limited application on such complex effluents, thus extensive pilot testing will be necessary to identify the best plant species for the job. In addition, the percentage of total water needs to be distilled and then blended with none distitlled water to yield a satisfactory TDS concentration for reuse in the plant must be studied. Each component of this train will need to be designed by trained engineers to handle the heavy effluent loads produced by the textile units, and tailored to the composition of the specific effluent.

One of the largest gaps of information needed for designing a new treatment system is comprehensive data. It is the recommendation of this research team that daily water use and effluent discharge from all units connected to the CETP be collected on a regular basis. Due to the seasonality of production in the region, this testing should be conducted weekly throughout the year so the treatment train can be designed to handle maximum loading. Additionally, to our knowledge there exists no set of values for describing the optimal water quality for different textile processes. This information is critical for tailoring the treatment to allow for effluent recycling. Finally, effluent quality data need to be properly monitored, both at present and for any future treatment train. These data should be used to optimize the treatment and ensure compliance with all PCB regulations.

In addition to optimizing the treatment, the process of remediating the Luni River and surrounding area will be a major next step in improving the environmental health of the area. With the extent of pollution in the river bed, this process will likely take years to complete and require a variety of cleanup methods. The constructed wetlands could contributed to this overall cleanup of the region. Stakeholders should actively pursue strategies for recharging subsurface aquifers that have been depleted by industrial exploitation. With an active commitment to remediation and recharge, the Luni River Basin could potentially be revived through a long-term comprehensive remediation plan.

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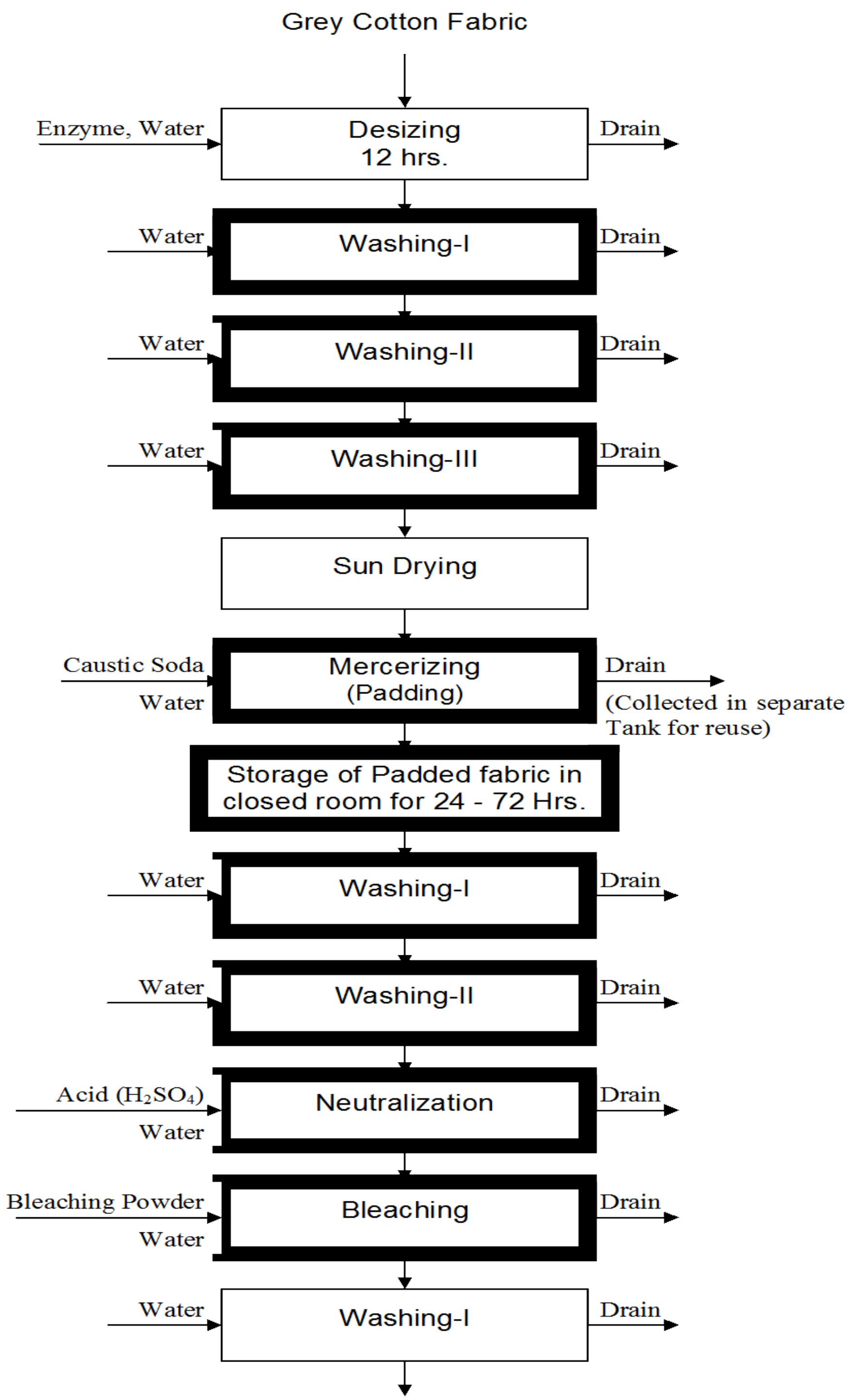
Appendices

Appendix A: Dyeing Process for Different Types of Fabric



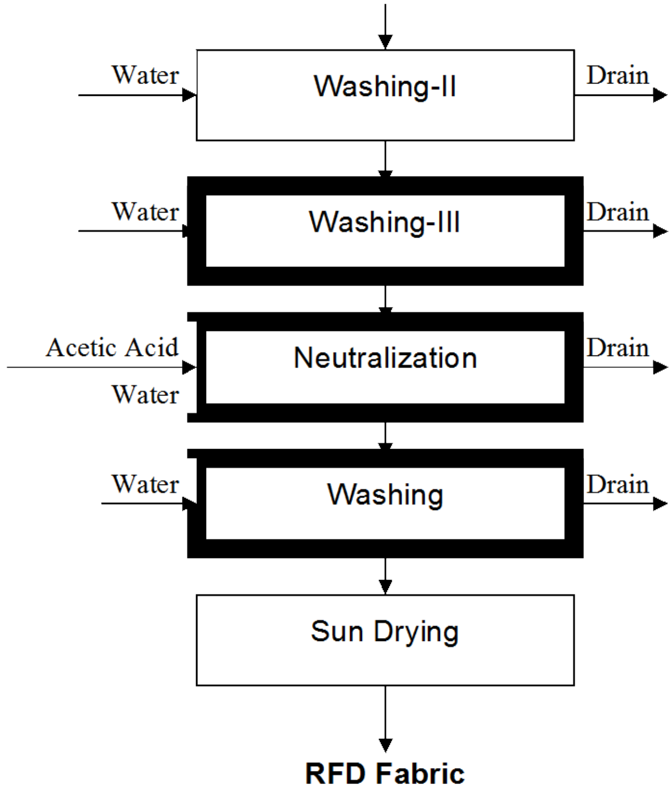


Figure 24: Process flow diagram of Ready for Dyeing (RFD) fabric

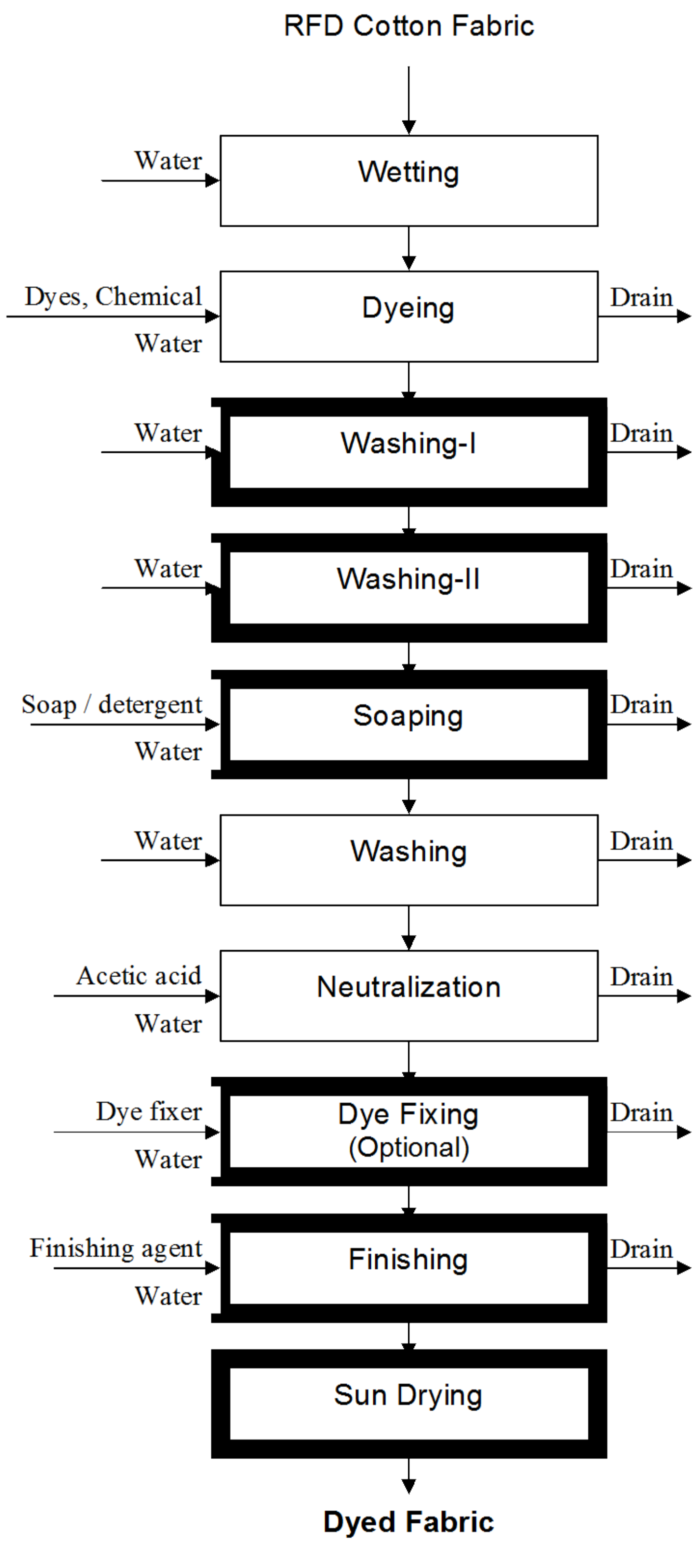
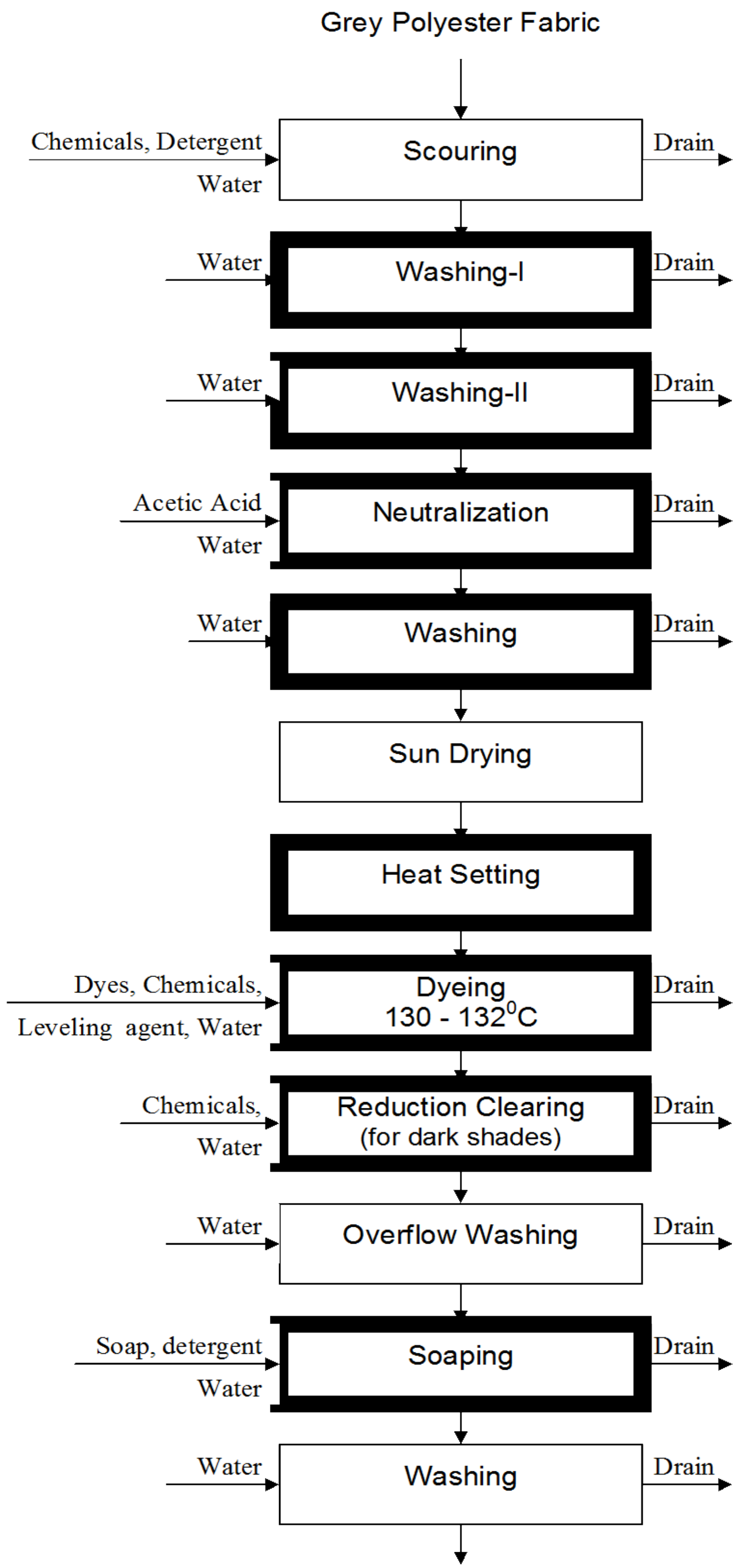


Figure 25: Process flow diagram of cotton dyeing fabric


Grey Polyester Fabric
Chemicals, Detergent
Water
Scouring
Drain
Water
Washing-I
Drain
Water
Washing-II
Drain
Acetic Acid
Water
Neutralization
Drain
Water
Washing
Drain
Sun Drying
Heat Setting
Dyes, Chemicals,
Leveling agent, Water
Dyeing
130 - 132^{0}C
Drain
Chemicals,
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Drain
Water
Washing
Drain

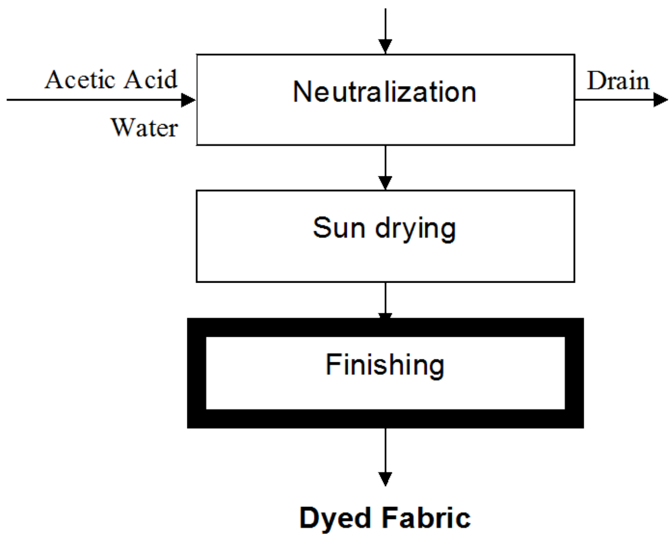

Figure 26: Process flow diagram of polyester fabric dyeing

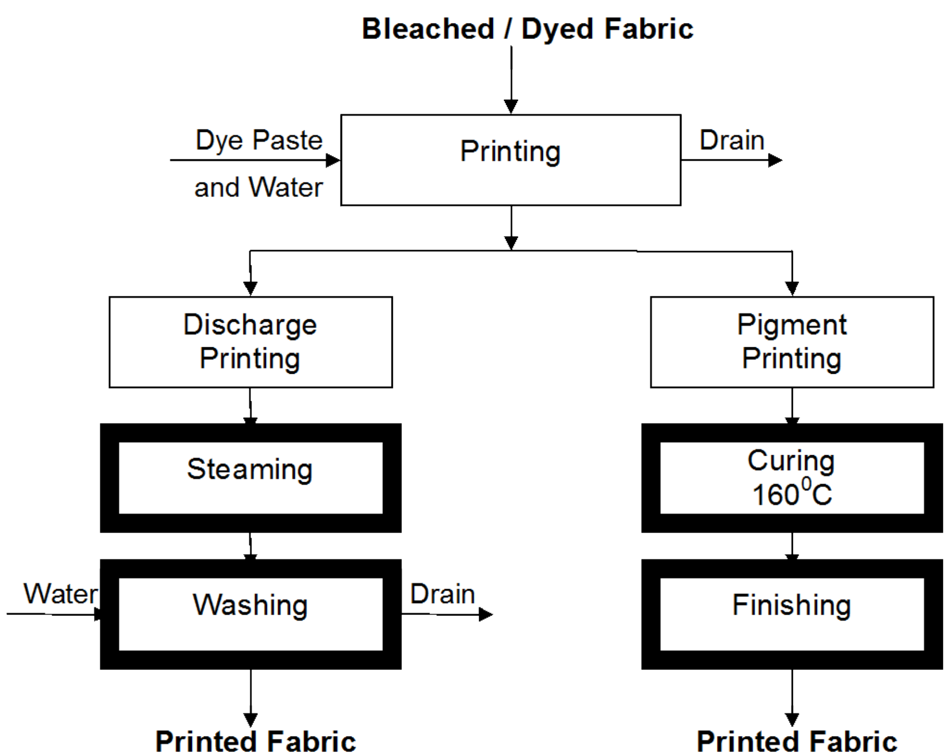

Figure 27: Process flow diagram for printing of bleached/dyed fabric

Appendix B: Results of JBF Water Sample Analysis

Nature of Sample		CETP Water	CETP Water	CETP Water	CETP Water	River Water	River Water	Industrial Waste Water	Industrial Waste Water
Body of Water		**Equalization tank**	**Primary Clarifier**	**Secondary Clarifier**	**Tertiary Treatment (Sand/Carbon Filters)**	**Luni River Upstream**	**Luni River Downstream**	**Dyeing Industrial Outlet**	**Washing Industrial Outlet**
Village		Jasol	Jasol	Jasol	Jasol	Balotra	Tilwara	Jasol	Jasol
District		Barmer	Barmer	Barmer	Barmer	Barmer	Barmer	Barmer	Barmer
Parameters	**Test Method**	**Results**				**Results**			
Color (Hazen Unit)	IS :3025 (Part-4)	5	1	1	1	1	1	15	1
pH	IS :3025 (Part-11)	9.89	9.2	7.68	8.05	9.18	8.86	12.47	10.87
Total Alkalinity (mg/l)	IS :3025 (Part-23)	566	540	720	610	640	176	1796	980
Total Hardness (mg/l)	IS :3025 (Part-21)	264	120	182	138	296	322	298	240
Total Dissolved Solids (mg/l)	IS :3025 (Part-16)	13300	9300	9500	4800	22100	30600	12900	14300
Total Suspended Solids (mg/l)	IS :3025 (Part-17)	480	90	92	60	0.6	0.15	3.5	1.7
Biochemical Oxygen Demand (mg/l)	IS :3025 (Part-44)	0.047	0.076	0.193	0.197	0.226	0.173	0.103	0.09
Chemical Oxygen demand (mg/l)	IS :3025 (Part-58)	93.33	106	112	117.33	112	101.33	66.66	90.66
Dissolved Oxygen (mg/l)	IS :3025 (Part-38)	4.8	8	12.4	12.7	10.9	10.5	9.6	9
Turbidity (NTU)	IS :3025 (Part-10)	16.2	8.4	8.8	4.3	23.6	9.9	85.5	79.2
Fluoride (mg/l)	IS :3025 (Part-60)	0.034	0.289	0.186	0.238	0.036	0.125	4.77	0.168
Chloride (mg/l)	IS :3025 (Part-32)	659.79	439.86	511.84	235.93	888.5	1516.7	452.96	1115.26
Sulphide (mg/l)	IS :3025 (Part-29)	38.4	28.8	4.8	9.6	24	9.6	3.2	11.2
Conductivity (mS)	APHA-21st Edn	43.7	21.6	64.6	90.5	0.13	19.7	45.8	70.5
Nitrate (mg/l)	IS :3025 (Part-34)	80	25	22.5	32.5	35	30	95	52.5
Phosphate (mg/l)	IS :3025 (Part-31)	6.8	0.9	7.2	0.2	1.9	0.55	6.2	5.8

Appendix C: Wetlands Calculations

Design Flow m^3/d	Q =	6500 m^3/d		(6.5 MLD) (.66 MGD)		
		Parameters				
		TSS	BOD	COD	TN	
Influent concentration, mg/L	Ci =	612	435	3035	xx	
Target effluent Concentration, mg/L	Ce =	100	30	250	50	
Wetland background limit, mg/L	C* =	46.356	26.555	xx	xx	
(For TSS, C* = 7.8 + .063Ci)						
(For BOD, C* = 3.5 + .053Ci)						
Reduction fraction to target	Fe = 1 - Ce/Ci=			0.836601307	0.931034	0.917628
Reduction fraction to background	Fb = 1 - C*/Ci =			0.924254902	0.938954	
Areal rate constant, m/yr				3000	180	
Required wetland area, ha				0.55886498	6.294286	
A = ((.0365*Q)/k)*ln(Ci-C*/Ce-C*)		**The necessary area =**		**6.294286473**	**ha**	
				62942.86473	**m2**	
				15.54688759	**acres**	
				0.062942865	**km2**	

Appendix D: Solar Distillation Sizing Calculation

$$\mathbf{6,500,000\ \frac{L\ capacity}{day} * 0.26417\ \frac{gal}{L} * \frac{m^2 * day}{2\ gal\ distilled} = 858,559\ m^2\ = 927m * 927m}$$

* When considering the upgraded capacity of the Jasol CETP to be 6.5 MLD, and scaling up the 2 gal/m^2 example solar still, a large solar still roughly 927m by 927m would be needed to process the entire daily capacity. However, as the technology is intended to provide a more supplementary process as opposed to a comprehensive process within the treatment train, the actual design could be much smaller, say, 500m by 500m. This would help reduce the cost of manufacturing and maintenance, and would greatly increase the capacity for wastewater recycling at the same time.