# IMPLEMENTING SUSTAINABLE PRACTICES IN WASTEWATER TREATMENT AND MATERIAL WASTE MANAGEMENT IN THE TEXTILE AND APPAREL SECTOR OF BANGLADESH

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## ABSTRACT

This research extensively evaluated the sustainability of thirteen manufacturing facilities in Bangladesh's textile and apparel sector, specifically associated with swift fashion production. Employing a multiple case study methodology, both qualitative and quantitative data were collected via concise surveys and subsequent discussions in focused groups. The textile and apparel industry is notorious for producing significant material waste, necessitating urgent and effective management to mitigate its detrimental environmental impacts. Strategically managing waste materials from the outset of textile production presents a substantial research opportunity, aligning with circular economy principles and supporting Bangladesh's pursuit of SDG 12. Additionally, this inquiry involves systematically identifying and classifying waste materials generated across diverse production phases while exploring options for recycling both pre and post-consumer textile waste. Beyond material waste, another critical issue in Bangladesh's textile sector involves releasing considerable volumes of wastewater into rivers, causing surface water pollution. Properly treating this wastewater is pivotal for advancing SDGs. This study also sought to evaluate the treated wastewater quality from textile industries and investigate methods for resource recovery, aligning with SDGs 6 and 12. The focus was on utilizing treated textile wastewater and reclaimed caustic soda for producing denim jeans. Remarkably, denim produced using these reclaimed resources and treated wastewater exhibited comparable performance to those made with treated groundwater by North American and European brands. Additionally, this research explored harnessing thermal energy from textile wastewater to preheat water before entering boilers, further enhancing sustainability in Bangladesh's energy-limited textile sector. This partnership underscores the correlation between eco-conscious textile practices and successful wastewater management, essential for SDG progression. It underscores the importance of technology-driven managerial and comprehensive strategies for sustainability and addressing forthcoming challenges.

***Keywords:*** *circular approach, supply chain, material waste, recycling, resource, thermal energy*

## 1. INTRODUCTION

The textile and apparel manufacturing industry in Bangladesh has been a significant driver of economic growth, contributing over 84% of the country's export earnings and 12.3% of its GDP, with an annual income of 42.613 billion USD in the Fiscal Year 2021-22 (fibre2fashion, 2023). With more than 7,000 operational industries employing over 4.5 million people, this sector plays a pivotal role in the nation's economy (Shahajada Mia & Masrufa Akter, 2019). However, it is known for its high ecological footprint, particularly in terms of water, energy, and chemical consumption in processes like yarn and fabric manufacturing, dyeing, washing, and finishing. These water-intensive processes contribute to the heavy dependence on groundwater. This consumption leads to a yearly drop in groundwater levels by 2.0-3.0 meters, with a projected depletion rate of 5.10 meters/year by 2030 (Moshfika et al., 2022). About 80% of the water used in the Bangladeshi textile industry goes into wet processing, subsequently becoming wastewater (Ranganathan et al., 2007). The wastewater from these processes often contains a range of pollutants, including oil, grease, caustic soda, Glauber salt, ammonia, sulfide, lead, and various heavy metals, with salts constituting approximately 50% of the discharged textile effluent, leading to elevated levels of, biological oxygen demand (BOD), chemical oxygen demand (COD) and dissolved solids.

The textile sector in Bangladesh released significant quantities of wastewater in 2011, 2015, and 2020, with discharge volumes reaching 145.0 million $m^3$, 201.0 million $m^3$, and 317.0 million $m^3$, respectively (Miah et al., 2023). The substantial amounts of wastewater have considerable detrimental impacts on the physical, chemical, and biological attributes of aquatic ecosystems, thereby presenting substantial risks to public health, wildlife, and ecological systems. Approximately 20% of freshwater pollution in Bangladesh can be attributed to the processes of fabric processing and dyeing, which release untreated or partially treated effluents (Gulfam-E-Jannat et al., 2023). Moreover, due to the fast fashion trend driving an upsurge in apparel production, the textile industry produces a significant amount of waste across multiple stages, encompassing spinning, knitting/weaving, dyeing, apparel manufacturing, and finishing (Koszewska, 2019). The global textile industry is one of the most environmentally damaging sectors, resulting in the disposal of 2.5 billion pounds of textile waste into landfills annually (*Waste to Fashion*, 2022). Recycling efforts are restricted in scope, resulting in a considerable portion being funneled into landfills or subjected to incineration, as brought to light by research conducted by Pensupa et al. in 2017 and Niinimamp et al. in 2020. In Bangladesh, approximately 400,000 tonnes of pre-consumer textile waste are generated each year, and only 5% of this waste is locally recycled (*The Business Standard*, *2023*). Among this waste is entirely reusable cotton material, which holds an estimated worth of approximately 100 million USD, as reported by Pavarini in 2021. Forecasts indicate that the global volume of textile waste is expected to increase by 60% annually from 2015 to 2030. In the context of Bangladesh, this waste is referred to as 'jhoot' (Patnaik & Tshifularo, 2021), and its handling has evolved into an escalating concern because of the immediate environmental ramifications. Research in Bangladesh has pinpointed cutting remnants as a major contributor to overall waste generation (Rahman, 2016). Cutting stands out as the primary origin of material waste in the garment industry, with this waste type classified as pre-production waste, encompassing unused fabric, cutting leftovers, surplus materials, and spreading loss (Cao et al., 2022). Importantly, despite these challenges, roughly 87% of the world's textile waste ends up in landfills, contributing to solid waste problems. Notably, as much as 90% of this waste can be transformed into economically valuable products through the application of reuse and recycling methods(Moazzem et al., 2021). Moreover, the integration of post-consumer waste (PCW) in textile production presents a promising solution for mitigating environmental concerns related to waste generation and resource depletion in the industry (Singh & Ordoñez, 2016). Given the textile industry's ongoing efforts to navigate sustainability predicaments, the incorporation of PCW components into manufacturing procedures provides a potential pathway to advance circularity and diminish reliance on new materials. This comprehensive strategy grapples with the diverse issues posed by textile waste and unveils avenues for sustainable techniques and resource preservation in the sector. This research focuses on evaluating how export-oriented factories in Bangladesh adhere to circular economy principles in handling wastewater treatment and material waste throughout the production and post-production stages. It aims to quantify pre-consumer material waste generation in spinning, fabric manufacturing, wet processing, and apparel production. The study proposes a conceptual model for managing both pre-consumer and post-consumer textile waste, emphasizing recycling within the circular economy framework. Additionally, it assesses the quality of treated wastewater discharged by textile industries to reduce environmental impact, explores the feasibility of using treated wastewater in a denim facility's wet processing unit in Narayanganj, Bangladesh, and investigates the recovery of caustic soda and heat from textile wastewater to contribute to sustainable development goals through circular economy principles.

## 2. METHODOLOGY

Utilizing an exploratory approach, this study adopted a multi-case methodology. Participant selection hinged on their industry experience, relevance to the research theme, and domain knowledge. Initial outreach to potential case companies was established through both email and direct phone communication. The selection criteria revolved around their location in Dhaka, Bangladesh, involvement in textile and apparel manufacturing geared toward exports, and their openness to sharing information for research purposes. Despite outreach efforts directed at 30 unique companies spanning various sectors of the textile and apparel production chain, only 8 companies ultimately granted their participation to share their information on waste and 5 companies agreed to participate in sharing information regarding their effluent treatment plant and quality of wastewater they release after treatment. Only one of the textiles, allowed us to perform the study on using recycled treated wastewater for using it in the wet processing in denim manufacturing. These selected companies varied in size and product categories, as outlined in Tables 1. They were primarily located on outskirts of Dhaka, the country's major textile industry hub. The research encompassed an in-depth examination of Bangladesh's textile and apparel industry using a semi-structured questionnaire and focus group discussions.

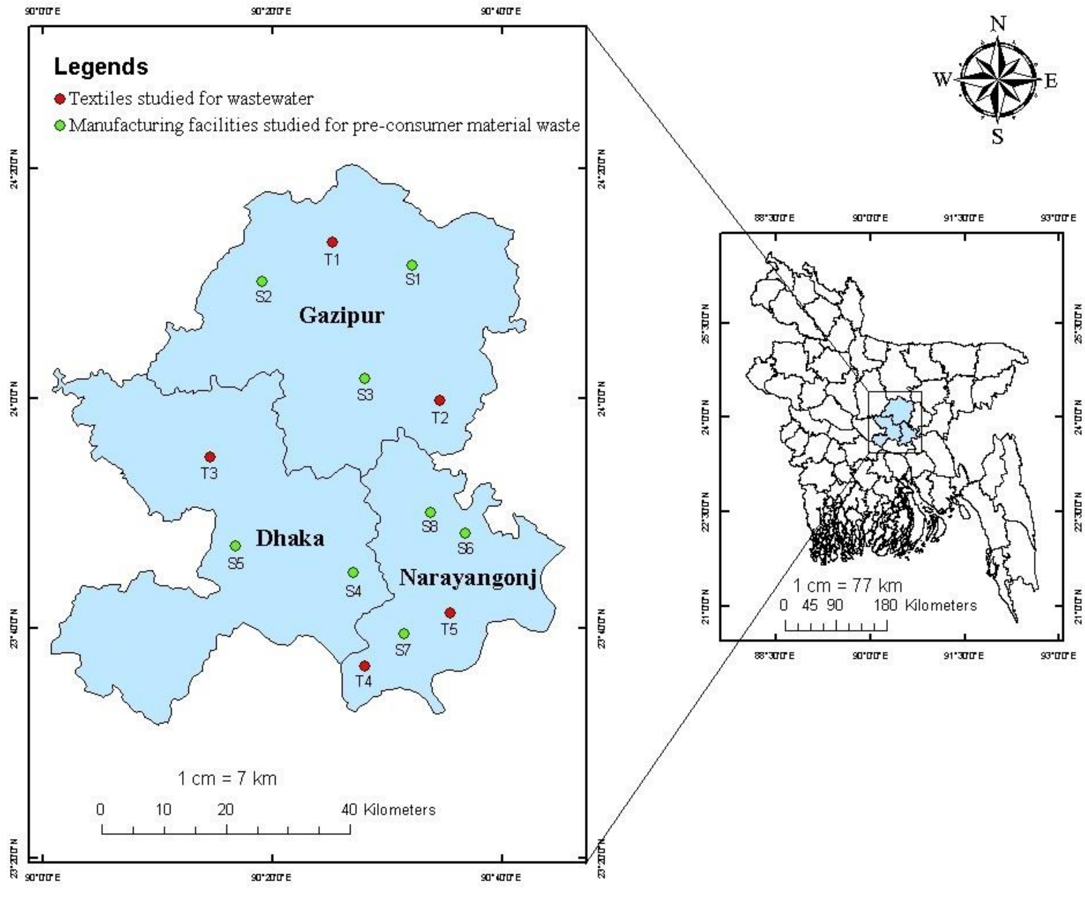


Figure 1: Map of the study area

Data collection was carried out by emailing the questionnaire to company contacts, followed by follow-up communications via phone and email and focus group discussions. Data for textile waste was obtained from their data log over a one-year duration (June 2022- 2023) to derive an average estimate.

The comprehensive wastewater study extensively examined the characteristics of both untreated and treated wastewater. Samples from these textiles underwent testing for various water parameters to assess their quality. Industries within the study routinely monitored wastewater parameters every hour, daily. We collected the data of 6 month period (June to November 2023) from their log books. To ensure result reproducibility, we obtained grab samples of wastewater from the inlet and outlet of the textile facilities on an hourly basis for a week per month from June to November 2023. These samples were meticulously tested to verify and cross-reference the data recorded in the factory logbooks. Ultimately, averaging the readings was done to ensure the accuracy and reliability of the results obtained. Confidentiality measures were implemented to protect sensitive waste material and underground business information. Data reliability and validity were further ensured by cross-referencing information from various sources, including company websites, archives, documents, and industry sources.

The study's goal was to assess economic losses related to waste data and calculate material consumption, waste, and excess inventory in the production of 100 kilograms of apparel. The analysis simplified the final product's representation in kilograms and examined these factors across various production stages. Furthermore, the research explored how production waste could be turned into valuable products, shedding light on the hidden aspects of textile and apparel waste management. Data was collected through interviews and discussions with eight industry experts, covering waste management and local trade. The study also tracked local markets engaged in textile waste trading, identified their destinations, and investigated the processes for converting waste materials into value-added products. Another objective of this research was to assess the prospect of resource reclamation from wastewater in the textile industry. Furthermore, it aimed to scrutinize the practicality of incorporating treated wastewater in wet processing, thereby reducing the burden on groundwater resources.

## 3. RESULT AND DISCUSSIONS

### 3.1 Loss of Materials and their associated Value during the Production Processes

The research findings illustrate the material flow mapping (MSM) of textile and apparel manufacturing within the surveyed factories, providing quantitative insights into material usage and wastage at various production stages. The conversion rate reveals the amount of materials needed to produce 100 kg of output across all relevant industries in the production chain. According to our calculations, a total of 512 kg of materials were employed to manufacture 400 kg (comprising 100 kg of yarn, 100 kg of greige fabric, 100 kg of finished fabric, and 100 kg of apparel) of end products, equivalent to 78% when expressed as a percentage. Further elaboration of the information in table 1 is provided below.

Spinning: The textile and apparel industry encompasses a range of fibers, including natural ones like cotton, wool, silk, flax, hemp, and synthetic fibers such as polyester, nylon, acrylic, and polypropylene. In Bangladesh, the primary emphasis is on materials based on cotton. Yarn production involves the processing of cotton into yarns using a ring/rotor spinning method, while synthetic fibers are converted into yarns through a melt/dry/wet spinning process. Research findings indicate that, for every 100 kg of yarn produced, 122.2 kg of cotton is consumed, resulting in 36.5 kg of waste and an excess inventory of 24.3 kg. The principal types of waste include cotton lint, damaged yarn, and unfinished cones.

In the spinning process, which typically yields yarn priced at 3.18 USD/kg, the waste generated amounts to 193.34 USD. The substantial disparity between production and delivery raises concerns. Spinning waste exceeds that of other processes, with only a fraction being recycled, while the majority is sold locally.

Fabric manufacturing: The textile and clothing industry primarily centers on the production of knitted and woven textiles, which are essential for making garments. On average, crafting 100 kg of fabric necessitates approximately 110.4 kg of yarn, resulting in 2.5 kg of discarded materials and an additional 7.5 kg stored in inventory. Common waste materials include leftover yarn and defective fabrics like unfinished greige

Table 1: Summary of table waste, excess inventory of the textile studied

| Type of manufacturing facility | Annual production capability in kilograms | Final product | All values are in kg calculated for every 100 kg of the final product | | | | |
|---|---|---|---|---|---|---|---|
| | | | Initial Raw Material ,kg | Waste Generated ,kg | Excess in-store, kg | Total Conver-sion Rate, % | Respondent Position |
| S1: Spinning Mills | 5,682,000 | Finished Yarn: Ring and open-end | 122.2 | 36.5 | 24.3 | 78 % | Deputy Manager, Production |
| S2: Spinning Mills | 6,852,000 | Finished Yarn: Carded and combed yarn | | | | | Manager, Quality Assurance |
| S3: Fabric Manufacturing: Knitting | 5,868,789 | Knit Fabric: T-shirt, jersey | 111.3 | 3.2 | 6.8 | | Manager, Knitting |
| S4: Fabric Manufacturing: Weaving | 5,375,432 | Woven Fabric: Woven and denim fabrics, jeans | | | | | Manager, Weaving |
| S5: Wet Processing | 6,800,000 | Finished fabric | 119.2 | 16.2 | 13.6 | | Manager, Dyeing, and Finishing |
| S6: Wet Processing | 5,960,000 | Finished fabric | | | | | Manager, Dyeing, and Finishing |
| S7: Apparel Manufacturing: Knit | 4,650,000 | Apparel: T-shirt, jersey, polo shirts | 159.2 | 11.2 | 8.2 | | Production Assistant General Manager |
| S8: Apparel Manufacturing: Woven | 4,570,942 | Apparel: Denim Pants, Jeans | | | | | Manager Production |

fabric, fly fabric, and scrap yarn. Interestingly, fabric production incurs the least value loss among all processes, with a loss of 31.4 USD. A significant part of the waste comes from surplus yarn, and the remaining is from substandard fabrics. Unused yarn waste is marketed as 'jhut,' while rejected fabrics are sold at reduced local prices.

Wet Processing: Comprising operations such as dyeing, printing, finishing, and washing, the wet processing stage represents a pivotal component. Within this stage, greige fabric is exposed to an array of chemicals, auxiliary substances, and dyes to attain the intended properties and hues. On average, the conversion of 119.2 kg of greige fabric is required to yield 100 kg of finished fabric, consequently leading to an additional stock of 13.6 kg. Fabric dyeing, in particular, results in an average waste of 16.2 kg per 100 kg, often due to issues like uneven dyeing and fabric imperfections. This waste includes defective colored fabric and surplus finished fabric. In the wet processing sector, the loss amounts to 160.92 USD for every 100 kg of processed fabrics. In brief, wet processing is geared toward enhancing greige fabric's properties and colors but generates notable waste due to dyeing and fabric-related issues, leading to excess inventory and finished fabric waste.

Apparel Manufacturing: As per our data findings, an average of 159.2 kg of finished fabric finds application within the cutting section for every 100 kg of final products. Additionally, there's a dedication of 8.2 kg of final garments marked as surplus inventory, while the process incurs a loss of 11.2 kg of materials. These losses emanate from fabric cuttings in both the cutting and sewing phases, along with the presence of surplus development samples and excess apparel. Material costs significantly contribute to shaping the overall expense structure in the apparel industry. It's a common industry norm to produce an extra 5–15% of materials to account for potential deficiencies, especially concerning quality concerns in export orders. Furthermore, the magnitude of discarded cut fabric is notably substantial. Our investigation reveals a total shortfall of around 77.21 USD for every 100 kg of clothing manufactured in production facilities. It's crucial to emphasize that roughly 32.64 USD of these deficits result from surplus inventory, with the remaining 44.57 USD linked to the disposal of cut fabric and rejected garments.

The inquiry reveals a substantial clandestine marketplace known as the "stock lot," specializing in surplus inventory apparel and "jhoot." This market deals with both reconditioned and newly crafted garments, often discreetly acquired from garment manufacturers. Local regulations are in place to safeguard the domestic market by prohibiting the sale of excess inventory clothing or fabric produced under a duty-free bonded warehouse license. Stock lot items are traded based on weight, with their pricing varying according to product categories and seasonal trends.

Cut-fabric waste comprises small fabric remnants, typically measuring between 2 to 125 mm. High-quality small fabric scraps are meticulously sorted and processed to create "garment fiber," a pivotal element in the production of recycled-content apparel. Lower-quality cut-fabric waste is shredded and repurposed for various applications, including cushion fillings, mattresses, and upholstery. The cost of cut-fabric waste can vary from approximately USD 0.16 to USD 0.39/kg. In contrast, recycled cotton fiber is valued at around USD 0.45/kg, significantly less expensive than regular cotton fiber. Furthermore, "cut-fabric panels" of diverse sizes are generated during apparel production. Medium-sized panels are transformed into smaller-sized clothing, while larger panels serve purposes such as boutique shop items, bag production, and the creation of cushion and quilt covers, contributing to local garment manufacturing. This recycling process effectively transforms jhoot waste into value-added products.

### 3.2 Implementing Circular approaches for Recycling Pre- and Post-Consumer Textile Waste to support Sustainable Development Goals.

In 2022-2023 period, Bangladesh approximately experienced a 5.6% increase in domestic cotton bale consumption, reaching 9.31 million bales (*The Daily Star*, *2023*). This coincides with major global brands like H&M, Tommy Hilfiger, GAP Inc., Zara, VF Corporation, Hugo Boss, and Ralph Lauren pledging to shift to recycled fibers by 2026 (Harnessing MMF Potential Vital for Bangladesh Textile and Apparel Industry, 2023). This transition offers Bangladesh a valuable opportunity to enhance its production of man-made fibers and strengthen sustainability initiatives. The textile sector plays a substantial part in environmental harm and its impact on climate change. To illustrate, textile waste takes up 5% of landfill space, and the procedures related to textile treatment account for a considerable 20% of freshwater pollution. This underscores the critical need for the adoption of circular economy principles, where recycling is a pivotal and indispensable element. Annually, Bangladesh generates approximately 400,000 tonnes of pre-consumer textile waste, with only 5% being recycled locally (*The Business Standard, 2023*). The export of post-industrial textile waste, known as "Jhoot," has been on the rise, creating a Tk 20 billion market (*The Story of Waste Fabric (Jhoot)*, 2020). Despite limited official data on garment manufacturing by-products, records indicate Jhoot exports reached US$64.95 million in FY 2018-19. Bangladesh is home to about 20 recycled fiber factories with a combined capacity of 2,400,000 tonnes, primarily using garment waste as their raw material source (fibre2fashion, 2023). However, the country faces significant challenges, including low local recycling rates (5%), incineration and landfilling of 35% of textile waste, and the export of 60% at higher costs (Juanga-Labayen et al., 2022). This highlights the urgent need to boost domestic recycling efforts and improve textile waste management in the nation. Figure 2 illustrates a recommended closed-loop system aimed at recycling both pre and post-consumer textile waste. This strategy aligns with Sustainable Development Goal 12, fostering responsible production and consumption, reducing strain on energy and resource-limited economies. Additionally, it facilitates economic growth and employment opportunities through the implementation of these circular approaches.

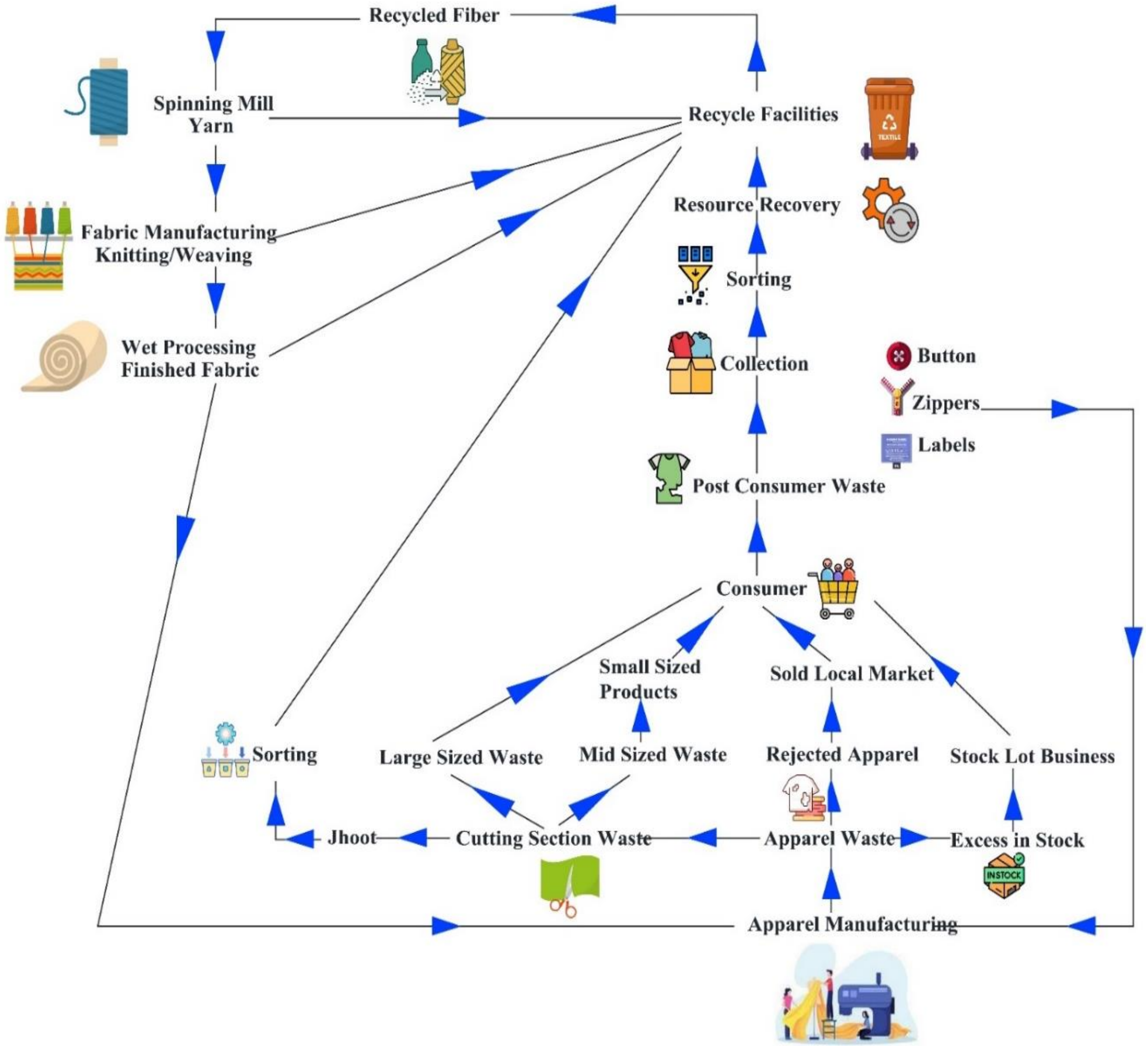


Figure 2: Circular Economy model for pre and post-consumer textile waste in Bangladesh

## 3.3 Assessing Textile Industry Wastewater and Adopting Circular Methods for Resource Reclamation

### 3.3.1 Assessment of Textile Wastewater Quality parameters

In our examination of textiles, we observed that the treated wastewater aligns with the Department of Environment of Bangladesh's discharge standards outlined in ECR 2023 (Bangladesh, 2023). Nevertheless, the BOD and COD discharge limits exceeded the maximum allowable values. These textiles primarily employed two types of effluent treatment plants: physiochemical and biological. Generally, our research indicated that denim manufacturing has a more pronounced water pollution footprint compared to knitwear production. Wet processing, which constitutes around 80% of water usage in fabric production, encompasses processes like de-sizing, scouring, bleaching, mercerization, and dyeing. These processes generate wastewater with heightened temperatures and dissolved salts. Table 2 displays the water quality parameters of untreated and treated wastewater from the examined textile facilities.

Table 2: Water quality parameters of the five textiles

| Water Quality Parameters | | T1 : Yarn Dyeing | T2: Denim | T3: Denim | T4: Knitwear | T5: Knitwear | ECR 2023 |
|---|---|---|---|---|---|---|---|
| $p^H$ | BT | 10.3 ± 0.02 | 9.6 ± 0.03 | 10.2 ± 0.03 | 11 ± 0.01 | 10 ± 0.03 | |
| | AT | 7.6 ± 0.03 | 7.2 ± 0.02 | 7.5 ± 0.02 | 7.85 ± 0.01 | 8.36 ± 0.02 | 6-9 |
| $BOD_5$ (mg/l) | BT | 285 ± 14.42 | 520 ± 6.65 | 631 ± 6.65 | 329 ± 9.07 | 298 ± 14.57 | |
| | AT | 58 ± 5.60 | 42.2 ± 4.16 | 62.2 ± 4.16 | 49 ± 7.67 | 53 ± 9.70 | 30 |
| COD (mg/l) | BT | 1344 ± 25.65 | 712 ± 16.78 | 819 ± 16.78 | 1422 ± 20.22 | 973 ± 7.22 | |
| | AT | 540 ± 11.93 | 62 ± 6.60 | 82.2 ± 6.60 | 277 ± 6.55 | 113 ± 3.22 | 200 |
| TDS (mg/l) | BT | 675 ± 31.41 | 3270 ± 26.68 | 3852 ± 26.68 | 2573 ± 32.14 | 2775 ± 24.33 | |
| | AT | 353 ± 22.71 | 1556 ± 31.29 | 1996 ± 31.29 | 1657 ± 32.22 | 1976 ± 34.72 | 2100 |
| TSS (mg/l) | BT | 370 ± 17.68 | 350 ± 6.50 | 620 ± 6.50 | 323 ± 11.72 | 398 ± 7.03 | |
| | AT | 160 ± 10.21 | 25 ± 7.23 | 28 ± 7.23 | 82 ± 4.04 | 89 ± 3.60 | 100 |
| Color (Pt-Co) | BT | 176 ± 5.00 | 760 ± 6.00 | 810 ± 8.00 | 544 ± 11.72 | 612 ± 7.03 | |
| | AT | 67 ± 4.00 | 138 ± 7.00 | 162 ± 7.00 | 162 ± 4.04 | 192 ± 3.60 | 150 |
| Hardness (mg/l) | BT | 220 ± 12.00 | 520 ± 6.50 | 632 ± 6.50 | 513 ± 11.72 | 592 ± 7.03 | |
| | AT | 140 ± 10.00 | 438 ± 7.23 | 462 ± 7.23 | 439 ± 4.04 | 487 ± 3.60 | - |
| Temp (°C) | BT | 46 ± 3.00 | 46 ± 5.00 | 45 ± 5.00 | 47 ± 6.00 | 48 ± 3.00 | |
| | AT | 38 ± 4.00 | 35 ± 2.00 | 39 ± 2.00 | 38 ± 4.04 | 40 ± 2.00 | - |
| $Cl^-$ (mg/l) | BT | 414 ± 12.00 | 482 ± 15.00 | 536 ± 15.00 | 439 ± 11.72 | 514 ± 7.03 | |
| | AT | 210 ± 10.21 | 238 ± 7.00 | 313 ± 7.00 | 262 ± 4.04 | 296 ± 3.60 | 600 |
| $SO_4^{2-}$ (mg/l) | BT | 279 ± 17.68 | 465 ± 6.50 | 482 ± 6.50 | 469 ± 11.72 | 498 ± 7.03 | |
| | AT | 123 ± 10.21 | 242 ± 7.23 | 293 ± 7.23 | 285 ± 4.04 | 293 ± 3.60 | 5 |

BT: Before Treatment AT: After Treatment

### 3.3.2 Resource Recovery from Textile Wastewater

The initial focus of the wastewater reuse feasibility assessment was on water sourced from the Denim facility's ETP outlet and process water originating from its groundwater. The demim manufactuirng textile (T3) was also recovering caustic soda, used in mercerization process. Mercerization, a pivotal step in cotton textile manufacturing, employs caustic soda (NaOH) to enhance fiber strength, sheen, and dye affinity. To remove excess caustic, the mercerization process is followed by a comprehensive hot water rinse, resulting in effluent characterized by high temperature and extreme alkalinity (60–70 g/L NaOH), along with various organic and inorganic contaminants. Recovering caustic soda from this wastewater yields significant advantages (*Cleaner Production Case Study*, 2021). Caustic soda is a costly chemical, with typical prices ranging from $300 to $900 per tonne of 100% solid caustic, contingent on manufacturing variables. Intercepting caustic soda before it reaches the drain and wastewater treatment plant translates to substantial cost savings. When caustic soda enters the wastewater treatment plant, it elevates the pH of the wastewater, complicating the treatment process.

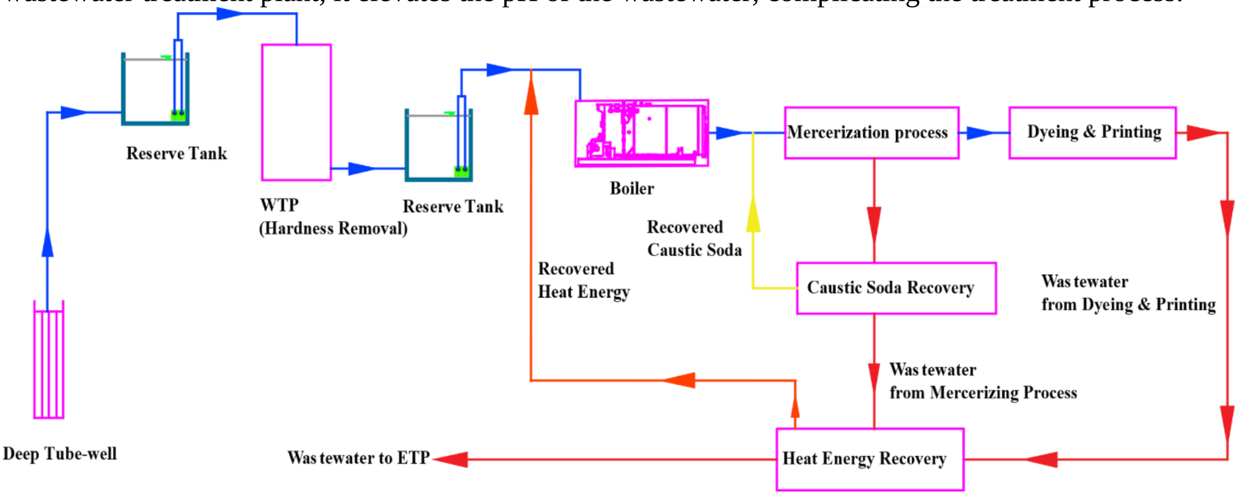


Figure 3: Circular approches for recovering caustic soda and thermal energy from textile wastewater

Therefore, neutralizing caustic soda before it enters the wastewater conserves caustic soda, reduces acid consumption for neutralization, decreases total dissolved solids and BOD levels, and diminishes the plant's carbon footprint (Guha & Rahman, 2014). This not only saves costs but also contributes to reduced wastewater treatment volumes. Furthermore, the raw wastewater discharged during wet processing features a high-temperature range of 42 to 50 degrees (Guha & Rahman, 2014). This surplus energy can be harnessed and directed to a boiler, thus resulting in an overall reduction in energy consumption. Thermal energy can be recovered from the both the treated and untreated wastewater, and pre-heat the groudnwater entering the boiler. This, in turn, aids in preserving natural resources and aligning with the pursuit of sustainable development goals (Australia, 2022). Integrating heat exchangers for harnessing thermal energy from textile wastewater presents a novel opportunity to conserve resources and address Bangladesh's energy crisis. This initiative, in turn, will contribute to minimizing the reliance on natural gas consumption. Figure 3 illustrates a proposed resource recovery processes from textile wastewater through circular methods.
The water samples from Denim manufacturing textile (T3) underwent testing for eight distinct parameters, as outlined in Table 3. Furthermore, the research involved evaluating the fabric quality of denim samples, and presenting a comparison with North American and European brands that source products from the Bangladeshi denim industry. The table also highlights the distinctions between denim samples manufactured and washed with virgin caustic soda and 100% treated groundwater and those manuctured and washed with treated wastewater and recovered casutic soda..

Table 3: Testing parameters for denim samples and a comparison with the requirements of two leading brands.

| Parameter | Source of Water | | Reuse Standard for denim | Test | Stand-ard Meth-od | Dyed and Washed Samples of Denim | | Brand Requirement | |
|---|---|---|---|---|---|---|---|---|---|
| | Treated Ground water | Outlet of ETP | | | | Treated Ground water | Recycl-ed water from ETP | North American Brand | European Brand |
| $p^H$ | 6.3 | 7.2 | 6.5-8.5 | Color Fastness to Rubbing (Dry) | ISO-105X12 | 4 | 4.5-5.0 | 3.50 | 2.0-3.0 |
| COD (mg/l) | 12 | 62 | 60 | | | | | | |
| BOD (mg/l) | 0.9 | 42 | 10 | | | | | | |
| TDS (mg/l) | 372 | 1556 | - | Color Fastness to Rubbing (Wet) | ISO-105X12 | 3.5 -4.0 | 4.5 | 2 | - |
| TSS (mg/l) | 12 | 25 | 30 | | | | | | |
| Hardness (mg/l) | 209 | 438 | 450 | | | | | | |
| $Cl^-$ (mg/l) | 29 | 238 | 250 | Tear Strength | ISO-13937-2 | Warp= 29.82 N Weft= 15.82 N | Warp= 28.36 N Weft= 14.62 N | As required by the brands | Greater than 15.0 |
| $SO_4^{2-}$ (mg/l) | 2.98 | 242 | 250 | | | | | | |

N: Newtons

Figure 5: Denim jeans manufactured and washed using virgin caustic soda and treated groundwater

Figure 6: Denim jeans manufactured and washed using recovered caustic soda and treated wastewater

Notably, both sets of samples surpassed the standards established by European and North American brands in terms of color fastness to the rubbing (dry) test. The positive outcome of the fabric quality tests, confirming that denim samples washed and dyed using 100% treated groundwater and recycled wastewater meet the requirements of major brands sourcing products from Bangladesh, opens up an opportunity to expand the use of recycled wastewater in production processes. This offers the potential to significantly reduce reliance on groundwater extraction and limit the volume of wastewater discharged into nearby government-maintained channels.

## 4. CONCLUSIONS

Promoting a circular approach to managing textile material waste and wastewater, involving both pre- and post-consumer phases, provides significant advantages and guarantees the enduring sustainability of Bangladesh's textile sector. This research findings includes,

- Material utilization inefficiencies in textile production pose significant challenges, with 78% of materials employed resulting in 512 kg of materials to manufacture 400 kg of end products.
- The apparel industry norm of producing an additional 5–15% of materials to address potential deficiencies and the substantial discard of cut fabric contributes to a shortfall of around 77.21 USD for every 100 kg of clothing manufactured.
- Despite compliance with wastewater discharge standards, textile processes show excess BOD and COD levels, necessitating effective treatment strategies.
- The mercerization process in cotton textile manufacturing generates effluent with high alkalinity, emphasizing the need for effective neutralization to conserve resources and reduce environmental impact.
- Efforts to neutralize caustic soda pre-discharge can save costs, reduce wastewater treatment volumes, and minimize the carbon footprint, while also harnessing surplus thermal energy from wastewater for energy conservation.
- The positive results from quality tests conducted on denim samples washed and dyed using treated groundwater, recycled wastewater, and caustic soda present a chance to broaden the application of recycled wastewater in manufacturing. This aligns with sustainable development objectives and decreases dependency on natural resources.

Therefore, through the recycling of textile waste materials, there is a potential reduction in cotton imports, ultimately lessening the overall water-intensive cotton production. This initiative also introduces a new sector capable of generating revenue and employment opportunities, contrasting with the current practice of landfilling or exporting these valuable materials. Decreasing landfill use contributes to methane emission reduction. Moreover, the recovery of caustic soda and reutilization of treated wastewater conserves essential resources like fresh groundwater, reduding pressure on aquifers. Additionally, recycling wastewater in the wet processing stage prevents water body contamination and reduces the need for groundwater extraction, leading to energy savings and subsequent reductions in carbon dioxide emissions. In summary, embracing circular approaches to manage textile waste can bolster resource-limited economies like Bangladesh in the long term while supporting Sustainable Development Goals 6 (clean water and sanitation) and 12 (responsible production and consumption).

## ACKNOWLEDGMENTS

The authors express their gratitude to the field assistants for their valuable assistance. Furthermore, the authors extend their appreciation to the textile industries for granting permission to utilize their laboratory facilities.

## REFERENCES

Australia, W. E. (2022). Revitalizing Resources: Promoting Caustic Soda (NaOH) Recovery in the Textile Industry. https://watermanaustralia.com/recovery-of-caustic-soda-naoh-in-textile-industry/

Bangladesh, R. M. G. (2023, March 21). Bangladesh sets new standards for textile wastewater discharge. https://rmgbd.net/2023/03/bangladesh-sets-new-standards-for-textile-wastewater-discharge/

Cao, H., Cobb, K., Yatvitskiy, M., Wolfe, M., & Shen, H. (2022). Textile and Product Development from End-of-Use Cotton Apparel: A Study to Reclaim Value from Waste. Sustainability, 14(14), 8553. https://doi.org/10.3390/su14148553

Cleaner Production Case Study: Installation of Caustic Recovery Plant Envoy Textiles Limited. (2021). https://policycommons.net/artifacts/1805911/cleaner-production-case-study/2538907/

fibre2fashion, 2023. (n.d.). Bangladesh's garment exports up 12.17% to $35 bn in July-Mar 2023. Retrieved October 24, 2023, from http://www.fibre2fashion.com/news/apparel-news/bangladesh-s-garment-exports-up-12-17-to-35-bn-in-july-mar-2023--286774-newsdetails.htm

Guha, A., & Rahman, M. (2014, August 16). AN ECO FRIENDLY TEXTILE TECHNIQUE: POLLUTION REDUCTION AND WATER SAVING BY REUSING MERCERIZATION EFFLUENT.

Gulfam-E-Jannat, S., Golui, D., Islam, S., Saha, B., Rahman, S. M., Bezbaruah, A. N., & Iskander, S. Md. (2023). Industrial Water Demand and Wastewater Generation: Challenges for Bangladesh's Water Industry. ACS ES&T Water, 3(6), 1515–1526. https://doi.org/10.1021/acsestwater.3c00023

Harnessing MMF potential vital for Bangladesh textile and apparel industry. (2023, September 17). In Textile News, Apparel News, RMG News, Fashion Trends. https://textiletoday.com.bd/harnessing-mmf-potential-vital-for-bangladesh-textile-and-apparel-industry

Juanga-Labayen, J. P., Labayen, I. V., & Yuan, Q. (2022). A Review on Textile Recycling Practices and Challenges. Textiles, 2(1), 174–188. https://doi.org/10.3390/textiles2010010

Koszewska, M. (2019). Circular economy in textiles and fashion—The role of a consumer. In Circular Economy in Textiles and Apparel (pp. 183–206). Elsevier. https://doi.org/10.1016/B978-0-08-102630-4.00009-1

Miah, Md. B., Haque, Md. S., Khaleque, Md. A., & Santos, R. M. (2023). Sludge Management in the Textile Industries of Bangladesh: An Industrial Survey of the Impact of the 2015 Standards and Guidelines. Water, 15(10), 1901. https://doi.org/10.3390/w15101901

Moazzem, S., Wang, L., Daver, F., & Crossin, E. (2021). Environmental impact of discarded apparel landfilling and recycling. Resources, Conservation and Recycling, 166, 105338. https://doi.org/10.1016/j.resconrec.2020.105338

Moshfika, M., Biswas, S., & Mondal, M. S. (2022). Assessing Groundwater Level Declination in Dhaka City and Identifying Adaptation Options for Sustainable Water Supply. Sustainability, 14(3), 1518. https://doi.org/10.3390/su14031518

Patnaik, S., & Tshifularo, C. A. (2021). Management of wastes in garment manufacturing. In Waste Management in the Fashion and Textile Industries (pp. 83–97). Elsevier. https://doi.org/10.1016/B978-0-12-818758-6.00004-1

Rahman, M. M. (2016). INVESTIGATION OF FABRIC WASTAGES IN KNIT T-SHIRT MANUFACTURING INDUSTRY IN BANGLADESH. International Journal of Research in Engineering and Technology, 05(10), 212.

Ranganathan, K., Karunagaran, K., & Sharma, D. C. (2007). Recycling of wastewaters of textile dyeing industries using advanced treatment technology and cost analysis—Case studies. Resources, Conservation and Recycling, 50(3), 306–318. https://doi.org/10.1016/j.resconrec.2006.06.004

Shahajada Mia & Masrufa Akter. (2019). Ready-Made Garments Sector of Bangladesh: Its Growth, Contribution and Challenges. Economics World, 7(1). https://doi.org/10.17265/2328-7144/2019.01.004

Singh, J., & Ordoñez, I. (2016). Resource recovery from post-consumer waste: Important lessons for the upcoming circular economy. Journal of Cleaner Production, 134, 342–353. https://doi.org/10.1016/j.jclepro.2015.12.020

The Business Standard , 2023. (n.d.). Retrieved October 24, 2023, from https://www.tbsnews.net/economy/rmg/experts-adopting-strategy-upstream-circularity-apparel-industry-694118

The Daily Star, 2023. (n.d.). Retrieved October 24, 2023, from https://www.thedailystar.net/business/economy/news/cotton-consumption-rebound-3342961

The story of waste fabric (Jhoot): Positioning Bangladesh. (2020, March 24). Textile News, Apparel News, RMG News, Fashion Trends. https://textiletoday.com.bd/the-story-of-waste-fabric-jhoot-positioning-bangladesh

Waste to fashion. (2022, January 20). Textile News, Apparel News, RMG News, Fashion Trends. https://textiletoday.com.bd/waste-to-fashion