USE OF THE INTERNET OF THINGS FOR WATER CONSUMPTION MONITORING IN APPAREL INDUSTRY

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Abstract Internet of Things (IoT) presents a promising solution for real-time monitoring and management. This study explores the key barriers to adopting IoT-based water consumption monitoring in Sri Lanka's apparel sector and proposes strategies to overcome them. A qualitative research approach was employed, involving semi-structured interviews with 11 industry professionals, including engineers, sustainability managers, and technical consultants. Findings reveal that high initial costs, lack of technical expertise, data security concerns, limited awareness, and integration complexities are major obstacles. Additional challenges include reliability issues, technological compatibility, and limited availability of high-quality IoT equipment, particularly in Sri Lanka. Despite these barriers, IoT has the potential to improve efficiency, reduce waste, and enhance sustainability in the apparel industry. Addressing these challenges requires strategic investments in training, financial incentives, government support, and enhanced cross-sector collaboration. These strategies can facilitate wider IoT adoption and drive sustainable transformation in Sri Lanka's apparel industry.

Keywords. Internet Of Things, Apparel Industry, Water Monitoring, Barriers, Strategies

1. Introduction

Water scarcity is a pressing global issue, with nearly 10 billion people expected to compete for limited freshwater resources by 2050 (Thiry, 2011). Although Earth contains approximately 1.4 billion km³ of water, only 0.01% is available for human and ecosystem use (UNEP, 2020). This scarcity significantly impacts industries that heavily rely on water, particularly the apparel sector, which ranks among the highest consumers of water due to its wet processing activities such as dyeing, washing, and finishing (Gupta et al., 2021). The situation is particularly concerning in Sri Lanka, where the apparel industry plays a vital role in the national economy but is also one of the largest contributors to freshwater depletion and wastewater production (De Fonskea T.S., 2023).Water shortages in the apparel industry are expected to increase due to rising domestic and agricultural water demands, leading to a projected 270.3% increase in apparel water demand compared to 2014, creating a water gap of 2.495 to 5.282 BCM (Billion Cubic Meters) per year (Haque et al., 2021). Despite its economic significance, Sri Lanka's apparel industry struggles with outdated water management practices, and while some factories have implemented process-based monitoring and wastewater treatment, real-time water consumption monitoring remains largely unexplored (De Fonseka, 2023). Current monitoring techniques, including process-based monitoring, life cycle assessment, and water accounting, provide insights into water consumption trends but lack real-time data analytics for proactive decision-making (Silva et al., 2015). Additionally, existing digital water monitoring systems are expensive, lack automation, and fail to provide immediate feedback (Swarnapali & Kumarage, 2020). Given these limitations, the core research problem addressed in this study is the absence of accessible, real-time, and data-driven water consumption monitoring systems in Sri Lanka's apparel industry. This gap hinders the industry's ability to detect inefficiencies promptly, respond to abnormal water usage, and implement timely conservation measures. Without the integration of intelligent technologies like the Internet of Things (IoT), water inefficiencies will persist undermining sustainability goals and placing further stress on national water resources.The integration of IoT-based water monitoring systems offers a potential solution by enabling real-time tracking, remote data storage, and automated alerts for parameter deviations (Liu et al., 2023; Wang et al., 2020). Without immediate intervention and technological advancements, the Sri Lankan apparel industry risks exacerbating water shortages and undermining long-term sustainability goals. Therefore, implementing cost-effective IoT-enabled monitoring systems can

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enhance water efficiency, reduce environmental impact, and ensure the resilience of Sri Lanka's apparel industry amid growing water-related challenges. In this regard this paper aims to investigate the potential of Internet of Things (IoT) technologies for enhancing water consumption monitoring practices in Sri Lanka's apparel industry. The specific objectives are to identify the limitations of current water monitoring practices in the industry, and then to examine the key barriers to implementing IoT-based water monitoring systems and explore effective strategies to overcome these barriers and improve water efficiency and sustainability.

2. Literature Review

2.1. WATER CONSUMPTION IN APPAREL INDUSTRY

The apparel industry is notorious for its substantial water consumption throughout the textile manufacturing process, from fabric dyeing to finishing. Water is a critical resource in achieving the desired aesthetics, durability, and quality of textiles. Among the various stages, fabric dyeing is the most water-intensive, involving multiple dye baths and chemical treatments to ensure uniform colour absorption and fastness (Samanta et al., 2019). Beyond dyeing, other processes such as washing, finishing, and printing also require significant amounts of water to achieve specific fabric characteristics (Luo et al., 2021). The high water demand in textile processing contributes to environmental concerns, including water pollution, scarcity, and depletion (Yang et al., 2020). Wastewater discharge from textile factories often contains harmful chemicals and dyes, disrupting aquatic ecosystems and affecting water quality. The industry's excessive water consumption, coupled with inefficient management practices, threatens long-term sustainability (Asif,2017).

To mitigate these challenges, water consumption monitoring has become essential for environmental, economic, and regulatory reasons (Chowdhury et al., 2022)Tracking water usage enables companies to optimize efficiency, reduce waste, and comply with environmental regulations (Ozek, 2017). Effective monitoring enhances brand reputation, regulatory compliance, and cost savings, particularly in an industry with narrow profit margins (Hossain & Khan, 2020). Apparel brands are also expected to ensure responsible water use throughout their supply chains, holding suppliers accountable for sustainable practices (Clifford et al., 2018).

2.2. CURRENT STATUS OF WATER CONSUMPTION MONITORING TECHNIQUES IN APPERAL INDUSTRY IN SRI LANAKA

Sri Lanka's apparel industry is actively improving water consumption monitoring and management, aligning with global sustainability standards and buyer expectations (Muthukumarana et al., 2018). Advanced water management systems, including water meters, sensors, data analytics, and software platforms, are being implemented to track usage and detect inefficiencies (Thiry, 2014). Leading manufacturers such as MAS, Brandix, and Hirdaramani have committed to significant reductions in water consumption, with goals like zero water wastage and a 65% reduction in water intensity by 2025 (Mohanaraj et al., 2023).

Despite progress, integrating IoT solutions and digital monitoring technologies remains a challenge but offers opportunities for enhanced water management in the industry. Current water consumption monitoring practices in Sri Lankan apparel industry are described in table 2.2.

Table 1: Water consumption monitoring practices and techniques in Sri Lankan Apparel Industry

Water consumption monitoring Practices and techniques.	**Description**
Water audits	The absence of existing standards for water audits is notable. These assessments determine the amount of water generated by a system and the way it is utilized. (Silva et al., 2015)
Metering	Apparel's water consumption was addressed by utilizing water metering data to identify and correct water leaks. (Silva et al., 2015)
Retrofitting and replacing inefficient fixtures	Optimizing water flow rate by installing water-efficient fixtures, such as dual-flush toilets. (De Fonseka, 2023)
Water saving taps and faucet aerators	To enhance water conservation in the washroom and canteen areas, consider installing flow rate reduction aerators on the taps. (De Fonseka, 2023)
Installing sensor and peddle taps	This prevents wastage and flooding, where the taps may be left running. It relies on infrared sensors to trigger the water flow. (De Fonseka, 2023)

2.3. CHALLENGES ASSOCIATE WITH EXISTING PRACTICES

The apparel industry in Sri Lanka has made worthy progress in adopting water consumption monitoring practices and technologies. However, several issues and challenges continue, delaying the industry's path toward more efficient and sustainable water management. (Hildebrandt et al. 2021) found that it faces challenges due to water scarcity and environmental impact, including over-extraction, ecosystem degradation, and competition with local communities. This has increased the industry's responsibility to monitor and reduce its water footprint, as water resources are limited in certain regions.

Weerasiri, (2012) have examined Sri Lankan apparel manufacturers have implemented water monitoring systems, but their coverage and comprehensiveness vary. Some focus on specific processes, while others monitor water flow from intake to discharge, limiting the industry's ability to identify inefficiencies and areas for improvement. According to the study of Rupasinghe and Liyanaarachchi, (2017) discussed that encounters difficulties in managing and analyzing the vast amount of data generated by water consumption monitoring systems, including issues with storage, processing, and interpretation, which can delay informed decisions for optimizing water usage.

Munasinghe et al. (2016) have tested that implementing water monitoring systems can be costly, especially for smaller and medium-sized apparel manufacturers. Despite the long-term benefits, some companies struggle to allocate funds, making finding cost-effective solutions for accurate monitoring a challenge. According to the words of Perry et al. (2015) found that the Sri Lankan apparel industry must adhere to evolving national and international regulations regarding water use and discharge, which are not only legal obligations but also environmental responsibility, making compliance complex and demanding for companies.

Hemchandra, (2014) revealed that organizations often face resistance to adopting new water consumption monitoring practices due to hesitancy from traditional employees. Overcoming this resistance requires employee training and change management efforts to foster a data-driven water management culture (Mohanaraj et al., 2023). Proper upkeep and calibration of sensors and equipment are crucial for the reliability and accuracy of monitoring systems, and apparel manufacturers must allocate resources for regular maintenance to ensure data quality (Khattak et al., 2015). The apparel industry faces challenges in monitoring water consumption due to the lack of standardized methods, making it difficult to benchmark and compare practices across facilities or companies (Mueller et al., 2015) . This is due to the industry's complexity and the need for consistent practices across partners with varying technological capabilities.

Bailey et al. (2022) stated that the raising awareness about water consumption monitoring and its sustainability is a challenge, requiring a multi-faceted approach including technology investment, regulatory compliance, employee training, and industry-wide commitment. As per the statement of Munasinghe et al., (2021) described that the apparel industry in Sri Lanka evolves, these challenges present opportunities for growth, innovation, and enhanced environmental responsibility, highlighting the need for sustainable water management.

2.4. IOT IN MANAGING WATER CONSUMPTION MONITORING EFFECTIVELY

The Internet of Things (IoT) is a transformative concept that involves connecting physical objects implanted with sensors and software to exchange data with other devices and systems over the internet (Bhat et al., 2007). It has the potential to reform various aspects of our lives, including urban governance, healthcare, and manufacturing (Zhanlin et al., 2014). IoT is still in its early stages, but it has already found applications in healthcare, transportation, and automotive industries, with the potential for even more innovative applications as technology continues to mature (Institute of Electrical and Electronics Engineers, n.d). As technology matures, the scope for innovative IoT applications continues to grow especially in resource-intensive industries like textiles.

In the context of the apparel industry, water is a critical input used extensively in dyeing, washing, and finishing processes. However, traditional water management practices often lack transparency, accuracy, and real-time control, which results in excessive consumption, undetected leakages, and increased wastewater generation. Implementing IoT technologies in water monitoring can address these challenges by providing real-time data, enabling predictive maintenance, and optimizing water use throughout production stages. The following table 2 summarizes the key drivers for adopting IoT in water consumption monitoring within the apparel industry:

Table 2: Drivers of using IoT for water management monitoring in apparel industry

Drivers	**References**
Real-time data insights for monitoring water usage, detecting inefficiencies, and reducing waste	Abbate et al. (2023)
Accurate water consumption measurements at different textile production stages for better accountability	Hader et al. (2022)
Proactive leak detection to prevent waste and operational disruptions	Neri et al. (2023)
Water quality monitoring to ensure product quality and regulatory compliance	Liu et al. (2023)

Optimization of water usage, reduction of pollution risks, and conservation of local resources for sustainability	Chowdhury et al. (2022)
Cost savings by reducing operational expenses and optimizing resource use	Morales et al. (2023)
Alignment with sustainability goals, enhancing brand reputation and attracting eco-conscious consumers	Wang et al. (2020)
Demonstrating responsible water management as a moral and corporate responsibility	Tsai (2018)

2.5. BARRIERS OF USING IOT FOR WATER CONSUMTION MONITORING IN APPAREL INDUSTRY

Barriers to implantation are presented in Table 03 These details elaborate according to the countries that already use IoT for water consumption monitoring, since it will help evaluate barriers regarding the Sri Lankan apparel industry context

Table 3: Barriers of using IoT for water management monitoring in the apparel industry

Barriers	**References**
High initial investment costs for sensors, infrastructure, and data analytics tools	Hynes et al. (2020)
Sensor reliability and maintenance challenges due to harsh textile production conditions	Wang et al. (2020)
Data privacy and security concerns requiring encryption and protection against cyber threats	Neri et al. (2023)
Need for skilled analysts to interpret IoT data effectively for actionable insights	Liu et al. (2023)
Integration challenges with existing operational and IT systems to avoid disruptions and data silos	Chowdhury et al. (2022)
Scalability and adaptability issues to meet different facility requirements while managing costs	Turner et al. (2022)
Dependence on reliable power supply and network connectivity for continuous data transmission	Achar (2020)
Resistance from traditional employees, requiring training and change management initiatives	Kant (2012)
Compliance with regulatory requirements and environmental reporting standards	Alves et al. (2022); Akram et al. (2022)
Need for a strategic approach to maximize cost savings and sustainability benefits	Rathore (2022)

3. Methodology

This study adopts a qualitative approach, Qualitative research involves gathering and assessing non-numerical data to gain an in-depth understanding of concepts, opinions, and experiences (Teherani et al., 2015). As Drury et al. (2011) described qualitative approach can greatly improve the comprehension of the research context, enabling the development of appropriate sampling frames and relevant research questions and leading to more precise data analysis and interpretation. A semi-structured interview was adopted as the data collection method for implementing this research. Semi-structured interviews were carried out to validate the information gathered in the literature chapter and to check the progress of the research in the track. In addition, it was pointed out some solutions for the problems related to the implementation of smart features which are not identified in the literature. Purposive sampling was used to recruit participants who had substantial professional experience and subject matter expertise in areas relevant to the study. Experts were selected based on their roles in IoT systems, automation, information technology, engineering, or environmental sustainability within the apparel manufacturing sector in Sri Lanka. All the experts were chosen based on their expertise and experience. Semi- structured interviews with 11 participants were conducted which is considered sufficient in qualitative research to achieve data saturation where no new themes emerge from additional interviews to fulfil the objective of the expert interviews (Guest et al., 2006). Participants had between 5 and over 10 years of industry experience, ensuring reliable data. An interview guideline was created based on the findings of the literature review. The data from the expert interviews was manually analysed using code-based content analysis method. Six areas were covered in the expert interviews: the interviewee's background information; an overview of the Internet of Things in the apparel industry; the attributes and driving forces behind the IoT; potential benefits (positive enablers); barriers and limitations; strategies for overcoming those barriers and limitations. Table 04 provides a summary of the participants' professional backgrounds, outlining their designations and relevant areas of expertise to highlight the diversity and relevance of the selected interviewees.

Table 4: Summary of interview respondents

Expert ID	**Designation**	**Area of Expertise**	**Years of Expertise**
E1	Machine Learning Engineer	IoT, Machine Learning, Smart Systems	10+
E2	Chief Technology Officer	Technology Strategy, Apparel Manufacturing	8+
E3	Head of Automation	Industrial Automation, Process Optimization	10+
E4	Head of Engineering	Engineering Management, Apparel Sector	10+
E5	IT Support Engineer	IT Infrastructure, Systems Support	5+
E6	Technical Consultant	Automation, Industrial IT	8+
E7	Deputy General Manager – Compliance & Sustainability	Environmental Sustainability, Compliance	5+
E8	IT Executive	Information Systems, IT Support	5+
E9	IT Executive	IT Operations, Network Systems	8+
E10	Group Manager – ICT	Enterprise ICT, Digital Transformation	10+
E11	Textile Engineer	Textile Engineering, R&D, Smart Fabrics	10+

4. Findings

4.1. THE BARRIERS FACED BY APPERAL COMPANIES IN ADOPTING IOT FOR WATER CONSUMPTION MONITORING IN SRI LANKA

Table 5 was engaged in investigate the barriers to adopt Internet of Things in the apparel industry in Sri Lanka. It was investigated through a semi structured interview with someone who has expertise in both the Internet of Things and apparel industry.

Table 5: Barriers faced by apparel companies in adopting IoT.

Barriers	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**	**E11**
High initial investment costs for sensors, infrastructure, and data analytics tools	✓	▪✓	✓	▪✓	✓	✓▪	✓	✓	✓	✓▪	✓
Sensor reliability and maintenance challenges due to harsh textile production conditions	✓	▪✓	✓	▪	▪		▪	▪		▪	▪
Data privacy and security concerns requiring encryption and protection against cyber threats			✓		✓		✓	✓		✓	✓
Need for skilled analysts to interpret IoT data effectively for actionable insights	✓	✓	✓	▪✓		✓	✓▪		▪✓	✓	▪
Integration challenges with existing operational and IT systems to avoid disruptions and data silos	✓	▪		▪✓		✓	✓	✓			▪
Scalability and adaptability issues to meet different facility requirements while managing costs	✓			✓	▪			✓			▪
Dependence on reliable power supply and network connectivity for continuous data transmission	✓	▪			✓		▪	▪			
Resistance from traditional employees, requiring training and change management initiatives			▪	▪	▪	✓▪	✓	▪	▪	✓▪	✓▪
Compliance with regulatory requirements and environmental reporting standards	✓					▪✓	✓		✓		
Need for a strategic approach to maximize cost savings and sustainability benefits			▪		✓	▪✓	▪	✓		▪	▪
Low quality and unavailability of IoT devices and technologies in the local market	✓		✓								
Evolving technology and rapidly changing standards	✓	✓									

Both the literature and expert interviews identified high initial investment costs as a major barrier. Hynes et al. (2020) highlight the substantial upfront costs of implementing IoT systems, particularly for small and medium-sized enterprises. This is supported by the all the experts that the capital required for infrastructure, sensors, and data analytics tools remains a significant challenge, especially for resource-constrained companies. The reliability of sensors in harsh textile environments is another barrier discussed in the literature by Wang et al. (2020), with sensors prone to failure due to exposure to chemicals and high-stress conditions. Experts (E1, E2, E3) confirmed this challenge, pointing out that maintaining sensor performance under these harsh conditions is a persistent issue for the apparel industry, highlighting the need for more durable and specialized IoT devices. Data privacy and security are critical barriers identified by Neri et al. (2023), emphasizing the need for strong encryption and protection against cyber threats. Experts E3, E5, E7, E8, E10 and E11 echoed this concern, underscoring the need for secure data management practices, particularly when handling large volumes of sensitive data. This barrier aligns with the literature, which stresses that security is a primary concern for IoT adoption across industries.

Liu et al. (2023) point out the lack of skilled personnel to interpret IoT data effectively. This was further highlighted by the most experts (E1, E2, E3, E4, E6, E7, E9, E10) that the shortage of trained professionals capable of managing and analysing IoT data is a significant impediment to IoT adoption. This gap in expertise aligns with the literature's call for specialized knowledge to support IoT systems. Chowdhury et al. (2022) discuss integration challenges with existing IT systems as a major barrier. Experts E1, E4, E6, E7 and E8 agreed, noting that integrating IoT systems with legacy systems can cause disruptions and requires careful planning. This finding reinforces the literature's concern that seamless integration with existing infrastructure is crucial to prevent operational disruptions and data silos. Technological compatibility emerged as a significant concern, as highlighted by experts E1, E4 and E8 that ensuring IoT systems work well with existing technologies like Wi-Fi, GSM, and GPS is vital for effective implementation. While scalability and adaptability were not directly mentioned in the expert interviews, these concerns are closely related to compatibility issues, as IoT systems must be flexible enough to meet the varying needs of different facilities, a point addressed by Turner et al. (2022). Resistance to adopting new technologies, as noted by Kant (2012), was identified by experts E6, E7, E10 and E11 as a significant barrier in the apparel industry. Experts pointed out that employees' reluctance to embrace change requires comprehensive training and change management initiatives to overcome. This aligns with the literature's suggestion that cultural and organizational factors play a critical role in the successful implementation of IoT systems. Experts E1, E6, E7 and E9 also noted limited awareness of the benefits of IoT, particularly regarding its role in water management and sustainability. This aligns with Alves et al. (2022), who stressed the importance of increasing awareness about IoT's regulatory advantages. Additionally, experts identified regulatory compliance as a challenge, particularly regarding environmental standards, which remains a key barrier in the Sri Lankan context. Apart from the barriers identified in the literatures some experts mentioned the barriers that relevant to Sri Lankan apparel industry such as the low quality and unavailability of IoT devices in the local market, identified by experts E1 and E3. They pointed out that local products are often of low quality or unavailable, forcing companies to rely on costly imports. This limitation highlights a gap in the literature and emphasizes the need for local IoT suppliers to meet the demand for reliable devices. Finally, evolving technology was mentioned by experts E1 and E2, noting the challenge of keeping up with rapidly changing IoT standards and innovations. This concern reflects the literature's acknowledgement that the fast pace of technological advancements can create uncertainty for businesses, making it difficult to ensure the long-term viability of IoT investments.

4.2. STRATEGIES TO OVERCOME IDENTIFIED BARRIERS IN IOT ENABLED WATER CONSUMPTION MONITORING SYSTEM IN APPAREL INDUSTRY IN SRI LANKA

Table 6 presents the strategies suggested by experts to overcome the identified barriers through literature review and the expert interviews

Table 6: Expert Responses on Strategies to Overcome the barriers.

Strategies to Overcome Barriers	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**	**E11**
Bulk purchase & maintenance	✓	▪	▪	▪	▪	▪				▪	▪
Scalability & futureproofing	✓	▪	▪	▪	▪		▪	▪	✓	▪	▪
Raising adaptation.	✓	▪	▪	▪	▪	▪	▪	▪	✓	▪	▪
Develop a data governance strategy	✓	✓	▪	▪	✓		✓	✓	▪	✓	✓
Proper documentation and installation	✓			▪	▪	▪		✓			▪
Training and improvement	✓	✓	▪	✓	✓		✓	✓	✓	✓	✓
Financial support	▪	✓	▪	▪	▪	▪	✓	▪	▪	✓	✓
Government must offer incentives & subsidies.		✓	✓	✓	✓	▪	✓	✓	✓	▪	✓
Market availability			✓	▪	✓	▪	▪	▪	▪	▪	▪
Continuous knowledge enhancement		✓		✓	✓			✓			
Consulting services to organizations.		✓		▪	✓	▪	✓	▪	✓	▪	✓
Standardization, Collaboration & User adoption		✓		✓	▪	✓	✓	✓		✓	✓
Government-led IoT water management.						✓				✓	✓
Conduct a pilot project										✓	

Experts proposed various strategies to overcome barriers and successfully adopt IoT-enabled water consumption monitoring systems in the apparel industry. To address high initial costs, they suggested progressive investment options, including government incentives and subsidies. E2 emphasized that government initiatives providing tax breaks, grants, and subsidies can reduce financial burdens, making IoT adoption more feasible. E3 recommended reducing or removing import taxes on IoT technology to promote local production, while E4 stressed the importance of creating a supportive regulatory environment. Financial support through leasing programs, as suggested by E2, and exploring financing options or initiating small-scale projects to demonstrate ROI, as noted by E11, were also highlighted. Bulk purchasing was identified as another way to reduce costs, as buying in larger quantities significantly lowers per-unit expenses, making IoT investment more manageable for companies. Lack of technical expertise and training gaps were identified as major barriers, with experts advocating for training and workforce improvement programs. E1 pointed out that many employees lack knowledge about IoT, making training essential. E4 suggested developing user-friendly dashboards and reports to simplify data interpretation, while E10 emphasized that in-house training programs can help build expertise necessary for implementing and maintaining IoT systems. Additionally, E7 highlighted that organizing training sessions and engaging employees in the adoption process can help reduce resistance to change.

Addressing data security and privacy concerns, experts recommended developing a strong data governance strategy. E10 suggested implementing policies and procedures for data collection, storage, and sharing to ensure secure and responsible management. E2 stressed the importance of understanding how data is stored and secured, advocating for reputable tech providers with proven cybersecurity measures. Industry-standard security protocols, data encryption, and staff education on data protection were seen as crucial components of a secure IoT system. E8 reinforced this view by advocating for strict cybersecurity safeguards and encryption standards, while E11 highlighted the need for strong security measures, including secure access controls and compliance with data privacy laws. A robust cybersecurity system also improves reliability, as noted by E1, who stated that better security ensures more reliable IoT performance. The complexity of implementation and technological compatibility issues were addressed through strategies like proper documentation, standardization, and collaboration. E1 emphasized that having detailed implementation documentation and proper installation practices, such as securing wiring and correctly positioning sensors, can facilitate a smoother setup process. E8 supported this by stressing the need for technical assistance and collaboration with tech companies to improve interoperability. Many experts, including E7 and E8, proposed industry-wide standardization initiatives and collaborations to tackle interoperability challenges. E4 suggested developing standardized plug-and-play systems to simplify IoT integration, while E6, E10, and E11 believed that apparel companies should participate in industry groups promoting IoT adoption and develop user-friendly monitoring solutions. Consulting services were also recommended, with E2 suggesting that technology providers offer on-site or remote consulting to assist organizations in implementation. E5, E7, and E9 noted that industry associations could promote IoT adoption through workshops, best practices, and research-driven initiatives to reduce complexity.

The low quality and unavailability of IoT solutions were addressed by ensuring market availability and competitive pricing. E3 emphasized the importance of bringing high-quality IoT products to the market at reasonable prices, while E5 highlighted the need for tailored IoT packages, training programs, and continuous support from technology providers. Similarly, the challenge of limited awareness was countered with continuous knowledge enhancement. E2 proposed that industry associations and technology providers develop educational materials, webinars, and workshops to raise awareness about IoT-based water efficiency. E4 stressed the importance of showcasing real-world case studies to demonstrate cost savings and environmental benefits, while E5 and E8 supported the idea of organizing industry events, training programs, and awareness campaigns to promote innovation and adoption. To mitigate the challenges posed by evolving technology, experts recommended scalability and future-proofing strategies. E1 and E9 emphasized the need for a well-planned approach that minimizes device waste, ensures proper maintenance, and facilitates phased implementation. Starting with small-scale projects and gradually scaling up was seen as a practical way to ensure long-term success. Resistance to change was another critical issue, with experts emphasizing the importance of communication and adaptation. E9 noted that effective communication is key to convincing stakeholders about the benefits of IoT, demonstrating how it simplifies operations and improves efficiency.

Government led IoT water management was another proposed strategy. E6 suggested that government institutions take the lead in IoT adoption for water monitoring, creating centralized initiatives that pool resources and knowledge to support widespread implementation. E10 and E11 emphasized that companies require clear government guidelines and regulatory support to confidently invest in IoT solutions. Clear regulations would also ensure data security and promote water conservation efforts. Additionally, conducting pilot projects was recommended as a risk mitigation strategy. E10 suggested that before implementing large-scale IoT solutions, companies should test pilot projects to identify potential issues, measure benefits, and refine implementation strategies. Overall, experts provided a comprehensive set of strategies addressing financial, technical, security, and awareness related barriers to IoT adoption in water consumption monitoring. By leveraging government support, improving workforce training, ensuring cybersecurity, simplifying implementation, enhancing market availability, promoting awareness, and planning for future scalability, apparel companies can successfully integrate IoT solutions for more efficient water management.

5. Conclusion

The adoption of the Internet of Things (IoT) for water consumption monitoring in Sri Lanka's apparel industry presents both promising opportunities and substantial challenges. This study has revealed that despite the transformative potential of IoT to enhance operational efficiency, minimize water waste, and promote environmental sustainability, several critical barriers impede its widespread adoption. These include high initial capital costs, limited technical expertise, data security concerns, lack of awareness, and complexities in system integration. Technological issues such as equipment reliability and compatibility, as well as the availability of quality IoT devices, further constrain implementation. The high upfront investment in IoT infrastructure remains the most significant hurdle, compounded by a shortage of trained personnel and insufficient capacity to interpret and utilize IoT-generated data effectively.

Importantly, the implications of this research are multi-dimensional. At the industry level, it underscores the urgent need for digital transformation in water management to meet both economic and environmental sustainability goals. At the policy level, the findings suggest a call for targeted interventions, including financial incentives, regulatory frameworks for data protection, and structured capacity-building programs. For technology providers, the study highlights opportunities to develop cost-effective, scalable, and user-friendly IoT solutions tailored to the needs of emerging economies like Sri Lanka. However, this study has several limitations. It primarily focuses on the current state and stakeholder perceptions within a limited sample of apparel manufacturing firms. The research did not include longitudinal data or pilot implementations of IoT systems, which could provide more detailed insights into real-time operational impacts. Additionally, economic analysis of return on investment (ROI) for IoT systems was beyond the scope of this study, though it remains a critical factor for adoption decisions.

In conclusion, while challenges persist, this research provides a foundational understanding of the enablers and barriers to IoT adoption in the Sri Lankan apparel industry. By addressing these issues through strategic collaboration among policymakers, industry leaders, and technology developers, the sector can unlock the full potential of IoT for improved water management, operational efficiency, and sustainability. Future research should explore empirical case studies, long-term cost-benefit analyses, and integrated implementation frameworks to further guide effective adoption and scale-up across the industry.

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