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SUSTAINABLE MATERIAL WASTE MANAGEMENT PRACTICES IN THE TEXTILE AND APPAREL SECTOR: A CASE STUDY IN BANGLADESH

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Article Info:
Received:
2 May 2024
Revised:
31 October 2024
Accepted:
4 December 2024
Available online:
11 January 2025

Keywords:
Circular approach
Supply chain
Material waste
Recycling
Resource

ABSTRACT

This research extensively evaluated the material waste management practices of thirteen manufacturing facilities in Bangladesh's textile and apparel sector, specifically associated with fast 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 are 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. From this study it was found out that textile production in the country faces material inefficiency, with 78% of materials used leading to a shortfall of 77.21 USD per 100 kg of clothing. It also focuses on the importance of technology driven managerial and comprehensive strategies for sustainability and addressing forthcoming challenges.

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).

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 (Rafiq et al., 2024c). 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 more than 1.1 billion kilograms 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 (Rafiq et al., 2024a) 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

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https://doi.org/10.31025/2611-4135/2025.19464

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 escalation 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 (Akter et al., 2022), emphasizing recycling within the circular economy framework (Haque et al., 2024).

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 15 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. These selected companies varied in size and product categories, as outlined in Table 1. They were primarily located on the 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).

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

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				
			Raw Material Consumed, kg	Material Wasted, kg	Excess Inventory, kg	Total Conversion Rate, %	Respondent Position
S1: SpinningMills	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

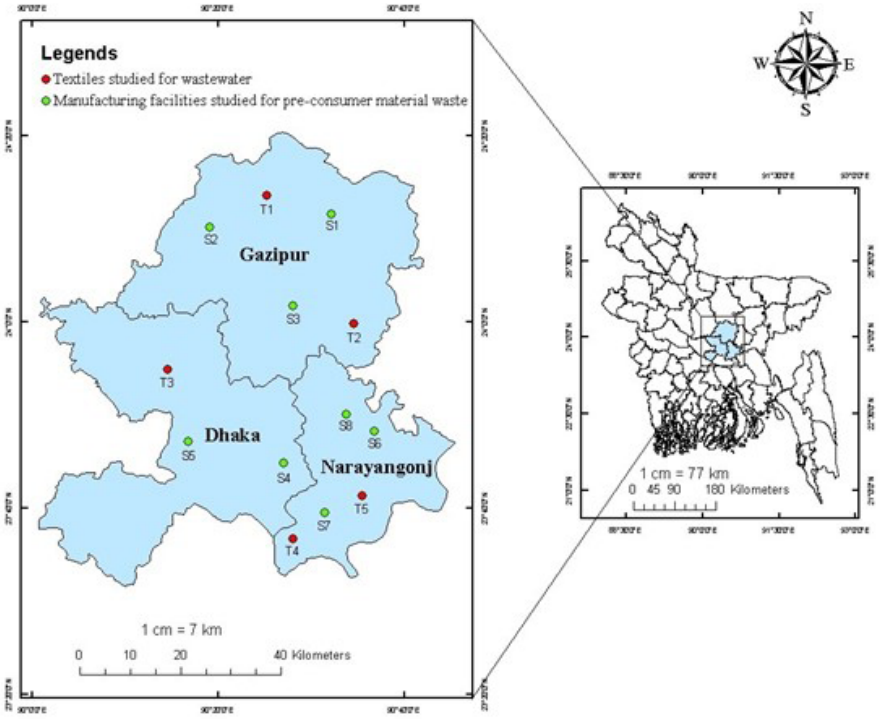

FIGURE 1: Response plot of temperature and sample quantity on % copper recovery.

log over a one-year duration (June 2022- 2023) to derive an average estimate.

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.

3. 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 number 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. Material usage in this context is influenced by the quality of the fiber. On the other hand, wastage consists of the total process loss (which is often unavoidable) and the amount rejected due to quality concerns.

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 greigefabric, fly fabric, and scrap yarn. Interest-

ingly, 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 faulty 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 textile waste due to uneven dyeing caused by fabric defects and issues related to GSM (grams per square meters), 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 market of more than 167 million USD (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). Local stakeholders purchase textile waste from textile businesses informally and then export it at a higher price. This business model thus benefits both parties, which explains why local recycling rates are as low as only 5%.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 (Rafiq et al., 2024b), reducing strain on energy and resource-limited economies. Additionally, it facilitates economic growth and

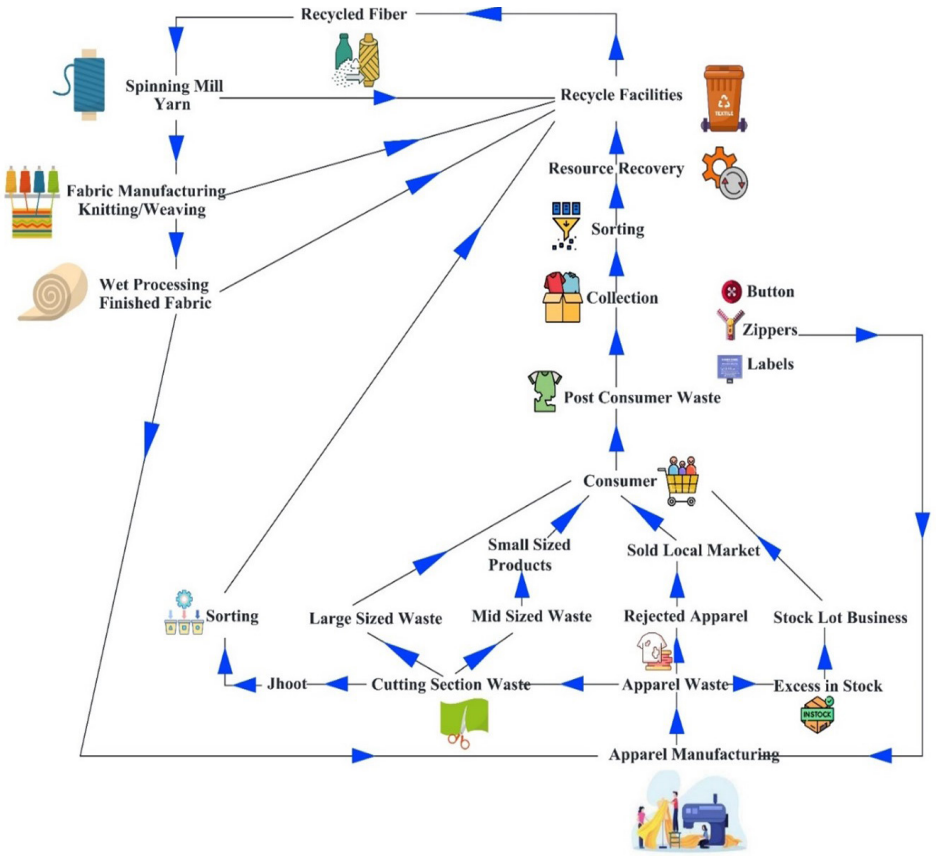

FIGURE 1: Response plot of temperature and sample quantity on % copper recovery.

employment opportunities through the implementation of these circular approaches. This approach is novel and new in context of Bangladesh and requires through study with the stakeholders to overcome the barriers incorpating the circular approach to manage the textile waste.

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.
- This study also suggests a circular economy approach to recycle pre and post textile material waste to foster sustainable development goals in a resource challenged economy.

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. In summary, embracing circular approaches to manage textile waste can bolster resource-limited economies like Bangladesh in the long term while supporting Sustainable Development Goal 12 (responsible production and consumption).

ACKNOWLEDGEMENTS

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.

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