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Mapping environmental sustainability of knitted textile production facilities

Md. Shamsuzzaman [a], Md Mazedul Islam [b,*], H M Rakib Ul Hasan [c], Adnan Maroof Khan [d], Abu Sadat Muhammad Sayem [e]

[a] Department of Textile Engineering, World University of Bangladesh, Bangladesh
[b] Department of Materials, The University of Manchester, UK
[c] Department of Textiles, Apparel Design and Merchandising, Louisiana State University, USA
[d] Department of Apparel Engineering, Bangladesh University of Textiles, Bangladesh
[e] School of Fashion, Manchester Metropolitan University, UK

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ABSTRACT

To achieve the Sustainable Development Goal (SDG) 12, it is important to investigate the sustainability of both products and manufacturing facilities to identify the areas to improve. The number of published research works on measuring the eco-indices of fashion products are plenty, while ignoring the measurement of the eco-indices of fashion production facilities. Therefore, this study investigated the environmental sustainability of knit-dyeing facilities linked to fast fashion production in Bangladesh. The Facility Environment Module (FEM) of the Higg index tool 2.0 from Sustainable Apparel Coalition (SAC) was applied to detect the sustainability scores. Multiple case study approach was adopted for this study. Seven tools of FEM related to the environmental management system, energy use, GHG emissions, water use, wastewater, air emissions, waste management, and chemical management were applied to collect data. Scores of these categories were calculated using the FEM tool. Qualitative data was collected through short interviews using a questionnaire. A varying range of scores (from low to high) was found for all the categories. The scores reveal the technical, managerial, and resource limitations on practicing sustainable production approaches in knit-textiles facilities. The overall finding urges all stakeholders, including manufacturers, researchers, buyers, and policymakers, to pay serious attention and reformulate strategies and resources to reduce the negative impact of knit manufacturing on the environment.

1. Introduction

Sustainable textile production has become a major concern of today's fashion industry. Sustainable textiles refer to processes and services that are non-hazardous, non-polluting, economically viable, and safe for workers, communities, and consumers (Jacometti, 2019). This conserves energy and natural resources. The textile and apparel industry is recognized as the second-highest environment-polluting sector, contributing over 10% of global Carbon-di-Oxide emissions and 20% of global wastewater output (UNCTAD, 2019; European Parliament, 2020). The industry is also responsible for health hazards, corrosion of sewer lines, and groundwater pollution. Therefore, investment of large capital in mitigating multidimensional negative impacts (Shamsuzzaman et al., 2021). Growing eco-activism by non-governmental organizations (NGOs) and responsible media is increasing consumers' awareness for purchasing sustainable and eco-friendly products (Gordon and Hill, 2015). Significant environmental impacts occur in the multiple processes of fibre production, knitting, weaving, dyeing, sewing, printing, washing and finishing stages (Resta et al., 2016; Islam et al., 2020). Therefore, it needs fundamental changes to holistically improve the textile and apparel industry's environmental sustainability and minimize environmental impacts.

Bangladesh is a key supplier of global fashion products (Akter et al., 2022; Shamsuzzaman et al., 2020, 2021) where the manufacturers are struggling to tackle multiple barriers and challenges towards sustainable development (Islam et al., 2020). Apart from the economic impact, its manufacturing processes and by-products are seriously polluting and endangering the surrounding environment (Mani et al., 2018; Saha et al., 2022). Research reveals that manufacturer lacks an understanding of green supply chain management practices to improve the firm

* Corresponding author.
E-mail address: mdmazedul.islam@manchester.ac.uk (M.M. Islam).

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sustainability performances (Habib et al., 2021). With increasing stakeholders' demand, Bangladeshi suppliers are under increased pressure to implement sustainable practices in fashion production to address sustainability issues. Therefore, the Bangladeshi Textile and Apparel (T&A) industry represents an ideal scenario where manufacturers struggle to address environmental sustainability issues. It has become essential to understand, quantify, and analyze T&A industry sustainability performance in line with the United Nations (UN) Sustainable Development Goals (SDGs) (Akter et al., 2022; Watson and Wiedemann, 2019)..

Environmental concern is not new to the fashion and textiles industry. Western brands often heavily invested in improving suppliers' environmental performance through strict regulations, and recommending multiple tools, standard and initiatives (Islam et al., 2020; Resta et al., 2016). For example, Sustainable Apparel Coalition (SAC) has developed several tools that standardize and measure industry hotspots to continuously improve sustainability performance and achieve environmental sustainability and social responsibility demand (Resta et al., 2016). To determine sustainable performance, the Higg Index was developed (SAC, 2018; Brett, 2018). A few studies have been conducted by applying the tools to evaluate environmental sustainability performance. Existing studies reveal limited findings regarding the environmental aspects of the upstream knit textile facilities linked with the fast fashion production operations. The complexity and challenge of the fashion supply chain make capturing production scenarios challenging and often opaque, requiring further investigation. To address this gap, two specific research objectives have been set for this research; (i) to understand, quantify, and evaluate the environmental sustainability of knit production factories, and (ii) to identify and analyze key risks, poor practice areas, and improvement opportunities to advance the environmental sustainability of knit fashion factories.

The rest of this paper is laid out as follows. It begins by reviewing essential literature, theoretical background in the textile industry, and dimensions of environmental sustainability challenges. The methodology section outlines a multi-case study, data collection, and analysis technique. Finally, the findings, discussions, and implications (theoretical and practical) part is presented, followed by conclusions and recommendations.

2. Literature review

2.1. Textile industry and environmental sustainability challenges

Water, dyes, and chemicals are used in textile wet processing, e.g., dyeing, printing, finishing, and washing. Almost 800 different types of chemicals are used in these processes globally, with 80% of them synthetic and hazardous (Nimkar, 2018). One kilogram (kg) knit fabric requires around 100–150L L of water to process. In particular, about 20 $\times 10^4$ L of water are needed in the dyeing and finishing steps to process 1×10^3 kg of knit fabric. Almost 27.56×10^9 L of water was utilized in Bangladesh between 2012 and 2016, with the figure expected to rise to 50×10^9 L by 2025 (Fashionating World, 2019; Hossain and Khan, 2020). To produce 4×10^9 pieces of jeans fabric requires 1.7×10^9 kg of chemicals and 2.5×10^9 gallons of water (Greenpeace, 2011). These are responsible for the production of wastewater and sludge. An estimated 28×10^7 kg of textile dyes are discharged per year through industrial wastewater worldwide (Zainith et al., 2016), with 10–15% containing diverse substrates such as fibers, dyes, chemicals, plastics, leather, paper, oils, and so on (Tkaczyk et al., 2020). As a result, over 5–10% of poisonous and harmful dyes and chemicals found in wastewater are discharged to the environment (Prasad and Aikat, 2014). Bangladeshi textile companies generated over 21.7×10^7 L of effluent in 2018, which was predicted to exceed 3.5×10^8 L by 2021 (Hossain et al., 2018). Water treatment and reuse facilities, on the other hand, have the potential to save 1.236×10^9 L of water. Using 1 L less water saves 7.8% of chemical costs (Hossain and Khan, 2020).

Use of sustainable technologies in product and process stages plays a significant role in reducing environmental impact. de Oliveira Neto et al. (2019) found that old rapier looms replaced by advanced air jet weaving machines in the denim weaving industry consumed less energy, achieving higher production efficiency at a lower cost with less environmental impact. Life cycle assessment (LCA) of recycled knit clothing found that 1 tonne of textile waste treatment/recycling may save up to 1×10^5 kg of CO_2 and 169×10^9 J energy (Zamani et al., 2015; Zhang et al., 2020)). A study by (Toshiro et al., 2020) reveal that chemical recycling and thermal recycling of 1 kg jeans/T-shirts can reduce Japan's 30–70% GHG emission.

Textile manufacturing generates a substantial amount of waste in different operations. The waste management policy focuses on reducing solid waste from raw materials and treating liquid waste effectively (Akter et al., 2022). For example, efficient waste management team may reduce expenses, waste, and time by collecting data, monitoring reports, audits, and recommending future action plans (Yacout et al., 2015; Mani et al., 2018). The use of nanofiltration membrane separation can separate COD, color, conductivity, and feed concentration from textile dye-house effluents (Abdel-Fatah et al., 2020). Alternative wastewater treatment methods include physiochemical, biological, and combined processes (Choudri and Baawain, 2016). Moreover, environment-friendly chemicals can significantly reduce pollution (Khan et al., 2014; Khan and Islam, 2015; Islam et al., 2020). Therefore, the current practice of effluent treatment needs to be measured for preparedness for tackling environmental pollution.

2.2. Application of Higg Index to evaluate sustainability performance of textile industry

The Higg Index is a question-based assessment tool developed by Sustainable Apparel Colation (SAC) that provides a common baseline for the footwear and apparel manufacturing industry to measure sustainability. It evaluates a company's sustainability management systems and performance across the value chain (Yang et al., 2017). The modules include: (i) assessment of product, (ii) assessment of production facility, and (iii) brand's/retailer's environmental and social impact. These modules generate standardized performance scores through life cycle assessment. The tools support management control over the policy, procedure, and performance (Higg Index, 2017). The scorecard incorporates questions, and most answers are standardized to promote easier post-assessment analysis. It incorporates a novel benchmarking and visualization section that help manufacturers to reduce their environmental impact (Koepsell, 2016; Radhakrishnan, 2015). The Higg Facility Environmental Module (Higg FEM) is a sustainability assessment tool that standardizes how facilities measure and evaluate their environmental performance on a year-to-year basis. The FEM module is designed to measure and quantify the facility's sustainability impacts, reduce redundancy in measuring, and reporting sustainability performance. The seven sections of Higg FEM, with weighted maximum 100 points, reflects the industries perspectives of different stages in products' life cycle towards sustainability (Higg, 2017).

3. Research methodology

This research adopts a multiple-case study approach. Three knit-dyeing factories (A, B and C) were selected based on their workforce, annual turnover and production capacity (small, medium, and large). As per Higg FEM module, multiple module-based questionnaires were developed to collect empirical data regarding the environmental aspects, namely environmental management system, energy use and greenhouse emission, wastewater/effluents, water use, emission to air, waste management and chemical management. Fig. 1 presents the plan and boundary of the research.

Collected data was analyzed using the FEM module of Higg 2.0 to generate sustainability scores achieved by individual factories. This enables categorization and determination of the level of sustainability performance. While generating scores, multiple criteria were carefully considered and analyzed to detect unsustainable accomplishments. The case factories are presented in Table 1 below.

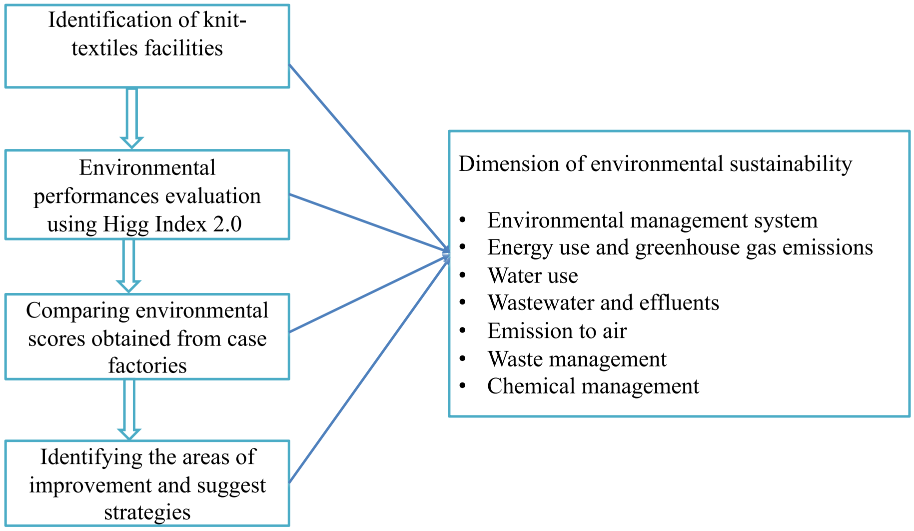

Fig. 1. Research conceptual plan.

Table 1
Sample factories for sustainability analysis through Higg Index 2.0

Factory Name	Factory type and Operations unit	Annual Turnover (Approx.),Manpower	Year of Establishment	Product type	No. of respondent	Documents analyzed
Factory A	Knitting, Dyeing, Washing, printing, finishing	169 million USD,20,000 staff	1990	Knit items	14	Audit report on chemical store, ETP plant, Environmental department, Power supply etc.
Factory B	Knitting, Dyeing, Washing, printing, finishing	70 million USD, 8500 staff	2000	Knit items	13	Power supply, ETP management, Chemicals store etc.
Factory C	Knitting, Dyeing, Washing, printing, finishing	35 million USD, 4800 staff	1997	Knit items	13	Environmental department, ETP plant, chemical stores etc.

Multiple practice based qualitative questions (Appendix A) were asked to several levels of employees of the selected factories. Then documents, website information and sustainability report related to environmental issues were analyzed from all the case factories for triangulation. The designation and number of interviewees are shown in Table 2.

4. Results

The scores of the factories as evaluated by Higg FEM module are presented in Tables 3–10.

Table 2
Factory respondents and their profile.

Respondent Position	Year of Experience	Responsibilities	Case factory
Head of Audit	15–20	Schedule, plans and organize internal audit, process audit, recommend policies	A, B, C
Compliance Manager	8–10	Responsible for organizations policies and procedures, perform regular audits, design control system and implement company policies	A, B, C
Head of ETP and Chemicals	12–15	Plan, organize and maintain ETP plan and chemical department	A
ETP Supervisor	5–7	Supervise, maintain and schedules ETP operations, personnel and equipment and ground storage tank	A, B, C
Head of Power Supply/Utility Manager	10–15	Operations and maintenance of boilers, steam & gas turbines, captive power plant, DM plant, cooling water & instrument air system, ETP	A, B, C
Sustainability Manager	10–15	Responsible for analyzing, evaluating and predicting health of surrounding environment	A, B, C
Finishing Manager	7–8	Duties to check, investigate and ensure product quality	A, B, C
Sustainability Manager	9–10	Coordinates and controls of chemical flow to different sections ensures safety of personnel and environment	B, C
Dyeing Manager	12–15	Manages dyeing and finishing process	A, B, C
Lab Manager	8–11	Calculates dyes and chemicals quantity	A, B, C
Chemical Store In-charge	4–6	Receives, stores, records, and ships chemicals	C
HR Manager	7–10	Managing, coordinating, and supporting the recruitment process and remuneration	A, B, C
R&D Manager	8–10	Responsible for the development, execution, commercialization, and distribution of new product	A, B, C
Quality In-charge	4–5	Development and implementation of inspection activities, detection, and resolution of problems	A, B, C
Quality Manager	6–8	Supervise, develop and implement quality control tests, inspections, reports documentation	A, B
Supply Chain Manager	8–12	Source, negotiate, control, plan and implement right products, manufacturing and distribution to customer	A

Table 3
Scores obtained from Higg Index evaluation of environmental management system of three sites.

Parameters/Allotted Scores	Factory A	Factory B	Factory C
Site's Environmental Impact (Positive/Negative)/5	5	5	5
Site's monitoring system/10	10	10	0
Site's legal permission/15	15	15	15
Elements of Environmental Management/10	10	10	0
Review systems of Environment management/5	5	5	0
Priorities over environmental performance/10	10	0	0
Supplier Responsibility/5	5	5	5
Sub conductors responsibility/5	5	5	5
Raw materials assessment system/10	10	10	10
Certified Audit system/5	5	0	5
Information regarding hazard/10	10	0	0
Information regarding energy/10	0	0	0
Total value/100	90	65	45

4.1. Environmental management system or program

The prior and current actions of the companies were monitored using sub module 1- Environmentally Sustainable Management Systems (EMSs, ISO 14000 certification). The facilities' scores were obtained after being evaluated using the Higg FEM 2.0 module (Table 3).

Factory A has demonstrated greater potential than the others in complying with environmental management system regulations. Other sites were found to neglect to maintain a proper environment-friendly approach. The faulty and ineffective monitoring systems and poor review of environmental management are mainly responsible for the low scores by the factories (B and C). The scores also indicate that the factories are least interested in setting priorities for such management systems and recording the hazards and potential consequences generated through multiple production operations.

4.2. Energy use and greenhouse gas emissions

Greenhouse Gases (GHG) are often emitted as a result of the site's energy consumption. The study investigated details on the energy sources and use, greenhouse gas emissions, and renewable energy scopes for the case factories.

Table 4 provides sustainability scores on factory energy consumption and potential greenhouse gas emissions during manufacturing steps. The majority of the firms used natural gas/petroleum to generate electricity for variable power consumption plants. Unfortunately, their performance was underrated (no scores for the 4th, 6th, and 7th parameters in factories A, B, and C, respectively) due to lack of effective monitoring systems for total greenhouse gas (GHG) generation and emissions as well as any reduction plans. Their audit system for energy use, GHG generation, GHG and other gas emissions, and mitigation strategies for environmental concerns appeared unconvincing.

Table 4
Higg Index evaluation of energy use and greenhouse gas emissions.

Parameters/Allotted Scores	Factory A	Factory B	Factory C
Energy consumption/10	10	10	10
Power consumption/5	5	5	5
Steam consumption/5	5	5	0
GHG emissions/5	0	0	0
Source of GHG/5	0	0	0
GHG reduction target/15	0	0	0
Audit on energy use/10	10	0	0
Audit recommendation/5	5	0	0
Measure of energy efficiency/15	15	15	15
GHG reduction policy/25	0	0	0
Total value/100	50	35	30

4.3. Water use

Water is regarded as the most important component of textile processing. Water is needed to execute all of the wet processing functions. The source of water supply, however, differs by region. The interview traces information on the factories' water supplies, uses, and recycling processes. The scores are presented in Table 5.

Most firms use the deep well water supply for industrial and drinking purposes. Among the three factories, Factory C received the lowest score (Table 5). One of the main reasons could be a lack of understanding of an acceptable source of water supply. Workers' health safety and appropriate wet processes rely on acceptable water sources. This demonstrates a lack of sustainable behaviors. None of the mentioned factories have exhibited even a genuine interest in water consumption policies, optimal utilization, and reuse. This may jeopardize their long-term sustainable practices. Therefore, properly guided instructions on water use and related measures should be implemented as soon as possible.

4.4. Wastewater/effluents

Textile wastewater contains unused dyes and chemicals, which could be hazardous for animals and plants in any freshwater body. These come from dyeing, washing, finishing and printing processes. The responsible factory personnel were asked to provide information on the wastewater type, wastewater sources, discharging procedure, wastewater management, toxicity and training information. The relevant obtained scores

Table 5
Scores obtained from Higg Index evaluation of water use by three sites.

Parameters/Allotted Scores	Factory A	Factory B	Factory C
Track of water use/15	15	15	15
Surface water source/5	5	5	0
Deep Water source/5	5	5	0
Water consumption/5	5	5	5
Review policy of water consumption/10	0	0	0
Audit on water/5	5	5	5
Opportunities identified/5	5	5	0
Opportunities implementation/10	0	0	0
Potential reduction of water use/10	10	10	10
Information of water reuse/20	10	0	0
Time observation/10	10	0	0
Total value/100	70	50	35

Table 6
Scores obtained from Higg. Index evaluation of wastewater/effluents use by three sites.

Parameters/Allotted Scores	Factory A	Factory B	Factory C
Wastewater treatment-Primary/5	5	5	5
Wastewater treatment-Secondary/5	5	5	0
Wastewater treatment-Tertiary/5	5	0	0
Contamination of wastewater/10	10	10	10
Daily Wastewater production/5	5	0	0
Improvement target/10	10	10	10
Treatment policy/10	0	0	0
Establishment/10	10	0	0
Wastewater types/10	10	10	10
Normalize of effluents/10	10	0	0
Quality improvement/20	20	20	20
Total value/100	90	60	55

are shown in Table 6.

All of the considered factories demonstrated the capacity to mitigate the hazardous impact of wastewater created during various manufacturing phases. Each factory runs ETP but does not comply with the correct level of treatment guidelines. Thus, when water and soil mingled with another source of water and soil, these become polluted. Factory owners sometimes overlook wastewater treatment due to their profit-oriented strategies. Factory A has demonstrated greater potential than the others. There were no scores in 5 and 6 parameters for factories B and C respectively.

4.5. Emissions of air

Greenhouse gas (GHG) is emitted from different textile and apparel production processes, which can cause global warming. The questionnaire set in order to collect information related to dust production, organic compound details, toxic air pollutants, emissions to air and inventory is presented in the appendix. The scores obtained as per the responses are shown in Table 7.

All of the factories were alleged to be producing considerable amounts of NOx and SOx dust particles, volatile organic compounds, and ozone depleting substances and then releasing them into the environment. According to the interviewers, factories have shown reluctance and incompetence in maintaining and monitoring any type of air pollution they have made. As a result, the three factories in this category of obtained extremely poor results.

4.6. Waste management

Textile factories are largely responsible for effluent and sludge production, but they also emit significant amounts of GHG, CO2 into the environment. We inquired about waste management, treatment techniques, and monitoring systems. Table 8 displays the corresponding scores obtained from the factory interviews.

The results clearly show that factory A outperforms the other two in terms of waste management. Factory A was observed to perform all three categories of wastewater treatment, namely primary, secondary, and tertiary, but the other two were in questionable conditions. The strategic plan and trash recycling program in the waste management system are poor or non-existent as found for the concerned facilities. These challenges contribute to pollution of the surrounding ecosystem, putting humans, aquatic creatures, and other species in danger. By separating suspended solids and minimizing the hazardous potential of wastewater in the environment, an effective effluent treatment plan (ETP) helps reduce wastewater problems.

Table 7
Scores obtained from Higg. Index evaluation of emissions of air by the three sites.

Parameters/Allotted Scores	Factory A	Factory B	Factory C
Main Emission to air/10	0	0	0
Emission monitoring/20	20	0	0
Target of air emission reduction/30	0	0	0
Air emission to energy consumption/20	0	0	0
Practices on air emission quality/20	0	0	0
Total value/100	20	0	0

Table 8
Higg. Index evaluation of waste management by three sites.

Parameters/Allotted Scores	Factory A	Factory B	Factory C
Waste generation/7.5	7.5	7.5	7.5
Solid waste/5	5	5	5
Hazardous waste/5	5	5	5
Waste disposal/5	5	5	5
Segregation of hazardous waste/7.5	7.5	0	0
Strategic Plan/10	10	0	0
Recycling Program/20	0	0	0
Types of waste/10	10	10	10
Normalized amount/10	10	5	0
Steps implementation/20	20	10	0
Total value/100	80	47.5	32.5

4.7. Chemicals management

Every day, over 8000 different types of dyes and chemicals are used to produce textile products globally. These are typically non-biodegradable and toxic, producing textile waste throughout the manufacturing process. Multiple questionnaires focused on the status of chemical inventory, listing chemicals based on their market reputation as branded or non-branded, compliance and RSL maintenance status, and chemical types based on end use (such as cleaning, dyeing, softening, washing, special finishing agents, solvents, reagents and so on). Table 9 displays the obtained scores in factory chemical management.

Factory A and B received far higher scores in terms of chemical management modules, but their rules appeared inadequate, with little transparency for the use of prohibited chemicals. Factory C's weaknesses were noted as a lack of adequate monitoring of synthetic chemicals, chemical improvement plan, assessment mechanism etc. Factory C received a score of 55% due to the influences of all those subcategories. In order to get higher sustainability scores, factories must adhere to certain chemical management guidelines and implement them accordingly.

4.8. Summary of the findings and discussions

It is noticeable that the scorecard varied significantly for most of the sub-section analysis of the subsections of Facility Module Environment, which indicates the technical and managerial limitations of the actions taken by the facilities. The environmental management system looks after the waste reduction policies, promotes efficient use of resources and raises awareness across sites. This research revealed gaps in the actual and prioritized action plan for the participating factories' environmental management systems. Factory A excelled in performance compared to the other two factories having shown excellent management over the environmental system.

On the other hand, Factory B and C combined scored almost half of the points of A. The facilities were found using petroleum over natural gas to produce electricity, and no renewable energy source existed as an alternative. Further, almost no or relatively poor tracking of GHG emissions and audit systems have earned them a low score of about 50% from the module sub-section 2. Upon interrogation about the water uses, the facilities were found to be using deep tube well water, although there were no review policies on water use and its reduction policies.

Moreover, the consumption of water and its reduction policies were found to be absent. The proper implementation of ETP policies over effluent treatment and wastewater management has been found faulty in the facilities in most cases. They seemed to be unaware or unwilling to reduce harmful effluents. This might become dangerous to all aquatic animals, living organisms and other water sources like rivers, ponds,

Table 9
Higg Index evaluation of chemicals management by three sites.

Parameters/Allotted Scores	Factory A	Factory B	Factory C
Chemicals Management Module/10	0	0	0
Systematic Chemical use monitoring/10	10	10	10
Inventory of Chemicals use/10	10	0	10
Chemical improvement plan/25	25	25	25
Restriction of chemicals use/5	0	0	0
Assessment of chemical improvement plan/30	30	30	0
Alternative assessment/10	10	10	10
Total values/100	85	75	55

Table 10
Key summary of the findings.

FEM Score Card (Out of 100)					
Tools No.	Tools Name	Factory A	Factory B	Factory C	Comments/Key gaps/Improvement areas
1.	Environmental management system or program	90	65	45	Proper monitoring is needed and the government guideline on waste management should be followed
2.	Energy use and Greenhouse gas emissions	50	35	30	No strong actions in place on GHG and energy use. Must formulate and implement strong guidelines
3.	Water use	70	50	35	Should develop waterless or less water consumed processing to avoid/reduce water use
4.	Wastewater/Effluents	90	60	55	ETP policy must be implemented strongly
5.	Emissions of air	20	0	0	Weak action in all cases, should concentrate more in this sector
6.	Waste Management	80	52.5	32.5	Try to reuse and recycle end products and re-design waste mana ement system
7.	Chemicals Management	85	75	45	Use more environmentally friendly chemicals during processing

canals, etc. The module also identified that facilities release NOx, SOx and volatile organic compounds (fabric finishes/solvents/adhesives/ printing and dyeing particles). These depleting ozone layers generate toxic air by polluting the atmosphere. The impact of air emissions is severe in the case of all the facilities. The practice of no emission of ozone and other harmful gases and related monitoring is found absent. The performance observed in the chemical management subsection was dissatisfactory since they do not use eco-friendly and biodegradable chemicals during their manufacturing stages. To overcome the technical and managerial limitations, it is mandatory to look after management systems, proper controlling, continuous monitoring and effective ETP and plant management. Therefore, relevant parties should work efficiently and proactively, including factory top management, middle management, workers, suppliers, trainers, government inspection teams, and other stakeholders. Table 10 shows the summary of the key findings of the sustainability performance of the facilities based on the Facility Environmental Module of Higg Index.

We arrived with the opinion that still a diverse kind of unsuitable, unsustainable practices are ongoing with regards to the seven environmental dimensions as identified by using the FEM module of Higg Index tool. The biggest responsible offender is textile processing, particularly dyeing and washing operations. They use a lot of water, dyes, and chemicals whilst generating a significant amount of GHGs, effluents, and sludge as byproducts of the clothing industry. This unregulated scenario is significantly contaminating the ecosystem around us. In order to make our planet greener and keep it remain livable, we need robust waste management policies for recycling and reusing chemical and reducing waste generation for the knit dyeing facilities linked to fast fashion production.

5. Research contributions and implications

This research has important theoretical and industrial implications. This study contributes to and expands the research stream of fashion and textiles by identifying issues related to environmentally sustainable practices linked to fast fashion production. It presents the results of a multiple case study into the environmental sustainability scenario prevailing in upstream knit garment production, which is often unclear to wider stakeholders and so far, has received little attention. This study covers seven specific criteria concerning sustainable production and environmental impact, including areas that need more focus. The finding will motivate manufacturing managers to improve their environmental performances in the areas where they are struggling to do so at the moment. It reveals valuable insights for practitioners, indicating what, how, why, and to what extent urgent action is needed to address environmentally unsustainable practices. The outcome of this research would appeal to decision-makers, especially industry practitioners and policymakers, to understand the eco-indices of knit textiles factories in Bangladesh. The critical areas, including water, chemical and energy uses, emissions of GHG and release of effluents and sludge, needs significant focus to mediate negative impact. Factories can trace their problems through the Higg FEM module, prepare a data bank on each criteria, plan strategically and allocate resources accordingly to be more sustainable. This research has important policy implications. For example, the outcome will help knit manufacturers in Bangladesh to tackle sustainability challenges in the global market by allocating resources and investment to resolve unsustainable practices. The government, factory management, brands, and other relevant stakeholders can find ways to restructure policies to promote sustainable knit garments production in developing countries like Bangladesh. Researchers and academics can implement Higg module to easily and effectively identify the issues on sustainable production in knit textile manufacturing that requires further development. Therefore, collaborative efforts inclusively from manufacturers, importers, third-party auditors, buyers, and regulatory bodies are necessary to address the identified issues.

6. Conclusion

This paper presents the mapping of sustainable practices and eco-indices from the environmental aspects of the upstream knit textiles production facilities linked to fast fashion, which is often hidden, opaque, and unreachable to wider stakeholders. It needs to be admitted that data access from the developing country manufacturers' perspectives of fashion and textiles is complicated and challenging. This is the key novelty of this research. We investigated the knit textiles facilities in Bangladesh to evaluate environmental sustainability, identify and suggest areas for improvement. The obtained eco-indices scores vary significantly from high to low on different facilities and production stages. Low scores indicate the unsustainable practices that prevail despite having well-established international compliance policies from importing retailers. Poor air emission management indicates that the knit production often focuses less on pollution control as long as it does not harm their interest. Limited sustainable approaches in production, neglecting attitudes towards factory by-products, and faulty recording systems are the critical points of unsustainable practices identified. In addition, limited resources, strategic planning, knowledge sharing and finance are other factors contributing to poor environmental performance. Many factory owners in Bangladesh focus on maximizing profit rather than addressing the impetus for sustainable development, which presents a challenge to further sustainability. However, the industry management should responsibly take care of any harmful byproduct generated from the production operations and environmental pollution. The consistency of performance in all seven modules according to facility size and contextual factors might indicate that maintaining the facility environment is related to the factories' financial capability and technical limitations. Therefore, the fashion supply chain downstream stakeholders (buyers, retailers, brands, consumers etc.), as well as government environmental agencies, should collaborate with upstream stakeholders with necessary technical and funding support to improve their facility conditions to be more sustainable. Exiting challenges and limitations with fast fashion production in tackling environmental issues need the fundamental transition to mitigate the detrimental environmental impacts of the upstream fashion supply chain.

This research has several limitations that call for further work. Only environmental dimensions of sustainability have been considered. However, the inclusion of social and economic sustainability can provide a comprehensive overview. Future research should consider both the downstream and upstream fashion companies to investigate sustainability aspects using standard tools. Inclusion of a larger number of factories would provide more generalized findings. The government is also advised to formulate and implement strict monitoring policies. This will smoothen the path of establishing environmental sustainability in knit textiles and other textile processing facilities (e.g., denim, woven). Finally, from the developing country's perspective, significant information about the sustainability scenario of upstream fashion manufacturing remains hidden that requires further in-depth investigation.

CRediT authorship contribution statement

Md Shamsuzzaman: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Software, Validation, Writing - original draft. **Md Mazedul Islam:** Conceptualization, Methodology, Validation, Formal analysis, Supervision, Resources, Software, Visualization, Writing - review & editing. **H.M. Rakib Ul Hasan:** Visualization, Methodology, Formal analysis, Validation, Writing - review & editing. **Adnan Maroof Khan:** Validation, Formal analysis, Methodology, Visualization, Writing - review & editing. **Abu Sadat Muhammad Sayem:** Methodology, Resources, Validation, Visualization, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2023.136900.

Appendix A

Sl. No.	Questionnaires	Factory A	Factory B	Factory C
Facility Environmental Module: Environmental management system				
1	Impact of Local environment	Partially impact	Negative impact	Negative impact
2	Promote efficient use of resources	Yes	No	No
3	Reduce wastage e.g. energy, water and raw material consumption	Yes, used conventional technique	No, used conventional technique	No, used conventional technique
4	Raising awareness across site	Yes	Yes	Yes
5	Management of environmental practices	Partially implemented	Negative	Negative
Facility Environmental Module: Energy use and greenhouse gas emissions				
6	Energy (Direct/Indirect)	Indirect (Gas, oil, petrol)	Direct	Direct
7	Energy source (coal/petroleum/natural gas etc)	Natural gas/petroleum	Petroleum	Petroleum
8	Renewable energy source (solar/hydropower/biomass/wind turbine etc.)	None	None	None
9	Combined Heart and Power	Existed	No	No
10	Source of greenhouse gas	Industrial/building/energy waste etc.)	Industrial/energy wastes	Industrial/energy wastes
11	Tracking of greenhouse gas	None	None	None
12	Greenhouse gas emit to air	Direct extraction	Direct extraction	Direct extraction
Facility Environmental Module: Water use				
13	Purpose of water use	Domestic and Industrial	Domestic and Industrial	Domestic and Industrial
14	Drinking water supplied by	Deep tube well	Deep tube well	Supplied Water
15	Non-drinking water supplied	Deep tube well	Deep tube well	Supplied water
16	Ground water (rain, canal, river)	Yes	Yes	No
17	Recycled grey water	Yes	No	No
Facility Environmental Module: Wastewater/effluents				
18	Wastewater types (Dying/washing/wet finish/printing/degreasing etc.)	All	Only dyeing and washing	Only dyeing and washing
19	Wastewater source (Various process, cooling wastewater, compressors, boilers, firewater, domestic water)	All	All	All
20	Does the site discharge wastewater/effluent from building activity, various processes?	Various treatment process	Dyeing and washing process	Dyeing and washing process
21	Wastewater treatment plant	Yes	Yes	No
22	Options for managing wastewater (on site treatment/off site treatment)	On site	On site	None
23	Consumption of water	Dyes, chemicals, fabrics, colorant etc.	Dyes, chemicals, fabrics, colorant etc.	Dyes, chemicals, fabrics, colorant etc.
24	Fully Trained manpower	Yes	No	No
25	Measures of wastewater (quantity/quality)	Quantity	Quantity	Quantity
26	Recording of wastewater parameters	Measured and Maintain	Missing	Missing
27	Wastewater contains (COD, BOD, DO, pH, TDS, TSS)	COD, BOD, DO, pH, TDS, TSS	COD, BOD, DO, pH, TDS, TSS	COD, BOD, DO, pH, TDS, TSS
28	Toxicity (chemicals/medicines/antibiotics/dyestuff)	Chemicals/dyestuffs	Chemicals/dyestuffs	Chemicals/dyestuffs

(continued on next page)

(*continued*)

Sl. No.	Questionnaires	Factory A	Factory B	Factory C
29	Heavy metal content (e.g. antimony, arsenic, cadmium, chromium, cobalt, copper, cyanide, lead, mercury, nickel, zinc, etc.)	Yes	Yes	Yes
30	Color	Blackish/Colorant	Deep Blackish/Colorant	Deep Blackish/Colorant
31	pH	Slightly alkaline	Alkaline	Highly alkaline
Facility Environmental Module: Emission of Air				
32	Dust particles (spinning/fuel combustion)	Yes (NOx)	Yes, NOx, SOx	Yes, NOx, SOx
33	Volatile organic compounds	Yes	Yes	Yes
34	Ozone depletion substances	Present	Present	Present
35	Toxic air pollutants (apparel finishes)	Yes	Yes	Yes
36	Emissions to air generated-	Generated	Generated	Generated
37	Emissions to air generated-	Generated	Generated	Generated
38	Emit systems	Chimneys/stack	Chimneys	Chimneys
39	Emission inventory	Yearly	None	None
Facility Environmental Module: Waste management				
40	Waste types (sludge/effluents)	Both	Both	Both
41	Primary/secondary/tertiary treatment	All three	Primary	Primary
42	Treatment quantity (%)	60–70%	<50%	<20%
43	Monitoring/training/operations involved	Monitored	Partially monitored	Partially monitored
Facility Environmental Module: Chemical management				
44	Chemicals inventory	Half Yearly	Yearly	Yearly
45	Branded/Non branded	Branded	Mostly branded	Mostly non-branded
46	Chemical types (Cleaning/dyeing/solvents/softening/washes)	All	All	All
47	Special finishes	Fire proof/water proof	None	None
48	Printing chemicals	Yes	None	None
49	Compliance	Yes	Yes	Yes

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