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Waste Management System of the Textile Industry and Possible Effective Solutions to Mitigate Waste

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ABSTRACT

The negative impacts of textile waste on ecosystems and human health have made it a serious environmental concern. To reduce environmental impacts and promote sustainable practices, the textile manufacturing sector generates substantial volumes of solid and effluent waste, necessitating prompt and efficient treatment solutions. Every step of the supply chain, from spinning to clothing production, generates a sizable amount of textile waste annually in Bangladesh. The present state of waste management in Bangladesh's textile and apparel sector is examined in this article, along with the main obstacles to efficient waste management. Biological Effluent Treatment Plants (ETPs) are the most popular and effective treatment method in the textile industry. They perform better than other types of ETPs in terms of sludge management, chemical and labor expenses, and removal efficiency. In addition, this study provides a number of workable and sustainable ways to lessen the production of industrial waste and investigates new prospects in the recycling of textile waste and waste-based business partnerships.

INTRODUCTION

With over 83 percent of Bangladesh's total export revenue coming from the textile and clothing sector, the sector is a vital part of the country's economy. The production of ready-made garments (RMG) on a huge scale has made Bangladesh a worldwide manufacturing hub (Rahman & Chowdhury, 2020). There is a substantial environmental cost associated with this accomplishment, though. The textile and garment business is one of the most significant producers of waste, both liquid and solid, among all industrial sectors. Due to ineffective waste management techniques and the quick development of industry, textile waste is now a major issue for resource efficiency, environmental sustainability, and long-term economic growth (Gupta *et al.,* 2022). The textile industry generates waste at several points during the production process, including spinning, weaving, dyeing, finishing, and clothing manufacturing. Various wastes are produced at each stage, such as sludge from effluent treatment plants, fabric cuts, discarded clothing, lint, and broken yarn. According to Chakraborty *et al.* (2025), this trash buildup not only damages the ecosystem around it but also results in large losses of energy, raw materials, and potential income. In the textile business, waste management is mostly dependent on how advanced technology is and how environmentally conscious industry participants are. Many of the waste management systems in Bangladesh are out-of-date or badly maintained. While some firms lack effective Effluent Treatment Plants (ETPs), the majority of factories have minimal capabilities for recycling and waste segregation. Public health and aquatic ecosystems are seriously threatened when untreated wastewater is released into neighboring rivers due to defective or nonexistent ETPs (Nurullah *et al.*, 2025). As a result, improving waste management procedures in the textile industry is now crucial to preserving the environment and promoting long-term industrial development. The 3Rs Reduce, Reuse, and Recycle and the adoption of cleaner industrial technology are key components of modern waste management. Reduction seeks to improve material use and process optimization in order to reduce waste generation at its source. By reusing materials in production processes, reuse prolongs their life cycle, whereas recycling turns waste into useful raw materials for new products (Psarommatis *et al.*, 2025). The textile sector in Bangladesh, regrettably, still uses these ideas sparingly. Small and medium-sized businesses (SMEs) frequently fall behind because to financial, technological, and regulatory limitations, even though major industries have implemented a number of programs to recycle wastewater and fabric scraps. According to Seifali *et al.* (2025), inadequate data and monitoring systems are also a contributing factor in the issue of textile waste management. There is currently a lack of information about the precise amounts and kinds of waste produced across the textile value chain. Without precise data, it is challenging to create policies that work or make the proper technological investments. Inadequate investment in waste management is another consequence of many factory owners prioritizing production efficiency over environmental compliance. Collaboration between government agencies, environmental organizations, and

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industrial players is necessary for a sustainable waste management system (Saputra *et al.*, 2025). Industries must be encouraged to adopt ecologically responsible practices through more aggressive regulation enforcement, financial incentives, and awareness campaigns. Plants that treat wastewater are essential for reducing the negative effects of textile wastewater. According to Deogaonkar-Baride *et al.* (2025), effective ETPs can drastically cut down on chemical pollutants, dyes, and hazardous elements before releasing wastewater into the environment. But in Bangladesh, a large number of ETPs are either not operating properly or are only used for formal inspections. High maintenance expenses, a lack of technical know-how, and inadequate monitoring frequently result in inefficient ETP functioning. Finding the best ETP systems for the local environment and fostering their long-term viability through technological advancement and governmental assistance are therefore crucial. Managing solid waste is a significant challenge in addition to managing liquid waste. Every day, a huge volume of packaging debris, fabric scraps, and faulty clothing gather. Open landfills and unofficial recycling marketplaces are frequent destinations for these products (Hossain *et al.,* 2025). Much of the fabric waste is left unused, even though some of it is recycled to make inferior goods like cleaning cloths or mattress stuffing. When paired with appropriate waste segregation and value chain cooperation, effective recycling systems have the potential to turn this obstacle into a business opportunity. According to Nademi and Kalmarzi (2025), recycling contributes to the circular economy by creating jobs and extra revenue in addition to easing environmental pressure. In order for the textile industry to be sustainable, economic success must be combined with social and environmental responsibility in an integrated manner.

In addition to lowering manufacturing costs and improving brand reputation in international markets, efficient waste management can increase resource efficiency (Oyelakin *et al.,* 2025). As the world's focus on eco-friendly production and sustainable design increases, Bangladesh needs to improve its waste management system to keep its edge in the global textile industry. It is necessary to identify the main obstacles, assess current waste treatment technologies, and suggest workable alternatives in order to develop a sustainable waste management framework (Bright *et al.*, 2025). Implementing cutting-edge ETP systems, funding recycling facilities, upholding environmental laws, and offering industry experts capacity-building initiatives are among these solutions. To achieve long-term environmental sustainability, stakeholders must be encouraged to collaborate, innovate, and do research. The textile sector in Bangladesh has both potential and challenges when it comes to efficient waste management. One must overlook the sector's ecological impact, even while it creates jobs and economic growth (Zada *et al.,* 2025). The industry needs to transition to sophisticated, eco-friendly waste management solutions in order to secure a sustainable future. By putting the appropriate laws, tools, and education initiatives into place, waste may be reduced and new opportunities for sustainable development and worldwide competitiveness can be opened up. The path to a more sustainable and environmentally friendly textile sector in Bangladesh can be paved by implementing a thorough and organized waste management system that turns textile waste from a nuisance to a useful resource.

LITERATURE REVIEW

The textile and apparel industry of Bangladesh has grown into one of the largest contributors to the global garment supply chain, generating billions in export earnings each year. However, this rapid industrial expansion has also led to large-scale production of textile waste, both solid and liquid, which has become one of the country's most pressing environmental challenges (Siddikey *et al.,* 2025). The industry consumes millions of tons of textile fibers annually, yet only a tiny portion is reused or recycled, while the majority ends up in landfills. This imbalance between production and recycling underscores the urgent need for an efficient, sustainable waste management system. Textile waste is generated at almost every stage of the production process, beginning from spinning and weaving to dyeing, finishing, and garment manufacturing (Abtew *et al.*, 2025). Each of these stages produces waste in various forms, including fiber, yarn, fabric, and defective apparel. On average, 12–15% of the raw materials used in these stages are lost as waste. The fibers used in Bangladesh's textile sector primarily include cotton, synthetics, and rayon, with most imported from abroad. The continuous use of imported fibers and inefficient production processes increases both the volume of waste and the manufacturing costs. Water consumption is another critical issue within the textile industry. The dyeing and finishing processes require vast amounts of water to color and treat fabrics (Catarino *et al.*, 2025). On average, the ratio of fabric to water is about 1:9, meaning that approximately 72 liters of water are required to finish 1 kilogram of fabric. Without proper treatment, this wastewater carries large amounts of pollutants, dyes, chemicals, salts, and other hazardous substances, severely contaminating local water bodies. If untreated, the amount of polluted water discharged into the environment can be several times that of clean water used, posing serious threats to ecosystems and human health (Okewling *et al.*, 2025). Effluent Treatment Plants (ETPs) are therefore a critical component of waste management in the textile industry. Their primary function is to treat wastewater before it is released into the environment. The efficiency of an ETP depends on its design, operation, and maintenance. ETPs are typically divided into four main treatment levels: preliminary, primary, secondary, and tertiary. Preliminary treatment removes large solids such as rags and grit to prevent equipment damage. Primary treatment focuses on removing suspended solids and organic matter through physical and chemical processes (Faggiano *et al.,* 2025).

Secondary treatment relies on biological methods to eliminate biodegradable substances, while tertiary treatment further purifies the effluent to remove any remaining pollutants. In Bangladesh, three main types of ETP systems are commonly used: biological, chemical, and combined biological-chemical treatment plants (Bresolin *et al.,*2025). Biological treatment plants utilize microorganisms to degrade organic matter. Since textile effluents often lack sufficient microorganisms, they are artificially introduced during setup, with cow dung traditionally serving as a natural source. These systems are effective in controlling biological pollutants but often struggle to obliterate color. Chemical treatment plants, on the other hand, use coagulation and flocculation methods to remove color and suspended solids (Kurniawan *et al.*, 2025). While effective for color removal, these systems cannot adequately reduce biological oxygen demand (BOD) or chemical oxygen demand (COD) to meet national standards. The combined biological and chemical systems are the most effective because they integrate both processes, achieving higher pollutant removal rates and improved compliance with environmental standards. Solid waste management represents another significant challenge for the textile industry. The major sources of solid waste include the spinning, knitting, and garment manufacturing sections. Solid waste consists of fiber residues, fabric cuttings, rejected garments, and packaging materials (Singh *et al.*, 2025). These wastes are typically generated due to fabric defects, incorrect designs, faulty stitching, or measurement errors. Many factories still treat this waste as a byproduct of production, failing to recognize its economic potential. Proper segregation, reuse, and recycling could not only reduce environmental damage but also recover lost value from discarded materials. The garment manufacturing process includes several stages: sample making, cutting, sewing, printing, embroidery, and inspection, all of which generate solid waste. A significant portion of this waste can be repurposed through recycling industries to produce new fabrics or low-value items such as cleaning cloths, pillow fillings, and industrial rags (Abtew *et al.*, 2025). However, the lack of organized waste collection and recycling infrastructure limits the effectiveness of such initiatives. To mitigate this, adopting the zero-waste concept in design and production can help reduce material loss. Zero-waste manufacturing emphasizes efficient pattern-making, fabric optimization, and the reuse of leftover materials to minimizes waste. Textile effluents contain numerous toxic substances that pose serious health and environmental risks (Fouda *et al.*, 2025). Common pollutants include dyes, formaldehyde, surfactants, phthalates, and heavy metals such as lead, cadmium, and chromium. Long-term exposure to these substances can lead to various health issues, including cancer, respiratory diseases, and skin irritation, while also causing damage to aquatic life and soil fertility. Therefore, ensuring that wastewater treatment meets national and international discharge standards is essential. The Government of Bangladesh has established discharge quality standards for large composite textile plants, specifying permissible limits for parameters such as pH, BOD, COD, total suspended solids (TSS), and total dissolved solids (TDS). Meeting these standards requires continuous monitoring, proper ETP operation, and adoption of advanced treatment technologies. From a management perspective, waste in the textile industry should be viewed not merely as an environmental burden but also as a potential resource. The principles of the circular economy and the 3R approach, Reduce, Reuse, and Recycle, offer practical solutions to transform waste into value. Reduction can be achieved by improving production efficiency, using eco-friendly raw materials, and optimizing design processes (Jiang *et al.,* 2025). Reuse and recycling can convert textile waste into secondary raw materials for new products, reducing dependency on virgin fibers and lowering environmental impact. Furthermore, energy recovery from textile waste can contribute to sustainable energy generation, supporting the broader goal of industrial sustainability. Developing an integrated waste management system requires collaboration among manufacturers, policymakers, and environmental authorities (Zhang *et al.*, 2025). It involves proper waste segregation at the source, the adoption of advanced ETP technologies, the establishment of recycling networks, and the enforcement of environmental regulations. Awareness programs and training for factory personnel are equally important to ensure compliance and promote sustainability practices at all operational levels. The textile industry in Bangladesh faces substantial challenges in managing both solid and liquid wastes. However, these challenges also present opportunities for innovation, resource recovery, and environmental improvement. Implementing efficient waste management systems, upgrading ETPs, and adopting circular economy principles can significantly mitigate waste generation and its harmful impacts. A structured and sustainable approach to waste management will not only protect the environment but also enhance the long-term competitiveness and resilience of Bangladesh's textile industry.

Table 1: Effluent characteristics from textile industry

Process	Effluent Composition	Nature of pollution
Sizing	Starch, waxes, Carboxymethyl cellulose (CMC), Polyvinyl alcohol (PVA), wetting agents.	High in BOD, COD
De-sizing	Starch, CMC, PVA, fats, waxes, pectin.	High in BOD, COD, SS, dissolved solids (DS)

Bleaching	Sodium hypochlorite, C12, NaOH, H202, acids, Surfactants, NaSi03, sodium phosphate, short cotton fiber.	High alkalinity, high SS
Mercerizing	Sodium Hydroxide, Cotton wax	High pH, low BOD, high DS
Dyeing	Dye-stuffs urea, reducing agents, oxidizing agents, Acetic acid, detergents, wetting agents.	Strongly colored, high BOD, DS, low SS, heavy Metals,
Printing	Pastes, urea, starches, gums, oils, binders, acids, thickeners, cross-linkers, reducing agents, alkali.	Highly colored, high BOD, oily appearance, SS slightly alkaline, low BOD

Source: AEPA (Australian Environmental Protection Authority, 1998).

Table 2: Toxic substances from textile industry

Toxic Substance	Sources (Dyeing, Printing, and Washing)	Health Effects	Regulations/ Standards
Azo Dyes	Used in dyeing and printing to produce bright colors.	May release carcinogenic aromatic amines upon degradation; long-term exposure linked to cancer and skin irritation.	OEKO-TEX Standard 100 (bans certain azo dyes); REACH.
Formaldehyde	Used in textile finishing (wrinkle-resistant), dyeing processes, and as a preservative.	Causes skin irritation, respiratory issues, and is carcinogenic with prolonged exposure.	OEKO-TEX Standard 100 (limits formaldehyde); REACH.
Phthalates	Used in plastisol inks and as a plasticizer in synthetic fabrics.	Causes endocrine disruption, liver toxicity, and reproductive harm.	REACH (restricts phthalates); OEKO-TEX Standard 100.
Lead	Found in certain dyes, pigments, and finishes.	Causes neurological damage, kidney issues, and cognitive impairment, especially in children.	REACH (limits lead content); OEKO-TEX Standard 100.
Cadmium	Present in yellow and red pigments used for printing.	Leads to liver and kidney toxicity, bone damage, and increased cancer risk.	REACH (limits cadmium); OEKO-TEX Standard 100.
Chromium	Used in dyeing, printing, and leather finishing.	Causes skin irritation, lung disease, and cancer (especially Cr^{6+}).	REACH; OEKO-TEX Standard 100 (limits chromium).
Perfluorochemicals (PFCs)	Used for water- and stain-resistant finishes.	Endocrine disruption, liver damage, bioaccumulation, and persistent environmental pollution.	OEKO-TEX Standard 100 (limits PFCs); REACH.
Brominated Flame Retardants (BFRs)	Applied in textile finishes for fire retardancy.	Causes hormonal disruption, developmental and reproductive toxicity.	OEKO-TEX Standard 100 (limits BFRs); REACH.
Toluene	Used in printing inks and as a solvent.	Affects the central nervous system; causes dizziness, headaches, and liver/kidney damage.	OEKO-TEX Standard 100 (limits solvents); REACH.
Xylene	Used in printing inks and dyeing solvents.	Causes respiratory and skin irritation, CNS effects, liver and kidney damage.	REACH; OEKO-TEX Standard 100 (limits aromatic hydrocarbons).
Acetone	Used as a solvent in printing inks.	Causes eye irritation, dizziness, and neurological issues with prolonged exposure.	OEKO-TEX Standard 100; REACH.
Mercury	Found in dyes, pigments, or washing agents (older products).	Causes neurological and kidney toxicity; developmental delays.	REACH (limits mercury); OEKO-TEX Standard 100.

Vinyl Chloride Monomer	Used in PVC-based inks and coatings.	Carcinogenic (linked to liver cancer); causes respiratory and neurological problems.	REACH; OEKO-TEX Standard 100.
Copper	Present in blue and green pigments.	Causes liver and kidney toxicity, and long-term exposure leads to neurological effects.	OEKO-TEX Standard 100 (limits copper).
Sodium Hypochlorite (Bleach)	Used in washing and whitening textiles.	Causes skin and eye irritation, respiratory issues, and lung tissue damage if inhaled.	OEKO-TEX Standard 100 (limits bleach residues); REACH.
Surfactants (e.g., Alkylphenol Ethoxylates)	Used in detergents for washing textiles.	Causes hormonal disruption, skin irritation, and reproductive effects.	OEKO-TEX Standard 100 (limits surfactants).
Chlorinated Solvents	Used in textile cleaning, printing, and finishing.	Causes liver and kidney damage, CNS effects, and potential carcinogenicity.	REACH; OEKO-TEX Standard 100 (limits toxic solvents).
Ammonia	Used in finishing and washing (softening) processes.	Causes skin and eye irritation, respiratory problems, and lung damage in high concentrations.	OEKO-TEX Standard 100 (limits ammonia levels).

Source: create by author

Table 3: Discharge Quality Standard for Classified Industries - Composite Textile Plant and Large Processing Units

Parameter	**Unit**	**Limit Standard**
Total Suspended Solid (TSS)	mg/L	100
BOD5 20° C	mg/L	150*
COD	mg/L	200
Total Dissolved Solid (TDS)	mg/L	2100
PH	mg/L	6.5-9
Dissolved Oxygen (DO)	mg/L	4.5-8
Electrical Conductivity		1200
Total Dissolved Solids (TDS)	mg/L	2100

** BOD limit of 150 mg/L will be applicable only for physico-chemical processing method.*

Table 4: Wastewater Treatment Levels, Mechanism, and Processes

Treatment level	**Description**	**Process**
Preliminary	Removal of large solids such as rags, sticks, grit and grease that may damage equipment or result in operational problems.	Physical
Primary	Removal of floating and settle able materials such as suspended solids or organic matter.	Physical and chemical
Secondary	Removal of biodegradable organic matter and suspended solids	Biological and chemical
Tertiary/advanced	Removal of residual suspended/Dissolved solids	Physical biological and chemical

Source: create by author

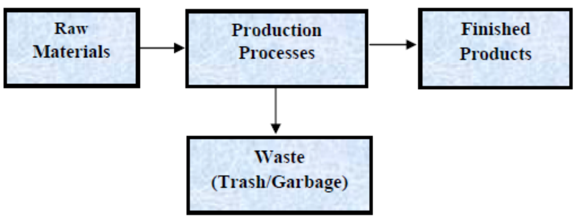

Figure 1: simple production flow

MATERIALS AND METHODS

Research Approach

This study follows a combined laboratory and survey-based research approach to investigate the generation and management of waste in the textile industry. The research is designed to identify the sources of both solid and liquid waste in different stages of textile and apparel production, evaluate the effectiveness of existing waste management practices, and explore potential solutions to mitigate environmental and human health impacts. Additionally, the study examines the challenges that prevent organizations from maintaining effluent treatment plants (ETPs) and implementing environmentally sustainable practices, as well as the economic losses associated with waste generation. Solid and liquid waste sources were observed across key production processes, including spinning, knitting, dyeing, and garment manufacturing. Fluid samples were collected from ETP inlets and outlets for laboratory analysis to assess physical and chemical parameters and determine ETP performance against regulatory standards.

Research Design

Empirical data were collected through direct observation of liquid and solid waste across the production floors of spinning, knitting, dyeing, and garment manufacturing sections. Liquid samples were taken from biological and chemical effluent treatment plants to assess treatment efficiency. Interviews were conducted with production managers to understand solid waste management practices. Secondary data were obtained from published research articles and journals related to waste management in the textile industry.

- Population: The study focuses on individuals associated with the textile industry in Bangladesh.
- Sampling Method: Convenient sampling was employed to select participants who were easily accessible and willing to participate.
- Sample Size: A total of 50 participants were included in the study.
- Sampling Unit: Individuals associated with different operational sections of the textile industry.

Study Area

The study was conducted in Gazipur district, which hosts approximately 2,220 textile factories. Among them, 1,222 are ready-made garment manufacturers, employing around 1.6 million workers. The remaining factories include spinning, dyeing, and washing mills. The Turag and Bangladeshi rivers in this area are heavily affected by industrial waste. The primary study location was GMS Knitting Factory Limited, Kashempur, Gazipur district, where both production processes and ETP operations were observed.

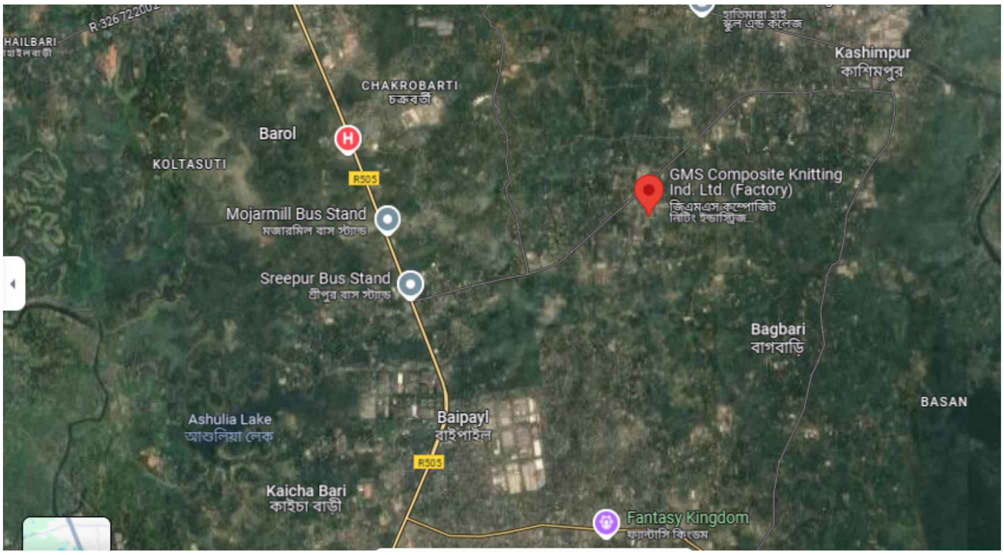

Figure 2: GMS Composite Knitting Ind. Ltd

Laboratory Analysis

Water samples were collected in bottles and diluted with distilled water to measure Biochemical Oxygen Demand (BOD_5). Dissolved oxygen (DO) was measured immediately using a multimeter, and the samples were stored at 20°C for five days. The BOD_5 was calculated by subtracting the final DO from the initial DO. For Chemical Oxygen Demand (COD), 2 mL of each sample was mixed with a potent oxidizing agent and heated in a reactor at 150°C for two hours. After the reaction, the solution was analyzed using a spectrophotometer and compared against a blank to determine COD levels. DO was also measured directly at the sampling site within 5–10 minutes of collection using a calibrated DO meter to ensure accurate readings. To determine the solid content, 100 mL of the water samples was evaporated at 103–105°C to measure Total Solids (TS). Total Suspended Solids (TSS) were calculated by subtracting Total Dissolved Solids (TDS) from TS, while TDS was measured using a multimeter. The pH of the samples was measured using a calibrated pH meter, with the electrode carefully immersed in the solution and air bubbles removed to ensure precise readings.

Sampling

Samples for analysis were collected from two points in the effluent treatment process: the inlet (pre-treatment) and the outlet (post-treatment) of the ETP at GMS Knitting Factory Limited. Before sampling, all bottles were thoroughly cleaned with detergent and rinsed with distilled water to avoid contamination. Water samples were collected in bottles of varying capacities, including 1 litre, 1.5 litres, and 2 litres. Each bottle was carefully labelled to indicate the sampling point and preserved at cool temperatures using ice to maintain sample integrity until laboratory analysis. Photographic documentation of the sampling process was also conducted to ensure proper record-keeping and traceability.

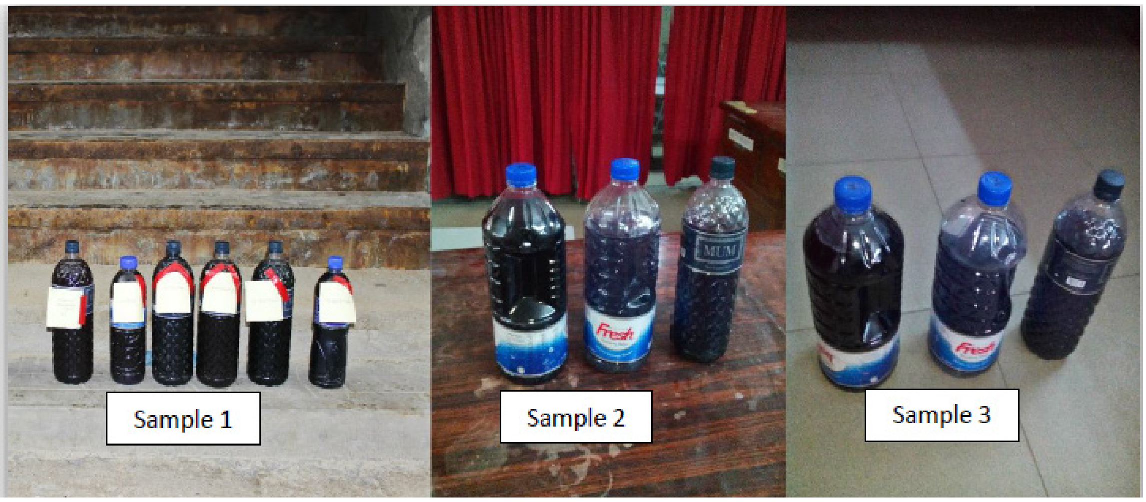

Figure 3: Sample Collection (Self Capture)

Instruments

The required instruments for conducting the experiments are listed below as table. Moreover, some regular lab tools are beaker (150 ml & 250 ml), measuring cylinder (100 ml & 1000 ml), funnel, dropping pipette, filter paper, stirrer etc.

Table 5: Instrument list of water quality parameters analysis in lab.

S/L	Parameter	Unit	Test Instrument	Test Method
1	pH	–	Multimeter	Electrode Method
2	TDS / Conductivity	mg/L	Multimeter	Direct Measurement Method
3	DO	mg/L	Multimeter	Direct Measurement Method
4	Temperature	°C	Glass Thermometers	Direct Measurement
5	TSS	mg/L	Spectrophotometer	Photometric Method
6	Color	Pl-CO	Spectrophotometer	Platinum-Cobalt Standard Method
7	COD	mg/L	Spectrophotometer with COD Reactor	Reactor Digestion Method
8	BOD	mg/L	BOD Incubator	Respiro metric Method

Data Analysis and Performance Assessment

The efficiency of ETPs was calculated using the removal efficiency (RE) formula:

$RE\ (\%) = ((BT - AT)/BT) \times 100$

where BT represents the parameter value before treatment, and AT represents the value after treatment. Frequency distributions for survey responses were calculated as:

$Frequency\ (\%) = (Frequency\ /Population) \times 100$

Collected data were analyzed using Microsoft Excel to generate diagrams, charts, and flowcharts representing current practices, performance of waste treatment systems, and areas for potential improvement.

Research Flow

The overall research methodology can be summarized as a sequential process: selection of factories, observation of present practices, analysis of waste management systems, problem identification, questionnaire and interview surveys for solid waste, collection of liquid waste samples, laboratory analysis, data evaluation, and presentation of results (Figure 4). This systematic approach ensures a comprehensive understanding of the textile industry's waste management practices and identifies effective solutions for waste mitigation.

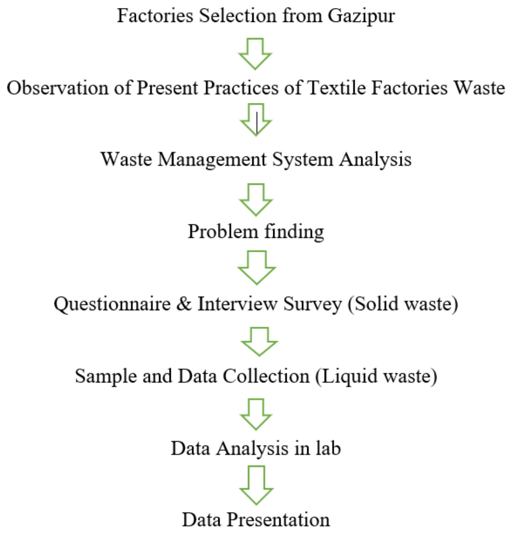

Figure 4: Research Flow

RESULTS AND DISCUSSION

The collected data from GMS Knitting Composite Factory in Gazipur were analyzed to assess existing liquid and solid waste management practices. The findings are presented through tables and charts to compare the performance of biological and bio-chemical effluent treatment plants (ETPs) and to evaluate the factory's solid waste management approach. Effluent from dyeing, washing, and all-over print (AOP) units is treated through two types of ETPs biological and bio-chemical systems. Samples were collected for three consecutive weeks (Sample 1, Sample 2, and Sample 3) to measure key parameters such as BOD, COD, TSS, and TDS. The overall treatment performance was found satisfactory and within acceptable discharge limits, although differences were observed between the two systems. The biological treatment system exhibited higher pollutant removal efficiency compared to the bio-chemical system. The average BOD removal efficiency reached 84%, while COD removal was 83%, about 7% higher than in the bio-chemical method. The TSS removal efficiency also peaked at 81% under biological treatment, indicating effective sedimentation and filtration. Furthermore, TDS removal in the biological system was more than double that of the bio-chemical process, showing its superior performance in meeting discharge standards.

Removal efficiency was calculated using the following formula:

$RE = ((BT - AT)/BT) \times 100$

where BT = Before Treatment Concentration and AT = After Treatment Concentration.

The levels of treated effluents were slightly below the discharge standard (4.5–8 mg/L), indicating limited oxygen availability for aquatic life. However, pH and temperature values were within standard limits, reflecting proper ETP operation. Solid waste generated by the factory, such as yarn cones, fabric scraps, and ETP sludge, is partially recycled, with the remaining portion disposed of through authorized vendors. Despite these ongoing practices, several challenges persist in adequate waste segregation, recycling, and proper utilization of reusable materials (Vanapalli *et al.,* 2021). The existing infrastructure for solid waste management requires improvement to ensure more efficient handling and reduced environmental impacts. To enhance sustainability, the factory needs to integrate Zero Liquid Discharge (ZLD) systems to maximize water reuse and minimizes effluent discharge. Upgrading the effluent treatment plants with hybrid treatment technologies would further improve pollutant removal efficiency and ensure compliance with environmental standards. Implementing the 3R principles Reduce, Reuse, and Recycle can play a vital role in minimizing waste generation at the source and promoting circular economy practices within the factory. In addition, regular training and awareness programs for workers and management staff are essential to ensure proper waste segregation and adherence to sustainable production guidelines (Sharma *et al.,* 2020). Adopting cleaner production technologies, such as low-water dyeing methods and eco-friendly chemicals, can further reduce waste generation throughout the production process. Overall, the findings suggest that biological ETPs perform more effectively than biochemical systems, and that, by adopting advanced treatment technologies and sustainable waste management practices, the textile industry can significantly mitigate its environmental footprint and contribute to long-term ecological balance.

The experimental findings from both Biological and Bio-Chemical Effluent Treatment Plants (ETPs) of GMS Knitting Composite Ltd., Gazipur, revealed significant variations in treatment performance. The Biological ETP demonstrated superior removal efficiency for key wastewater quality parameters BOD, COD, TSS, and TDS compared to the Bio-Chemical ETP. The average removal efficiency (RE%) for BOD, COD, TSS, and TDS

Table 6: Bio-chemical Treatment Plant

Parameter	Unit	Standard	Sample 1 (BT)	Sample 1 (AT)	RE%	Sample 2 (BT)	Sample 2 (AT)	RE%	Sample 3 (BT)	Sample 3 (AT)	RE%	Avg. RE%
BOD	mg/L	<50	158	43	73%	144	36	75%	112	28	75%	74%
COD	mg/L	<200	359	78	68%	410	110	63%	435	132	70%	64%
TSS	mg/L	<150	77	52	32%	175	45	74%	65	45	31%	46%
TDS	mg/L	<2100	1677	1521	9%	1745	1415	19%	1875	1565	17%	15%
DO	mg/L	4.5–8	1.32	5.26	—	1.25	5.10	—	1.15	5.40	—	—
pH	—	6–9	10.40	7.50	—	10.80	7.90	—	11.00	8.10	—	—
Temperature	°C	<35	41.5	32.6	—	42.0	33.0	—	42.5	32.5	—	—

Notes:

- *BT = Before Treatment*
- *AT = After Treatment*
- *RE% = Removal Efficiency*
- *Parameters such as DO, pH, and Temperature were measured but not used to calculate removal efficiency.*

Table 7: Performance Analysis of Biological Effluent Treatment Plant (ETP)

Parameter	Unit	Standard	Sample 1 (BT)	Sample 1 (AT)	RE%	Sample 2 (BT)	Sample 2 (AT)	RE%	Sample 3 (BT)	Sample 3 (AT)	RE%	Avg. RE%
BOD	mg/L	<50	120	29	76%	145	21	86%	287	24	92%	84%
COD	mg/L	<200	410	61	85%	450	78	83%	490	95	81%	83%
TSS	mg/L	<150	145	21	86%	210	52	75%	208	38	82%	81%
TDS	mg/L	<2100	791	640	19%	1200	750	38%	1372	815	41%	32%
DO	mg/L	4.5–8	2.21	6.50	—	2.05	6.80	—	2.35	6.65	—	—
pH	—	6–9	8.90	7.10	—	9.00	7.30	—	9.50	7.10	—	—
Temperature	°C	<35	42.6	33.0	—	41.5	31.0	—	42.0	31.5	—	—

Table 8: Comparison of Removal Efficiency %

ETP Type	Bio-chemical Treatment Plant	Biological Treatment Plant
Parameters	Avg. RE% (Bio-chemical ETP)	Avg. RE% (Biological ETP)
BOD	74%	84%
COD	74%	83%
TSS	46%	81%
TDS	15%	32%

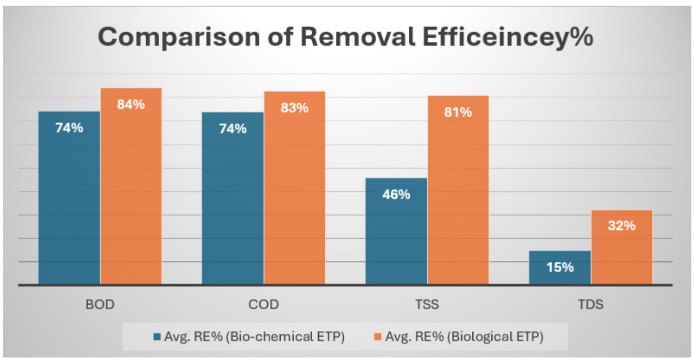

Figure 5: Average removal efficiency of Biochemical and Biological Method

in the Biological ETP was 84%, 83%, 81%, and 32%, respectively, whereas the Bio-Chemical ETP achieved only 74%, 64%, 46%, and 15%, respectively. This result indicates that biological treatment methods are more effective in reducing organic load and suspended solids from textile effluents. The higher performance of the Biological ETP can be attributed to the microbial degradation of organic pollutants, efficient aeration, and stable operation parameters. It can be vividly observed that, to ensure continuous and efficient plant operation while maintaining business profitability, factory owners prefer Biological ETPs. From economic, ecological, and functional perspectives, Biological ETPs outperform other types of treatment systems, making them the most sustainable option for textile wastewater management in Bangladesh. In addition to treatment efficiency, cost analysis is a crucial factor in selecting the most suitable ETP system. The study found that Biological ETPs incur approximately 12 times lower chemical costs compared to Bio-Chemical or Physic-Chemical plants. Generally, the Bio-Chemical treatment process is applied before the biological treatment stage. However, through process modifications and optimization, the operational cost per cubic meter (m^3) of wastewater in the Biological ETP was reduced by nearly 28%, primarily due to lower chemical consumption and lower sludge treatment and disposal costs. According to data provided by GMS Knit Composite Ltd., these operational savings make Biological ETPs not only environmentally sustainable but also economically viable for long-term industrial use. The comparative analysis and cost findings highlight that Biological ETPs play a vital role in achieving sustainable waste management in the textile sector. Their higher efficiency, reduced operational costs, and lower environmental footprint make them a practical, scalable solution for mitigating industrial wastewater pollution in Bangladesh. Adopting efficient biological treatment systems, coupled with waste minimization strategies such as the 3R (Reduce, Reuse, Recycle) and Zero Waste initiatives, can significantly improve environmental performance and support the country's sustainable industrial development goals.

Table 9: Chemical Consumption and Cost Analysis for Biological and Bio-Chemical Effluent Treatment Processes

Process	Peak Flow (m^3/hr)	Chemicals	Dosing Rate (kg/day)	Consumption (kg/m^3)	Price (Tk/kg)	Cost (Tk/m^3)	Total (Tk/m^3)
Biological	65	H_2SO_4 (98%)	150–200	0.10–0.139	8–12	0.83–1.6	1.5–2.0
		Polyelectrolyte	1.5–2	0.001–0.0013	260–300	0.27–0.36	
		Antifoam	Occasional	N/A	200–250	N/A	
		DE colorant	Occasional	N/A	95–100	N/A	
		Nutrient	Occasional	N/A	150–300	N/A	
Bio-Chemical	65	Lime	650–800	0.49–0.61	10–12	4.92–7.32	17–25
		$FeSO_4$	1000–1300	0.75–0.98	14–16	10.6–15.68	
		Polyelectrolyte	2–3	0.0015–0.002	260–280	0.39–0.64	
		HCl	120–150	0.09–0.11	8–12	0.72–1.32	
		Nutrient	Occasional	N/A	150–300	N/A	

From the comparative analysis, it is evident that the Biological ETP requires much lower chemical use per cubic meter of treated wastewater. The total cost for the biological process ranges between Tk 1.5–2.0 per m^3, whereas the Bio-Chemical process incurs a significantly higher cost of Tk 17–25 per m^3. This indicates that the biological treatment process reduces chemical costs by nearly 12 times, primarily by minimizing the use of reagents such as sulfuric acid (H_2SO_4) and polyelectrolytes. In contrast, the Bio-Chemical ETP consumes large quantities of lime and ferrous sulfate ($FeSO_4$), resulting in higher operational expenses and sludge generation. Overall, the Biological ETP not only achieves better pollutant removal efficiency but also offers economic advantages through reduced chemical consumption, sludge handling, and disposal costs, making it a more sustainable and cost-effective wastewater management solution for the textile industry in Bangladesh.

Table 10: Remarkable Sludge Features of Biological and Combined Chemical & Biological ETPs

Parameters	Biological ETP	Combined Chemical & Biological ETP
Sludge Quantity	300–400 g/m^3	2–5 kg/m^3
Sludge Toxicity	Non-toxic	Toxic
Sludge Disposal Problem	Slight	Medium
Sludge Disposal Cost	Very low	High
Sludge Utilization	Fertilizer / Brick	Brick

The table clearly shows that Biological ETPs generate significantly less sludge, which is non-toxic and easier to manage, resulting in lower disposal costs and opportunities for beneficial reuse as fertilizer or in brick production. In contrast, combined chemical and biological treatment produces higher quantities of toxic sludge, which increases disposal challenges and costs.

Table 11: Manpower Cost Comparison for Biological and Bio-Chemical ETPs

Process	Peak Flow (m^3/hr)	No. of Labor	Salary / Month (Tk)	Treatment / Month (m^3)	Cost (Tk/m^3)
Biological	65	9	60,000	46,800	1.28
Bio-Chemical	75	10	80,000	54,000	1.48

The manpower cost analysis indicates that Biological ETPs are slightly more economical compared to Bio-Chemical systems. Although both systems require trained personnel to operate efficiently, the Biological ETP requires fewer labor hours and lower total salary expenses per unit of wastewater treated. The cost per cubic meter of treated wastewater is Tk 1.28 for the Biological ETP, compared to Tk 1.48 for the Biochemical ETP, highlighting the operational cost efficiency of biological treatment. This supports the broader observation that Biological ETPs are more sustainable and cost-effective, not only in chemical consumption and sludge handling but also in labor requirements, making them a preferred solution for textile industries aiming to reduce operational expenses while maintaining high treatment efficiency.

A comprehensive survey was conducted to identify the probable discharge points of Effluent Treatment Plants (ETPs) and their corresponding treatment methods across key textile industrial zones in Dhaka, Gazipur, and Narayanganj districts. The findings, presented in the following table, reveal that biological ETPs are the most widely used treatment systems within Bangladesh's textile sector. This dominance of biological treatment reflects the industry's preference for cost-effective and environmentally friendly wastewater management approaches. However, despite their prevalence, many ETPs face operational inefficiencies, inadequate maintenance, and improper monitoring, which often result in partial treatment and subsequent environmental contamination.

Table 12: List of Textile Factories with ETP Types and Probable Discharge Points

No.	Textile Factory Name	Address	Probable Discharge Point	ETP Type
1	GMS Knitting Composite Factory	Kashimpur, Gazipur	Turag River	Biological ETP
2	GMS Knitting Composite Factory	Kashimpur, Gazipur	Turag River	Bio-Chemical ETP
3	AnonTex Group	Tongi, Gazipur	Turag River	Biological ETP
4	MS Dyeing, Printing & Finishing Ltd.	Fatullah, Narayanganj	Shitalakkha River	Conventional ETP
5	Cotton Club (BD) Ltd.	Kashimpur, Gazipur	Turag River	Biological ETP
6	Esquire Knit Composite Limited	Narayanganj	Shitalakkha River	Biological ETP
7	JK Group (Knit Fabrics & Garments)	Savar	Dhalewshwari River	Biological ETP
8	Keya Knit Composite Ltd.	Konabari, Gazipur	Turag River	Biological ETP
9	Abanti Color Textile Ltd.	Narayanganj	Shitalakkha River	Biological ETP
10	Padma Polycotton Knit Fabrics Ltd.	Tejgaon Industrial Area	Hatirjheel	Biological ETP
11	Echotex Limited	Shafipur, Chandra, Gazipur	Turag River	Bio-Chemical ETP
12	Square Knit Fashion Ltd.	Gazipur	Turag River	Conventional ETP
13	Zaara Textile Composite Ltd.	Kashimpur	Turag River	Conventional ETP
14	Fair Apparels Ltd.	BSCIC I/A, Narayanganj	Shitalakkha River	Physio-Chemical ETP
15	Zaheen Knitwear Limited	Modonpur, Narayanganj	Shitalakkha River	Bio-Chemical ETP

From the data presented, it is evident that Biological ETPs are the most commonly adopted treatment systems in Bangladesh's textile industry, particularly in the Gazipur and Narayanganj districts. These biological systems are favored for their cost-effectiveness and ability to treat the high organic loads typical of textile wastewater. However, a considerable number of biochemical and conventional ETPs are also in operation, suggesting varied technological adaptation across factories. Despite this positive trend, several ETPs still discharge partially treated or untreated effluent into nearby rivers, including the Turag, Shitalakkha, and Dhalewshwari, leading to severe environmental degradation. To ensure an effective waste management system, it is essential to upgrade existing ETPs with advanced technologies, establish regular performance monitoring, and enforce strict compliance with environmental regulations. Additionally, capacity-building programs for ETP operators and the reuse of treated water in production processes can serve as effective, sustainable solutions to mitigate textile waste pollution.

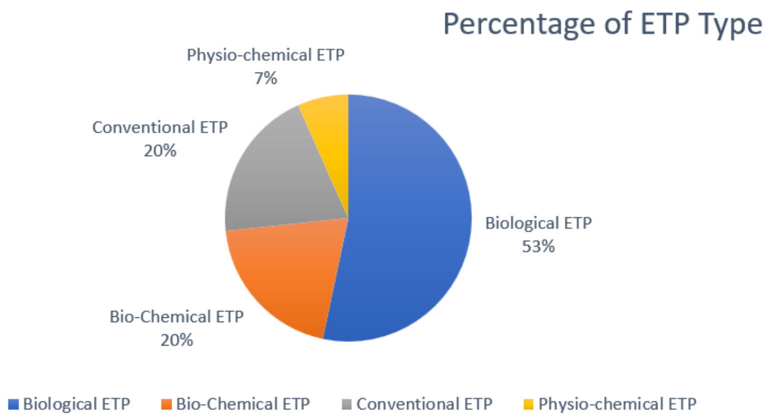

Figure 6: Percentage of ETP Type

In the textile manufacturing process, significant waste is generated at various stages, from spinning to final garment production. The quantity of waste varies depending on the production process, the efficiency of the machinery, and the operational practices used in each section. Among these, the dyeing section accounts for the highest share of waste, approximately 10–12%, mainly due to the extensive use of dyes, chemicals, and water during color fixation and washing. In contrast, the knitting section produces the least waste, accounting for only 2–4% of total production waste. The summarized data presented in Table 12 illustrate the average waste percentage across different sections of textile production. It is observed that the overall waste generation in the textile and apparel manufacturing process averages 29%, indicating substantial raw material loss and potential environmental impact if not properly managed.

Table 13: Total Wastage in Each Section During Manufacturing

Section	Sub-section	Percentage Range of Wastage	Middle of Wastage Range
Spinning	—	4–5%	4.5%
Knitting	—	3–4%	3.5%
Dyeing	—	10–12%	11%
Garments	Cutting	5–7%	6%
	Sewing	3–5%	4%
Total		25–33%	29%

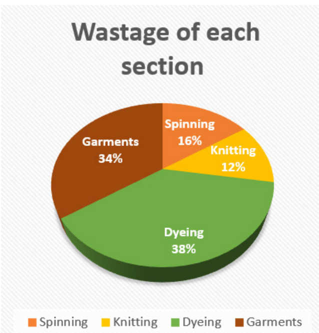

Figure 7: Wastage percentage of each section

The monetary value of a garment depends on various factors such as design, material composition, fabric weight, customer specifications, and payment terms. Common knitwear products in Bangladesh's textile industry include tank tops, T-shirts, polo shirts, jackets, hoodies, shorts, joggers, sweatshirts, and sweatpants. However, during production, a significant portion of the product's value is lost due to material wastage, process inefficiencies, and handling errors at different manufacturing stages. The analysis presented in Table 15 indicates that, on average, 29% of a garment's total value is lost throughout the production process. For example, a tank top with a Free on Board (FOB) value of $1.45 incurs a monetary loss of approximately 50.46 BDT, while a hoodie with an FOB value of $9.50 results in a loss of about 330.60 BDT. This loss not only represents a reduction in profitability for manufacturers but also highlights inefficiencies in resource utilization within the textile production system.

Table 14: Monetary Value Loss of a Garment

Product	Brand	Composition	Weight (GSM)	Price (USD)	Average Percent Loss	Monetary Value Loss (USD)	Monetary Value Loss (৳)
Tank Top	Gekas	100% Cotton Single Jersey	180	$1.45	29%	$0.42	50.46৳
T-shirt	Oakley	95% Cotton, 5% Elastane Single Jersey	160	$1.80	29%	$0.52	62.64৳
Polo Shirt	Gekas	100% Cotton Piquet	240	$4.20	29%	$1.22	146.16৳
Zip Jacket	Gekas	48% Modal, 47% Cotton, 5% Elastane Single Jersey	255	$7.90	29%	$2.29	274.92৳
Hoodie	Lager 157	80% Cotton, 20% Elastane Fleece (Inside Brushed)	320	$9.50	29%	$2.76	330.60৳
Tops	Gekas	95% Cotton, 5% Elastane Single Jersey	200	$2.50	29%	$0.73	87.00৳
Dress	Gekas	95% Cotton, 5% Elastane 4X2 Rib	220	$4.80	29%	$1.39	165.67৳

The findings clearly demonstrate that material wastage leads to a substantial monetary loss, directly impacting profit margins and production efficiency. The losses are more pronounced in high-value products such as jackets, hoodies, and sweatshirts, where higher fabric weight and multiple processing steps increase the risk of waste. To mitigate these financial and material losses, textile manufacturers should implement lean manufacturing techniques, digital cutting optimization, and real-time quality monitoring systems. Reusing fabric scraps, improving inventory management, and training operators to handle materials efficiently can further reduce wastage. Additionally, integrating sustainable design principles such as pattern efficiency, modular design, and circular fashion approaches can minimize raw material consumption and enhance resource recovery (Radu *et al.,* 2025). Solid waste generation is a significant concern in the textile industry, arising primarily from spinning, knitting, and garment manufacturing processes, particularly in the cutting and sewing sections. To assess the current status of solid waste management practices, five key parameters were analyzed based on survey data and presented using descriptive statistics and bar diagram representations. The survey results reveal that most company owners are unaware of proper solid waste management systems and often lack structured waste-handling procedures. However, an encouraging trend has recently emerged, as many manufacturers have begun to recycle waste materials to produce yarn from recycled fibers. According to the survey findings, approximately 60% of garment manufacturers engage in recycling activities, while the remaining waste is either sold to local markets, landfilled, or incinerated.

Table 15: Solid Waste Management Practices Adopted by Textile Factories

Response	Frequency	Percentage
Source Reduction	5	10%
Landfilling	10	20%
Recycling	9	18%
Incineration	3	6%
Sell to Local Markets	20	40%
Others	3	6%

From the data in Table 15, it is evident that selling waste to local markets (40%) is the most common disposal practice, followed by landfilling (20%) and recycling (18%). Although a growing number of industries are adopting recycling practices, a large proportion of waste is still managed through unsustainable methods such as landfilling and incineration, which contribute to soil contamination and air pollution. To ensure a sustainable solid waste management system, the textile industry should prioritize source reduction, segregation at source, and recycling-based circular models. Encouraging waste-to-resource initiatives, such as converting fabric scraps into insulation materials, cleaning cloths, or low-cost apparel, can help minimize landfill dependency (Al-Qodah *et al.,* 2025). Furthermore, the introduction of government-led policies, incentives for recycling units, and training programs for waste handling can significantly enhance the industry's capacity for sustainable solid waste management.

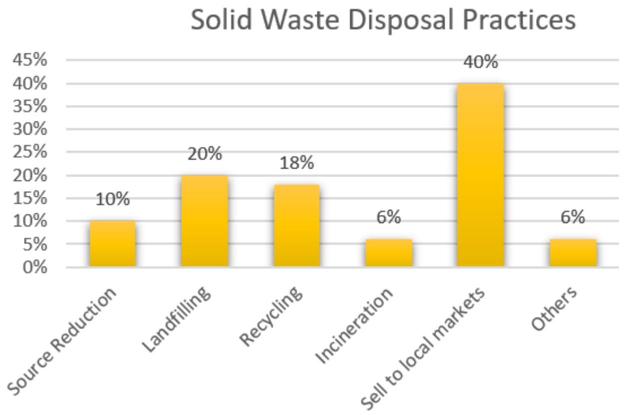

Figure 8: Solid Waste Disposal Practices

Although recycling presents a significant opportunity for sustainable waste management in the textile industry, its effective implementation remains limited due to several operational and structural barriers. Despite the availability of recyclable materials and growing consumer awareness, most factories fail to achieve efficient recycling practices. The survey results reveal that lack of suitable technology and inadequate equipment are the most critical obstacles preventing large-scale recycling within textile manufacturing units.

Table 16: Barriers to Recycling

Response	Frequency	Percentage
Production Cost	4	8%
Lack of Consumer Awareness	6	12%
Lack of Material	3	6%
Lack of Equipment	10	20%
Lack of Law	4	8%
Lack of Technology	20	40%
Lack of Skilled Manpower	3	6%

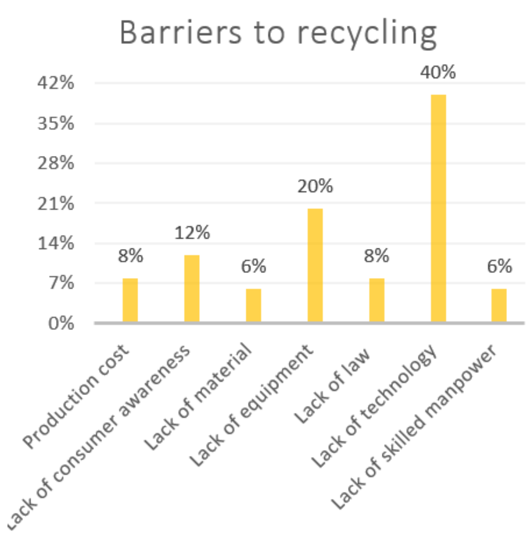

Figure 9: Barriers to recycling process

According to Table 16, lack of technology (40%) emerged as the most significant barrier, followed by lack of equipment (20%) and limited consumer awareness (12%). These findings indicate that many factories still rely on outdated or manual processes that restrict the efficient sorting, processing, and reuse of textile waste. Furthermore, high production costs (8%), absence of strict recycling laws (8%), and a shortage of skilled manpower (6%) also contribute to the poor recycling performance in the industry. To overcome these barriers, it is essential to promote technological innovation in recycling systems, such as automated fiber separation, mechanical and chemical recycling, and digital waste tracking mechanisms. Government and industry associations should collaborate to establish recycling infrastructure, financial incentives, and training programs to build worker competence in waste handling. Additionally, consumer awareness campaigns can strengthen the market demand for recycled textile products, thereby creating a sustainable circular economy within the sector. Although Bangladesh has a large potential market for clothing and a growing segment of consumers for secondhand apparel, the recycling of waste garments remains underutilized across most textile suppliers. A considerable portion of solid waste is not effectively recovered or repurposed. The findings indicate that selling to clothing markets and reusing items in secondhand clothing markets are the two most common recycling methods adopted by factories, accounting for a combined 64% of all recycling practices.

Table 17: Methods of Recycling Waste Garments

Response	Frequency	Percentage
Sell to Clothing Market	15	30%
Recovery from the Waste	7	14%
Reuse (Secondhand Clothing Market)	17	34%
Conversion to New Product	5	10%
Others	6	12%

From Table 17, it is evident that the reuse of garments in secondhand clothing markets (34%) is the most prevalent recycling approach, followed closely by selling QC-rejected items to the clothing market (30%). Together, these two practices highlight a growing informal recycling network in Bangladesh's textile sector. However, conversion to new products (10%) and recovery from waste (14%) are still at a nascent stage, primarily due to technological limitations, low investment in recycling infrastructure, and limited market incentives for upcycled products. To enhance recycling efficiency, textile industries should focus on developing circular textile systems that enable fiber-to-fiber recycling, material recovery, and product redesign. Encouraging partnerships between manufacturers and recycling enterprises can accelerate innovation in fabric regeneration and waste valorization. Moreover, implementing policy support and extended producer responsibility (EPR) can help formalize the recycling process, ensuring that waste garments are transformed into valuable resources rather than being discarded. Solid waste generated from garment factories is recycled into a variety of home textile and utility products, contributing modestly to waste reduction and resource recovery. Common recycled outputs include waste cotton, mattresses, pillows, seat stuffing, and padding materials used in cars, buses, and rickshaws. Among these, Tula represents the highest share (26%), as it is widely reused in both domestic and industrial applications. Padding used in vehicles such as cars, buses, and rickshaws ranks second with 22%, indicating its significant role in recycling activities within the textile waste ecosystem.

Figure 10: Recycling way of the waste garments

From Table 18, it is evident that waste cotton (Tula) and padding materials are the two most dominant recycled products derived from garment waste, together constituting nearly half (48%) of the recycled outputs. These products are mostly manufactured in small-scale cottage industries and local workshops, which use low-cost manual techniques. However, recycling into high-value products such as fiber blends, insulation materials, or nonwoven fabrics remains limited due to technological and infrastructural constraints. The findings indicate that the informal recycling sector plays a key role in waste utilization, but there is significant scope for improvement through the adoption of modern recycling technology, industry research collaboration, and capacity-building programs. Zero waste management aims to eliminate or minimize waste generation throughout the entire production process by optimizing design, production, and operational efficiency. The survey findings indicate that eco-design is perceived as the most effective strategy for achieving zero waste in garment manufacturing, representing 40% of respondents' preferences. Eco-design involves the use of computer-aided design (CAD) systems to optimize fabric utilization during pattern and marker making, ensuring minimal leftover material. Through effective layout planning, this technique significantly reduces cutting waste and improves material efficiency. In addition to eco-design, maintenance and housekeeping (22%) and clean production (16%) are also identified as important strategies to achieve zero waste in textile industries. Proper equipment maintenance, regular cleaning, and process optimization contribute to a more sustainable and organized production environment, reducing unnecessary material loss and operational inefficiencies.

Table 18: Products Made from Garments Waste Recycling

Response	Frequency	Percentage
Waste Cotton (Tula)	13	26%
Mattress	8	16%
Pillows	6	12%
Seat Stuffing	5	10%
Padding in Cars, Bus & Rickshaw	11	22%
Others	7	14%

Figure 11: Recycled products in the local market

As shown in Table 19, eco-design plays a pivotal role in minimizing waste generation, especially in the cutting section, where fabric loss is often significant. By adopting eco-design and integrating automated marker-making software, garment factories can increase material utilization efficiency up to 85–90%. The pricing of recycled textile products is a critical factor influencing their market acceptance. The survey indicates that most customers are reluctant to pay a premium for recycled goods, although a few buyers have shown a willingness to assign additional value to products made from recycled materials. For sustainable market penetration, the price of recycled products must align with their perceived quality, ensuring competitiveness with goods made from virgin raw materials. Currently, high production costs and challenges related to certification and quality assurance contribute to the relatively higher prices of recycled products. As a result, many recycled goods are less accessible to price-sensitive consumers, limiting the scale of circular production practices.

Table 20 shows that the majority of respondents (74%) perceive the price of recycled products as low to moderate or moderate, indicating that recycled goods are not considered prohibitively expensive compared to products made from new materials. However, a smaller portion (18%) considers the prices moderate to high or high, reflecting concerns about production costs and market competitiveness. Solid waste from garment factories including fabric scraps, jhuts, and paper-based accessories poses a range of environmental challenges. Waste composition significantly influences its environmental impact. Cotton-based fabrics are generally biodegradable, decomposing naturally over time, whereas non-biodegradable materials such as polyester, polythene, acrylic, and elastane persist in the environment for centuries. These materials can remain in soil for more than 400 years, contributing to soil contamination, water pollution, and reduced land fertility. Survey responses indicate that approximately 30% of solid waste is biodegradable, while 28% of respondents

Table 19: Strategies for Zero Waste Management in Textile Industries

Response	Frequency	Percentage
Eco Design	20	40%
Clean Production	8	16%
Production Stewardship	3	6%
Inventory Control	5	10%
Maintenance and Housekeeping	11	22%
Others	3	6%

Figure 12: Zero waste strategies of garments manufacturing

Table 20: Perception of Price of Recycled Products Compared to Products Made from New Raw Materials

Response	Frequency	Percentage
Low	4	8%
Low to Moderate	20	40%
Moderate	17	34%
Moderate to High	4	8%
High	5	10%

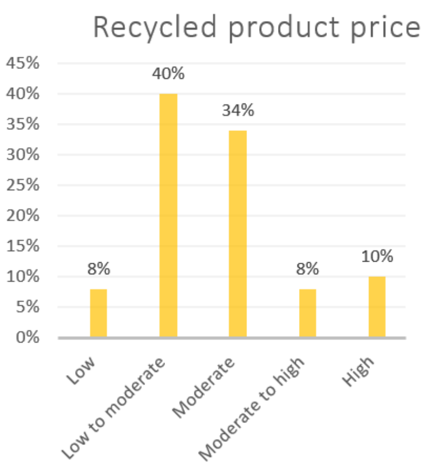

Figure 13: Recycled product price

perceive the waste as harmful due to the presence of polyester and polythene products. This mixed perception highlights that, despite significant environmental risks from non-biodegradable materials, a portion of the solid waste stream can still be managed sustainably through biodegradation and recycling practices.

As shown in Table 21, 58% of respondents consider solid waste to be moderately harmful, harmful, or hazardous, underscoring the significant environmental threat posed by non-biodegradable textiles and accessories. Conversely, 30% perceive waste as degradable, offering an opportunity for sustainable waste management practices such as composting, bio-recycling, or controlled biodegradation. The study conducted at GMS Knitting Composite Factory in Gazipur revealed important findings regarding liquid and solid waste management practices. Effluent from

Table 21: Environmental Impact of Solid Waste from Garment Manufacturing

Response	Frequency	Percentage
Degradable	15	30%
Less Harmful	5	10%
Moderately Harmful	11	22%
Harmful	14	28%
Hazardous and Toxic	5	10%

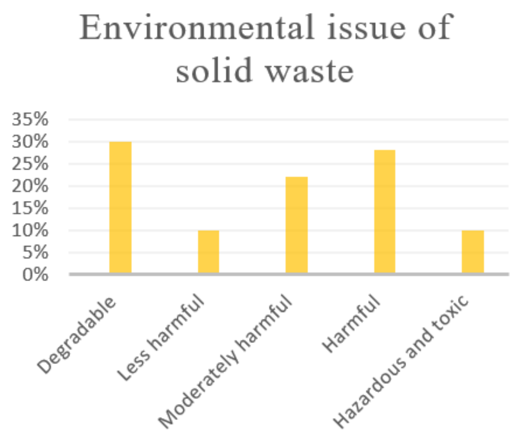

Figure 14: Environmental issue of solid waste

dyeing, washing, and all-over print units was treated using both Biological and Bio-Chemical Effluent Treatment Plants (ETPs). The Biological ETP demonstrated superior performance in removing key pollutants, achieving average removal efficiencies of 84% for BOD, 83% for COD, 81% for TSS, and 32% for TDS, whereas the Bio-Chemical ETP achieved only 74%, 64%, 46%, and 15% respectively. While pH and temperature values were within standard limits, dissolved oxygen levels were slightly below the recommended range. In addition to better treatment efficiency, the Biological ETP required substantially fewer chemicals, generated less non-toxic sludge, and incurred lower operational and manpower costs compared to the Bio-Chemical system, making it a more cost-effective and environmentally sustainable option. Solid waste generation across spinning, knitting, dyeing, and garment production sections averaged 29%, with dyeing contributing the highest share. This wastage resulted in significant monetary losses, with high-value products such as hoodies and jackets incurring substantial reductions in profitability. The survey of factory practices indicated that approximately 40% of solid waste is sold to local markets, 18% is recycled, while the remainder is either landfilled or incinerated. Despite the growing practice of recycling, barriers such as lack of technology, inadequate equipment, and limited consumer awareness hinder the effective recovery of materials. The primary recycling methods involve reuse in secondhand clothing markets and selling quality control rejected garments, while the most common recycled products include waste cotton, known locally as Tula, and padding materials for vehicles such as cars, buses, and rickshaws. Strategies to achieve zero waste were highlighted by respondents, with eco-design recognized as the most effective approach to minimize fabric loss during cutting, followed by proper maintenance, housekeeping, and clean production practices. Pricing of recycled products was generally perceived as low to moderate, though high production costs and certification challenges limit wider market adoption. Regarding environmental impacts, 58% of respondents considered solid waste to be moderately harmful to hazardous due to non-biodegradable materials such as polyester, polythene, acrylic, and elastane, whereas 30% of waste was deemed biodegradable, offering opportunities for sustainable management. Overall, the findings indicate that the adoption of biological treatment systems, combined with circular economy practices, recycling, zero-waste strategies, and eco-design, can significantly improve environmental performance, reduce operational losses, and contribute to the sustainable development of Bangladesh's textile industry.

CONCLUSION

The study demonstrates that effective waste management in Bangladesh's textile industry is both feasible and necessary for environmental sustainability and economic efficiency. Biological Effluent Treatment Plants (ETPs) outperform Bio-Chemical systems in pollutant removal, chemical consumption, sludge generation, and operational costs, making them the most suitable solution for industrial wastewater management. Solid waste remains a significant challenge, with high material losses across production stages, yet recycling and reuse practices, particularly through secondhand markets and the production of items like Tula and padding, show promising potential. Barriers such as lack of technology, equipment, and awareness limit recycling efficiency, while zero-waste strategies, including eco-design and clean production, can significantly reduce material wastage. Addressing these issues through advanced treatment technologies, circular economy practices, and capacity-building initiatives can improve resource efficiency, minimize environmental impacts, and promote sustainable industrial development. Overall, integrating efficient biological treatment systems with sustainable solid waste management offers a comprehensive pathway for the textile sector to enhance profitability while contributing to long-term ecological balance.

REFERENCES

Abtew, M. A., Atalie, D., & Dejene, B. K. (2025). Recycling of cotton textile waste: Technological process, applications, and sustainability within a circular economy. *Journal of Industrial Textiles, 55*, 15280837251348663.

Al-Qodah, Z., Al-Shannag, M., Bani-Melhem, K., Al-Anber, Z., & Assirey, E. (2025). Continuous electrocoagulation processes for industrial inorganic pollutants removal: A critical review of performance and applications. *Water, 17*(17), 2639.

Bresolin, B. M., Pires, D. B., Silva, A. R., & Rodrigues, L. (2025). Anaerobic digestion of tannery sludge and tannery waste: A systematic review. *Environmental Technology Reviews, 14*(1), 839–862.

Bright, T., Adali, S., & Trois, C. (2025). Systematic review and meta-analysis: The application of AI-powered drone technology with computer vision and deep learning networks in waste management. *Drones, 9*(8), 550.

Catarino, M. L., Sampaio, F., & Gonçalves, A. L. (2025). Sustainable wet processing technologies for the textile industry: A comprehensive review. *Sustainability, 17*(7), 3041.

Chakraborty, S., Paul, A., & Saha, P. (2025). Agricultural waste: A new leap toward encouraging global economy. In *Innovative technologies for waste management: Strategies, challenges and future directions* (pp. 289–317). Springer Nature Switzerland.

Deogaonkar-Baride, S., Mahadik, S., Kulkarni, R., & Park, J. (2025). Application of electron beam treatment for degradation of pollutants in real textile wastewater. *Radiation Physics and Chemistry, 230*, 112567.

Faggiano, A., Di Natale, F., Erto, A., & Lancia, A. (2025). Comparative study of greywater treatment using activated carbon and woodchip biochar for surfactant and organic matter removal. *Separation and Purification Technology, 356*, 129861.

Fouda, S. H., El-Halim, E. A., & Ghany, H. A. (2025). Radiological and chemical hazards of persistent organic pollutants in the textile sector. *Scientific Reports, 15*(1), 20102.

Gupta, R., Chatterjee, K., & Das, P. (2022). Waste management in fashion and textile industry: Recent advances and trends, life-cycle assessment, and circular economy. In *Emerging trends to approaching zero waste* (pp. 215–242).

Hossain, M. N., Rahman, M., & Chowdhury, T. (2025). Material flow analysis of municipal plastic waste for sustainable solutions in Chattogram City, Bangladesh. *Next Research*, 100664.

Jiang, A., Liu, S., & Zhao, Y. (2025). Optimizing eco-friendly jewelry design through an integrated eco-innovation approach using artificial neural networks. *Scientific Reports, 15*(1), 6441.

Kurniawan, T. A., Yap, P. S., & Chen, Z. (2025). Techniques for pollutant removal, nutrient recovery, and energy production from landfill leachates: A review. *Environmental Chemistry Letters, 23*(2), 517–577.

Nademi, Y., & Kalmarzi, H. S. (2025). Breaking the unemployment cycle using the circular economy: Sustainable jobs for sustainable futures. *Journal of Cleaner Production, 488*, 144655.

Nurullah, A. B. M., Khatun, M. S., & Ritchie, L. (2025). Industrial wastewater disposal and its socio-environmental consequences: Evidence from the Uttara Export Processing Zone, Bangladesh. *Sustainability, 17*(17), 7716.

Okewling, J. K., Eyre, M., & Hudson-Edwards, K. A. (2025). Aqueous potentially ecotoxic metal(loid)s in a tropical mining-affected river system: Sources and environmental and human health risks. *Environmental Geochemistry and Health, 47*(11), 504.

Oyelakin, I. O., Adeola, O., & Hassan, A. (2025). Building resource capabilities through green servitization and ISO 14001 for sustainable performance: Perspectives from manufacturing firms. *Corporate Social Responsibility and Environmental Management, 32*(3), 3770–3784.

Psarommatis, F., May, G., & Azamfirei, V. (2025). Product reuse and repurpose in circular manufacturing: A critical review of key challenges, shortcomings and future directions. *Journal of Remanufacturing,* 1–38.

Radu, I.-C., Popescu, D., & Marinescu, M. (2025). Advancing sustainability in modern polymer processing: Strategies for waste resource recovery and circular economy integration. *Polymers, 17*(4), 522.

Rahman, K. M., & Chowdhury, E. H. (2020). Growth trajectory and developmental impact of the ready-made garments industry in Bangladesh. In *Bangladesh's economic and social progress: From a basket case to a development model* (pp. 267–297). Springer Singapore.

Saputra, T., Zuhdi, S., & Setiawan, I. (2025). Charting a greener future: Collaborative governance dynamics in Pekanbaru sustainable waste management. *International Journal of Sustainable Development & Planning, 20*(4).

Seifali Abbas-Abadi, M., Zhang, X., & Lee, S. (2025). Advancing textile waste recycling: Challenges and opportunities across polymer and non-polymer fiber types. *Polymers, 17*(5), 628.

Sharma, H. B., Vanapalli, K. R., & Dubey, B. (2020). Challenges, opportunities, and innovations for effective solid waste management during and post

COVID-19 pandemic. *Resources, Conservation and Recycling, 162*, 105052.
Siddikey, F., Nguyen, T., & Lee, S. (2025). Enzyme technology in the food industry: Molecular mechanisms, applications, and sustainable innovations. *Food Science & Nutrition, 13*(9), e70927.
Singh, A., Sahay, S. S., & Sharma, P. (2025). Overview of textile waste. In *Nanotechnology-assisted recycling of textile waste: Sustainable tools for textiles* (pp. 1–27).
Vanapalli, K. R., Sharma, H. B., & Ranjan, V. P. (2021). Challenges and strategies for effective plastic waste management during and post COVID-19 pandemic. *Science of the Total Environment, 750*, 141514.
Zada, M., Rehman, S. U., & Li, X. (2025). *Driving sustainable development through CSR leadership: Insights into organizational learning and technological innovation.* Sustainable Development.
Zhang, J., Luo, G., & Yan, Y. (2025). Toward an effective policy mix for domestic waste management in China: Interdepartmental cooperation as an enabler. *Review of Policy Research, 42*(3), 658–681.