Research Article

Sustainability Practices and Green Lab Initiatives in Clinical Laboratories in Pakistan: A National e-Survey-Based Analysis

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Abstract

Introduction: Clinical laboratories play a vital role in healthcare but contribute significantly to environmental challenges through high energy consumption, water usage, and waste generation. Pakistan's healthcare sector faces challenges, including limited funding and inadequate awareness of sustainable practices. There is little data on the extent to which clinical laboratories in Pakistan have implemented green practices, making it crucial to assess current efforts and identify barriers to adoption. This study aims to assess the adoption of sustainability and green lab practices in clinical laboratories across Pakistan.

Methods: A cross-sectional survey was conducted by the Chemical Pathology section at Aga Khan University (AKU) using a structured questionnaire. The survey comprised 13 sections to evaluate sustainability practices, covering demographics, current green practices (energy efficiency, water conservation, waste management, etc.), barriers to implementation, environmental and cost impacts, and future goals. It assessed laboratories' existing efforts, challenges, and aspirations for improving sustainability. The survey was distributed via Google Forms to major laboratories across Pakistan via WhatsApp and email. Data was analyzed using Excel (Microsoft Corporation, 2018) software.

Results: A total of 12 laboratories across the country, from the capital Islamabad and all provincial capitals participated in the survey. Key findings include widespread adoption of energy-efficient lighting (75%) and electronic reporting (91.7%), but limited use of water-saving technologies (8.3%) and renewable energy (0%). Barriers like limited resources (58.3%), lack of staff awareness (50%), and financial constraints (41.7%) hindered green practices, though 41.7% reported moderate cost savings. Future goals focused on green certifications (58.3%), recycling programs (50%), and energy-efficient upgrades (41.7%).

Conclusion: Our findings underscore the urgent need for structured sustainability policies, financial incentives, and educational programs to enhance green laboratory practices in Pakistan. While some progress has been made, significant gaps remain in energy efficiency, waste management, and regulatory compliance

Introduction

Clinical laboratories play a critical role in healthcare delivery, providing essential diagnostic services that inform patient care and treatment decisions [1]. However, the operations of these laboratories often come with significant environmental costs, including high energy consumption, water usage, and the generation of hazardous and non-hazardous waste [2]. As global awareness of environmental sustainability grows, there is an increasing need for healthcare institutions, including clinical laboratories, to adopt practices that minimize their ecological footprint while maintaining high standards of patient care [2,3].

Sustainability in clinical laboratories encompasses a wide range of practices, from energy-efficient lighting and equipment to waste reduction, water conservation, and the use of environmentally friendly chemicals [4]. These practices not only contribute to environmental preservation but can also lead to operational cost savings and improved efficiency [5–7]. Despite these potential benefits, the adoption of sustainable practices in clinical laboratories remains uneven, particularly in low- and middle-income countries where resource constraints and competing priorities often take precedence [8–10].

In Pakistan, the healthcare sector faces numerous challenges, including limited funding, inadequate infrastructure, and a lack of awareness about sustainable practices [11]. While there is growing recognition of the importance of sustainability in healthcare, there is a paucity of data on the extent to which clinical laboratories in Pakistan have embraced green practices. Understanding the current state of sustainability in these laboratories is essential for identifying gaps, addressing barriers, and developing strategies to promote environmentally responsible operations.

This study aims to assess the adoption of sustainability practices in clinical laboratories across Pakistan. Through a comprehensive survey, we evaluated key areas such as energy and water consumption, waste management, and the use of environmentally friendly chemicals. The survey also explored the barriers laboratories face in implementing sustainable practices and the potential cost savings associated with these initiatives. By providing a snapshot of the current state of sustainability in Pakistani clinical laboratories, this study seeks to inform policymakers, healthcare administrators, and laboratory professionals about the opportunities and challenges in promoting greener laboratory practices.

The findings of this study are expected to contribute to the growing body of literature on sustainability in healthcare, particularly in resource-constrained settings. Furthermore, they will provide a foundation for future research and interventions aimed at reducing the environmental impact of clinical laboratories while enhancing their operational efficiency and cost-effectiveness.

Methods

Study Design

This study employed a cross-sectional, survey-based design to assess sustainability practices in clinical laboratories in Pakistan. The survey aimed to evaluate current green practices, identify barriers to implementation, and explore future goals for improving sustainability. Data was collected through an online survey administered over a two-week period.

Participant Recruitment

The target population for this study included clinical laboratories in Pakistan. A total of 12 large-scale clinical laboratories were invited to participate in the survey, and all 12 responded (100% response rate). Inclusion criteria required laboratories to be operational and actively engaged in diagnostic activities. Recruitment was conducted via WhatsApp and email invitations sent to Consultant Pathologists and Lab Directors.

Survey Instrument

The survey consisted of 13 sections designed to comprehensively assess sustainability practices:

Section I: Demographics (e.g., laboratory size, type, and location).

Section II: Current Green Practices, divided into subsections:

- II-A: Energy Efficiency
- II-B: Water Conservation
- II-C: Material and Resource Optimization
- II-D: Waste Management
- II-E: Digital and Paperless Operations
- II-F: Chemical and Biological Sustainability
- II-G: Green Certifications and Policies
- II-H: Sustainability Training and Awareness
- II-I: Additional Practices

Section III: Barriers to Implementing Green Practices
Section IV: Environmental and Cost Impact
Section V: Future Goals and Improvements
The survey included a mix of closed ended (e.g., Likert scale, multiple-choice) and open-ended questions. The instrument was pretested for clarity and relevance with a small group of laboratory professionals prior to distribution. The full questionnaire is provided in Supplementary File.

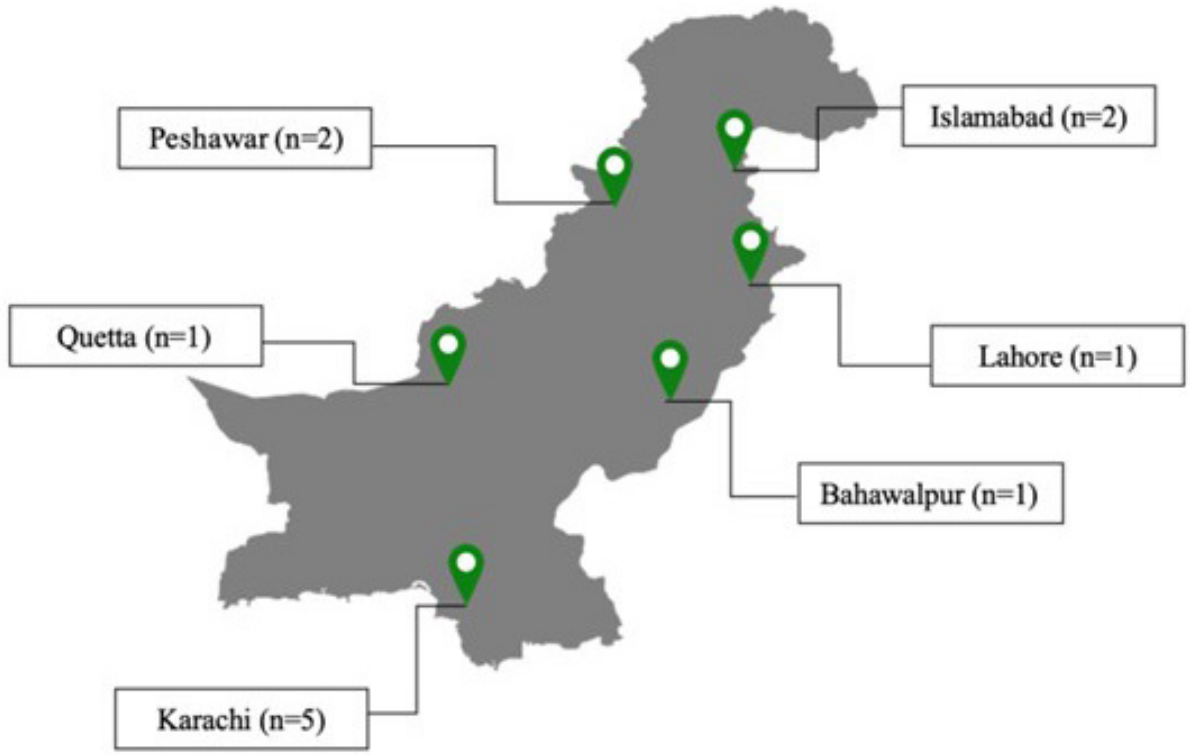
Data Collection
The survey was administered online using a secure survey platform (Google Forms). Participants were provided with a unique link to access the survey. The survey remained open for two weeks, and reminders were sent to non-responders after the first week. Electronic informed consent was obtained from all participants before they could proceed to the survey questions. Participation was voluntary, and responses were anonymized to ensure confidentiality.

Data Analysis
Descriptive statistics were used to summarize demographic data and responses related to current green practices, barriers, and future goals.

Ethical Considerations
All participants provided electronic informed consent prior to participating. The survey was designed to ensure anonymity, and no personally identifiable information was collected. Data were stored securely on password-protected servers, and access was restricted to the research team. Approval was sought from the institutional ethical review committee of the Aga Khan University (2025-11186-33468).

Results
Laboratory Size, Type, and Location
The survey collected responses from clinical laboratories of varying sizes, with the majority being large laboratories (> 50 staff members) (10/12; 83.3%). A smaller proportion comprised medium-sized laboratories (10–50 staff members) (2/12; 16.7%). Laboratories from multiple cities participated, as depicted in Figure 1, with the highest number of responses coming from Karachi (5/12; 41.6%), followed by Islamabad (2/12; 16.7%), Peshawar (2/12; 16.7%), and others from Lahore, Quetta, and Bahawalpur (1/12 each; 8.3%). Most participating laboratories were affiliated with private hospitals (5/12; 41.7%), while public hospitals (4/12; 33.3%), diagnostic centers (2/12; 16.7%), and independent laboratories (1/12; 8.3%) also contributed.

Figure 1: Map of Pakistan highlighting the cities from which responses were received, along with their respective frequencies.

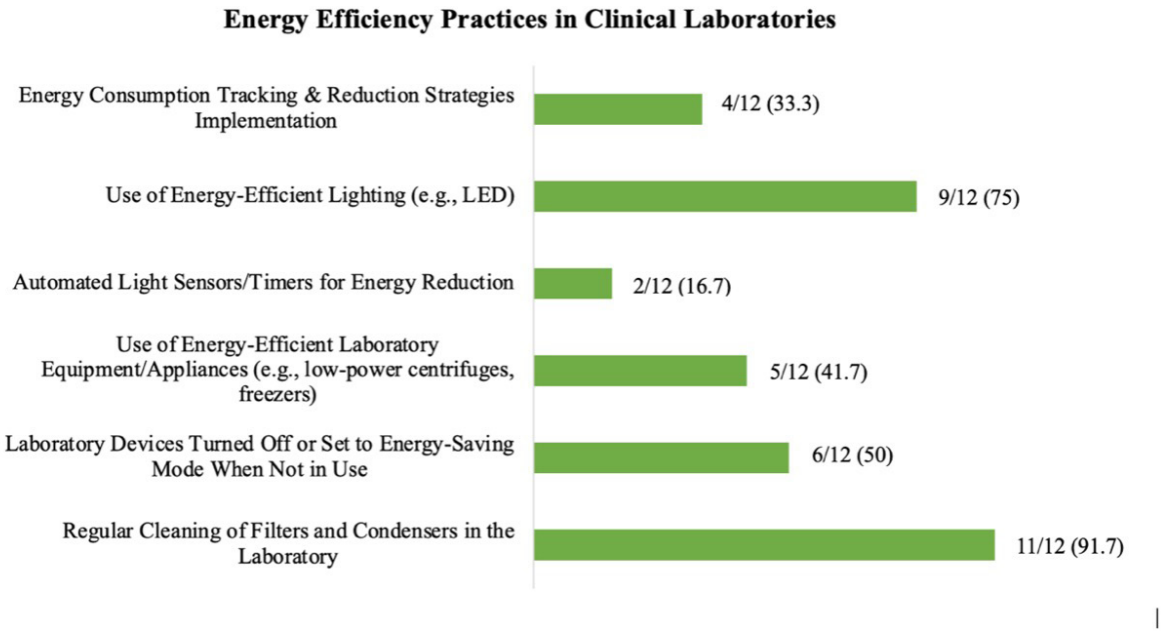


Current Green Practices

Energy Efficiency

Energy consumption tracking was implemented in 8/12 (66.7%) laboratories; however, only 4/12 (33.3%) actively employed strategies to reduce energy use. Energy-efficient lighting was widely adopted, with 9/12 (75.0%) laboratories utilizing LED lighting throughout their facilities and an additional 3/12 (25.0%) incorporating LED lighting in some areas. However, automated light sensors or timers were either fully or partially installed in only 2/12 (16.7%) laboratories. Furthermore, 7/12 (58.3%) laboratories lacked energy-efficient equipment, such as low-power centrifuges and freezers. While half of the laboratories (6/12, 50.0%) actively minimized unnecessary energy consumption through scheduled equipment shutdowns, a notable 11/12 (91.7%) prioritized regular maintenance by either frequently cleaning filters and condensers, or as needed. Findings have been summarized in Figure 2.

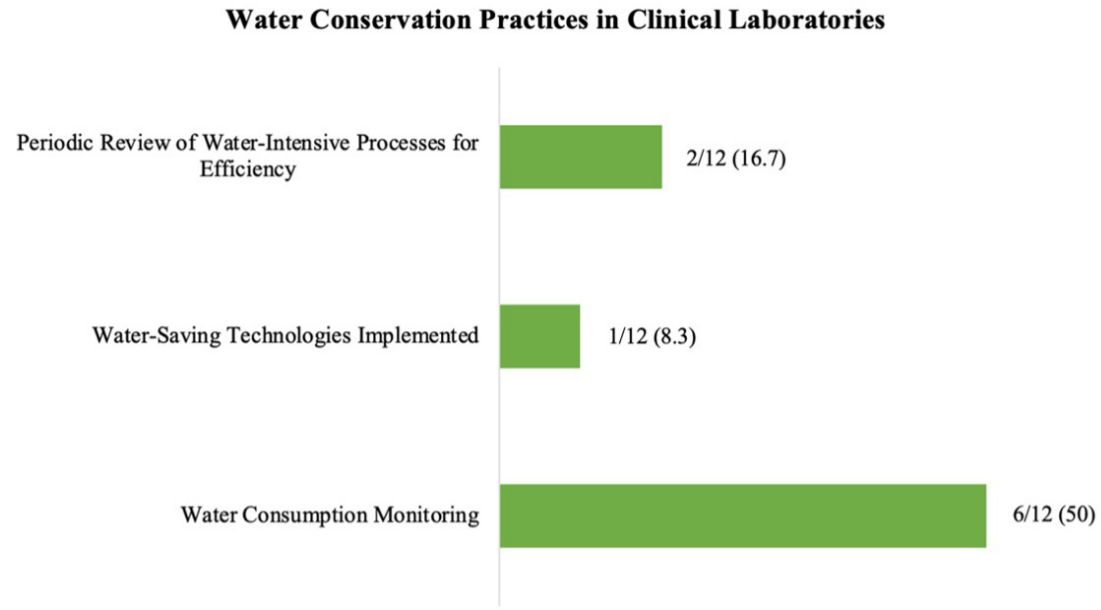
Figure 2: Adoption of energy efficiency practices in clinical laboratories, showing the percentage of laboratories implementing various sustainability measures.



Water Conservation

Water consumption (either all or only water-intensive processes) was actively monitored in 6/12 (50.0%) laboratories, while only 1/12 (8.3%) reported implementing water-saving technologies such as reusing wastewater from their reverse osmosis plant for flushing toilets. A majority, 10/12 (83.3%), did not conduct routine reviews of their water-intensive processes for efficiency improvements. Findings have been summarized in Figure 3.

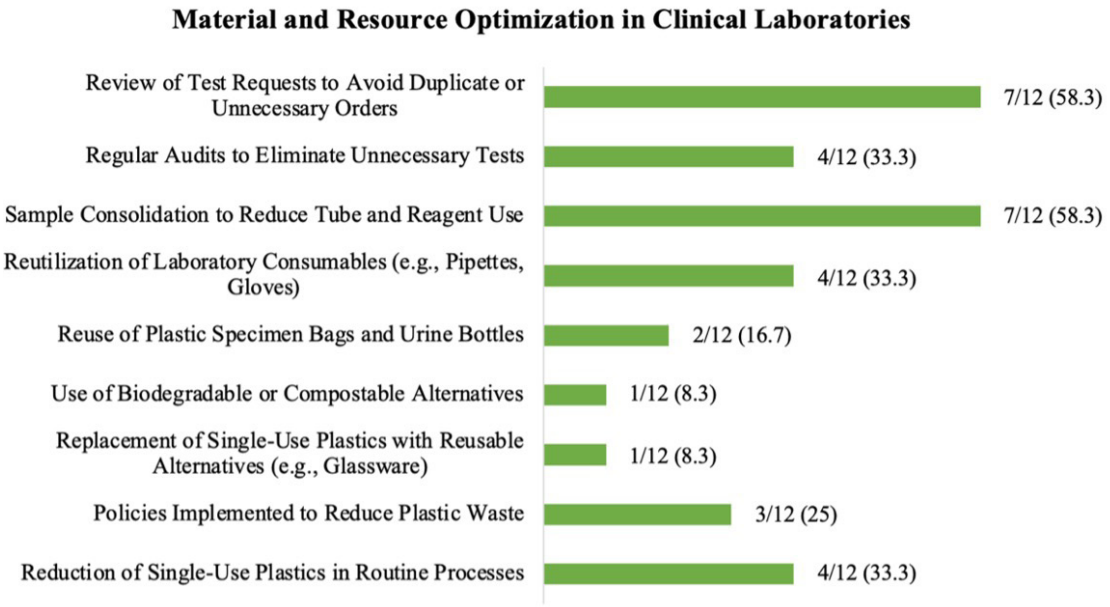
Figure 3: Adoption of water conservation practices in clinical laboratories, showing the percentage of laboratories implementing various sustainability measures.



Material and Resource Optimization

The survey results highlight varying levels of commitment to reducing single-use plastics in laboratories. While 4/12 (33.3%) laboratories have taken steps to limit the use of single-use plastics in routine processes, an equal proportion, 4/12 (33.3%), reported that no actions have been taken, indicating a gap in sustainability efforts. 3/12 (25.0%) laboratories have implemented policies aimed at reducing plastic waste, reflecting a structured approach toward sustainability. However, the adoption of alternative materials remains low, with only 1/12 (8.3%) replacing single-use plastics with reusable alternatives such as glassware, and another 1/12 (8.3%) switching to biodegradable or compostable options. 2/12 (16.7%) laboratories identified and reused plastic specimen bags and 24-hour urine bottles within safe limits to minimize plastic waste. Additionally, 4/12 (33.3%) implemented the reutilization of laboratory consumables, such as pipettes and gloves, where safety permitted. The consolidation of samples to reduce collection tube and reagent use was reported by 7/12 (58.3%), ensuring resource optimization and minimizing unnecessary consumption. Regular audits to identify and eliminate outdated or unnecessary tests were conducted in 4/12 (33.3%) laboratories, helping to prevent the excessive use of reagents and consumables. Furthermore, 7/12 (58.3%) laboratories reviewed test requests to reject unnecessary or duplicate test orders, improving efficiency and reducing excess material usage. Findings have been summarized in Figure 4.

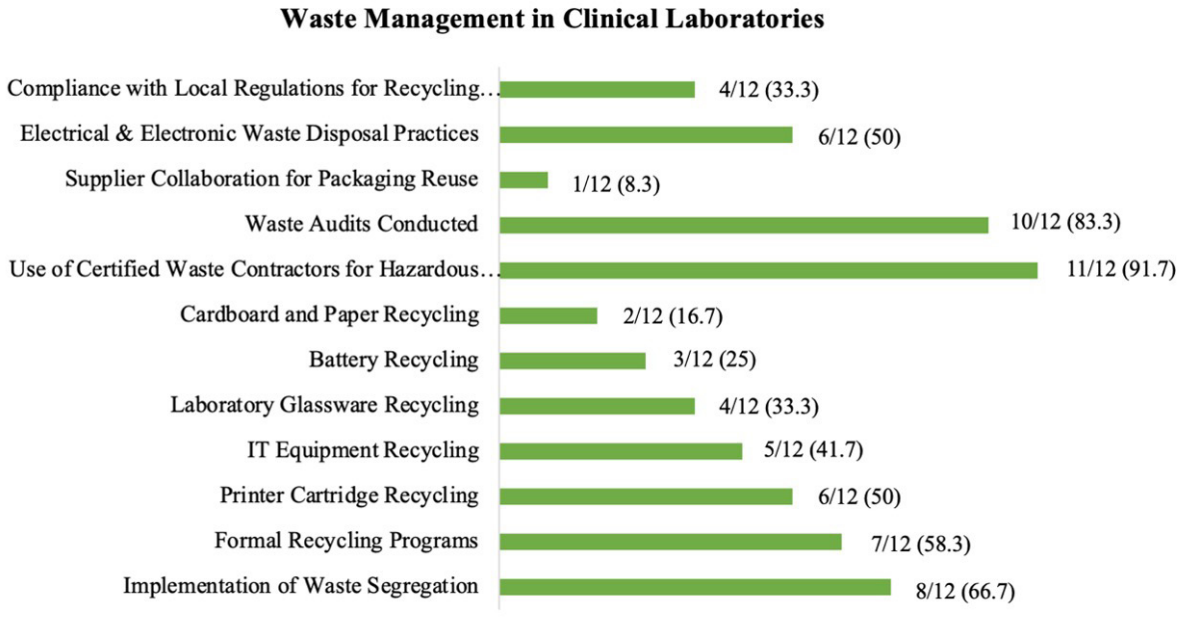
Figure 4: Material and resource optimization in clinical laboratories, showing the percentage of laboratories implementing various sustainability measures.



Waste Management

Waste segregation was implemented in 8/12 (66.7%) laboratories, ensuring the separation of hazardous, recyclable, and general waste. Despite this, 5/12 (41.7%) laboratories had no formal recycling programs in place. Among those actively engaged in recycling, printer cartridge recycling was reported by 6/12 (50.0%), IT equipment recycling by 5/12 (41.7%), and laboratory glassware recycling by 4/12 (33.3%), followed by battery recycling in 3/12 (25.0%) and cardboard/paper recycling in 2/12 (16.7%). For hazardous waste disposal, a majority of 11/12 (91.7%) laboratories relied on certified waste contractors to handle hazardous materials safely. Additionally, 10/12 (83.3%) laboratories conducted waste audits to evaluate and improve their waste separation practices, with 8/12 (66.7%) conducting them on a regular basis. However, only 1/12 (8.3%) laboratories worked with suppliers to return and reuse packaging materials such as Styrofoam, paper, and cardboard. Half of the laboratories (6/12, 50.0%) adopted electrical and electronic waste disposal practices, but only 4/12 (33.3%) reported compliance with local regulations for recycling items such as fluorescent tubes, batteries, phones, and computers. Findings have been summarized in Figure 5.

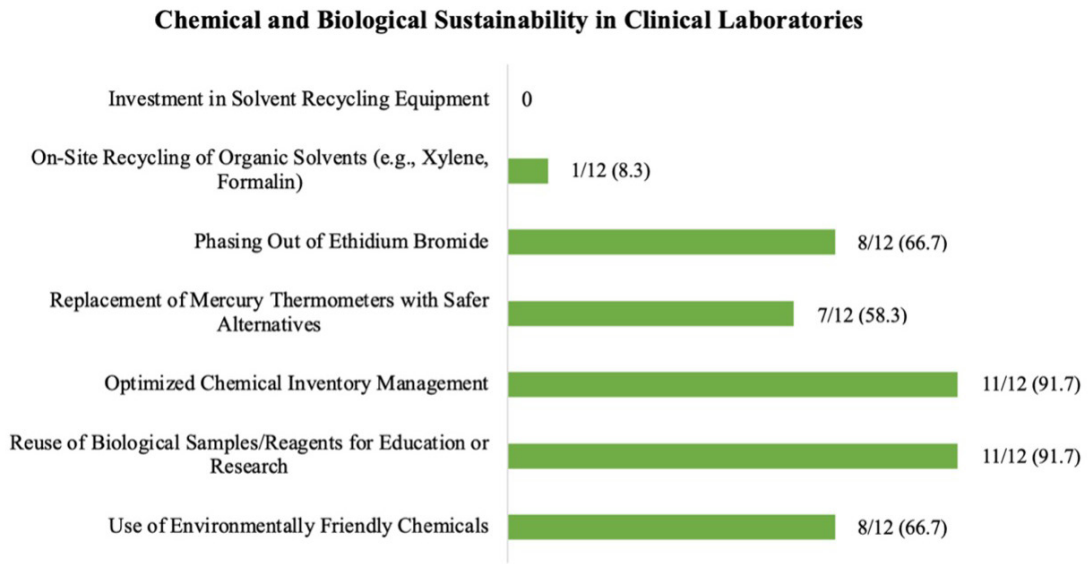
Figure 5: Waste management practices in clinical laboratories, showing the percentage of laboratories implementing various sustainability measures.



Digital and Paperless Operations
Paper reduction strategies were widely adopted, with 11/12 (91.7%) laboratories implementing electronic reporting to minimize paper use. Furthermore, 6/12 (50.0%) had fully transitioned to electronic medical records (EMRs). Moreover, 9/12 (75.0%) laboratories reported encouraging their staff to practice double-sided printing or avoid printing when necessary.

Chemical and Biological Sustainability
Environmentally friendly chemicals were used in 8/12 (66.7%) laboratories, primarily replacing toxic solvents with safer alternatives such as xylene substitutes, and 11/12 (91.7%) were involved in the reuse of biological samples or reagents for educational or research purposes where applicable. Additionally, 11/12 (91.7%) laboratories had optimized their chemical inventory management to minimize overstocking and reduce waste. Mercury thermometers were completely replaced with safer alternatives in 7/12 (58.3%) laboratories, while 8/12 (66.7%) had either completely or almost completely phased out ethidium bromide for safer nucleic acid staining methods. Only 1/12 (8.3%) laboratories recycled certain organic solvents like xylene and formalin on-site, while none of the laboratories had invested in a solvent recycler. Findings have been summarized in Figure 6.

Figure 6: Chemical and biological sustainability practices in clinical laboratories, showing the percentage of laboratories implementing various sustainability measures.



Green Certifications and Policies
5/12 (41.7%) of the laboratories had either a formal (2/12, 16.7%) or informal (3/12, 25.0%) sustainability and environmental policy in place. None of the laboratories had green purchasing policies, and only 3/12 (25.0%) reported that their suppliers were aware of their green policies, though these had not been formally communicated. 7/12 (58.3%) of the laboratories expressed that their suppliers provided eco-friendly reagents and materials, but this was not consistent. Additionally, 9/12 (75.0%) laboratories expressed that they had no interest in obtaining any green certifications such as ISO 14001 to align sustainability efforts with industry standards.

Sustainability Training and Awareness
Staff training on sustainability practices was implemented in 4/12 (33.3%) laboratories, with 1/12 (8.3%) conducting regular workshops or awareness sessions. Moreover, 9/12 (75.0%) laboratories reported ongoing initiatives or campaigns to promote environmental awareness among staff, with 2/12 (16.7%) conducting regular campaigns and initiatives.

Additional Practices
11/12 (91.7%) of the laboratories expressed that they did not use any carbon offset programs or any kind of renewable energy sources.

Barriers to Implementing Green Practices
The most cited barriers to sustainability adoption, as depicted in Figure 7, included limited resources (space, equipment, etc.) in 7/12 (58.3%) laboratories; lack of awareness or training among staff in 6/12 (50.0%); and financial constraints in 5/12 (41.7%). Additionally, resistance to change by staff was reported by 4/12 (33.3%), and regulatory or legal constraints by 4/12 (33.3%). Lack of support from leadership was cited by 1/12 (8.3%) laboratories. In terms of perceived significance, 7/12 (58.3%) respondents described these barriers as somewhat significant, while 5/12 (41.7%) considered them very significant.

Figure 7: Key barriers to sustainability adoption in laboratories.

Environmental and Cost Impact

The adoption of green practices resulted in a moderate reduction in operational costs for 5/12 (41.7%) laboratories, while 1/12 (8.3%) reported a significant reduction in operational costs (e.g., energy savings, reduced material usage, waste management cost reduction). However, 3/12 (25.0%) laboratories reported no change in operational costs. In terms of environmental benefits, 9/12 (75.0%) laboratories reported a reduction in waste production, and 5/12 (41.7%) reported reduced water usage, an increased recycling rate, and improved air quality (e.g., reducing chemicals or emissions). 4/12 (33.3%) noted a decrease in carbon footprint as well as improved resource efficiency. Additionally, 5/12 (41.7%) experienced cost savings, but only in specific areas (e.g., energy savings from energy-efficient equipment).

Future Goals and Improvements

When asked about desired future sustainability practices, respondents identified key areas for improvement. The most frequently suggested initiatives included obtaining green certifications and water-saving technologies in 7/12 (58.3%) laboratories; enhancing recycling programs in 6/12 (50.0%); investing in energy-saving equipment upgrades and comprehensive waste reduction programs in 5/12 (41.7%); and collaborating with environmentally conscious suppliers in 4/12 (33.3%).

Discussion

This study provides a comprehensive assessment of sustainability practices in clinical laboratories across Pakistan, shedding light on current green initiatives, obstacles to implementation, and potential areas for improvement. Although the sample size was limited to 12 laboratories, these represented major diagnostic centers located in the federal capital and all four provincial capitals of Pakistan. Given the centralized nature of diagnostic services in Pakistan-where provincial capitals and national referral centers serve as hubs for high-volume testing-this cohort provides a meaningful reflection of current practices and barriers to sustainability in the country. While not exhaustive, the geographic breadth and inclusion of both public and private sector laboratories strengthens the representativeness of our findings. While there is growing recognition of environmental responsibility, many laboratories face significant challenges in fully integrating sustainability into their operations. Stronger institutional commitment, clearer policy guidelines, and widespread awareness efforts are essential to making meaningful progress [12].

Although some laboratories have adopted sustainability measures, their implementation remains inconsistent. Energy efficiency strategies, such as LED lighting and regular equipment maintenance, indicate progress in reducing energy consumption; however, the adoption of automated light sensors and energy-efficient equipment remains limited, largely due to financial constraints and a lack of technical guidance. Many laboratories struggle to justify the initial investment despite the potential for long-term cost savings. To overcome these financial barriers, several mechanisms could be explored, including government-led subsidies, preferential tax benefits for eco-friendly equipment, targeted funding programs, and external support through international sustainability grants or public-private partnerships. The economic case for sustainability is strong: for instance, an Australian laboratory implementing ISO 14001 reported over $500,000 in savings by adopting digital reporting, energy-efficient upgrades, and optimized air conditioning use [7]. Such examples highlight the substantial return on investment (ROI) that can be

achieved when sustainability is integrated strategically [13]. Demonstrating these long-term cost savings may also help secure stronger leadership commitment-an obstacle identified by 8.3% of respondents-and emphasizes the importance of aligning financial incentives with sustainability outcomes to overcome both economic and institutional resistance to change.

Water conservation is another area where sustainability efforts remain inadequate. Most laboratories do not prioritize water-saving technologies, despite Pakistan's ongoing water scarcity crisis. Simple measures, such as installing low-flow fixtures, optimizing water-intensive processes, and recycling water where possible, could significantly reduce water waste. Greater regulatory oversight and awareness campaigns could encourage laboratories to adopt these measures [5,14].

Efforts to optimize material and resource use also vary widely. Some laboratories have reduced reagent use by consolidating samples, but the shift away from single-use plastics remains slow. While reducing single-use plastics is a key step toward minimizing environmental impact and long-term operational costs [15], many laboratories hesitate to make this transition due to short term cost concerns and limited supplier options. Collaboration with suppliers to provide affordable biodegradable alternatives, along with incentives for sustainable procurement, could facilitate greater adoption. Waste segregation is practiced in some laboratories, but the absence of formal recycling programs and the lack of supplier partnerships for reusing packaging materials highlight gaps in waste management. Establishing structured recycling programs, engaging suppliers in sustainable packaging solutions, and enforcing waste reduction policies could significantly improve these practices [4]. Additionally, digital documentation and electronic reporting have played a crucial role in reducing paper waste in majority of the clinical laboratories, demonstrating that sustainability efforts can be both feasible and impactful when integrated into routine workflows [16].

The adoption of environmentally friendly chemicals and safer alternatives reflects a positive shift toward greener laboratory practices. The replacement of toxic solvents and the phasing out of hazardous substances like mercury thermometers and ethidium bromide indicate growing awareness of chemical safety and sustainability. Additionally, the widespread reuse of biological samples and optimized inventory management highlight efforts to minimize waste. However, the limited adoption of solvent recycling, with no laboratories investing in dedicated recycling equipment, suggests that cost and infrastructure barriers remain. Addressing these challenges through financial incentives, supplier partnerships, and regulatory support could enhance sustainable chemical management in laboratories [17].

A lack of awareness and training among laboratory staff further exacerbates the problem. Many professionals are unfamiliar with best practices in sustainability or lack the motivation to implement them. Regular training programs, workshops, and incentive-based participation in sustainability initiatives could help bridge this knowledge gap and create a culture of environmental responsibility. Additionally, resistance to change and limited regulatory enforcement contribute to slow progress. Without strong leadership commitment and clearly defined sustainability policies, laboratories are unlikely to prioritize green initiatives [18].

The absence of formal green policies and certifications presents another significant challenge. Few laboratories have implemented sustainability policies, and most do not follow established green purchasing guidelines. This lack of commitment was further underscored by our finding that 75.0% of laboratories reported no interest in pursuing ISO 14001 certification. Voluntary uptake alone appears insufficient in this context, highlighting the need for stronger regulatory intervention. Regulatory bodies should therefore introduce mandatory sustainability frameworks, accompanied by technical support, training, and clear implementation guidelines to help laboratories achieve compliance. Regular audits, coupled with incentives such as preferential accreditation or funding for compliant laboratories, would promote accountability and encourage integration of sustainability into routine operations [5]. Strengthening regulatory oversight in this way would help laboratories align with international best practices and ensure that sustainability becomes an institutional priority rather than an optional initiative.

Despite the challenges, adopting sustainable practices offers significant environmental and financial benefits. Laboratories that have implemented waste reduction strategies report noticeable decreases in waste production and water usage. However, the financial impact varies, with some institutions experiencing cost savings while others see no immediate economic benefits. The financial feasibility of sustainability initiatives depends on factors such as the scale of implementation, initial investment costs, and access to government incentives. Cost-benefit analyses and long-term financial planning could help laboratories better understand and maximize the economic advantages of sustainable practices [19,20].

Supplier engagement also emerged as a critical area requiring improvement, with only 8.3% of laboratories reporting collaboration with suppliers on packaging reuse. Strengthening these partnerships is essential to reduce upstream waste and encourage the use of eco-friendly reagents and materials. Establishing return-and-reuse programs for packaging, promoting biodegradable or recyclable alternatives, and incorporating sustainability criteria into supplier contracts

could facilitate more responsible waste management [20]. Such initiatives, alongside investments in energy-efficient equipment, water conservation technologies, and structured waste management systems, would not only minimize laboratory-generated waste but also drive broader changes in the healthcare supply chain, embedding sustainability across the lifecycle of laboratory operations and ensuring long-term environmental and financial benefits [5].

To advance sustainability in clinical laboratories, a multifaceted approach is necessary. Education, policy enforcement, and financial incentives must work together to create meaningful change. Training programs tailored for laboratory staff can increase awareness and encourage practical implementation of green practices, while regulatory bodies should take a more active role in enforcing sustainability policies and offering incentives to help laboratories transition smoothly [5]. Recognized sustainability certifications such as ISO 14001 should be actively promoted to establish a structured framework for green practices. Adopting these certifications would not only standardize sustainability efforts but also help laboratories align with global environmental standards. Additionally, fostering collaborations between government institutions, healthcare providers, and environmental organizations could create a more cohesive and effective approach to sustainability. By working together, these stakeholders can ensure that clinical laboratories contribute to a greener and more efficient healthcare sector [5].

This study has several limitations that should be acknowledged. The most important is the small sample size (n = 12), which limits the generalizability of the findings. While the participating laboratories included major institutions from the federal capital and all four provincial capitals, the results cannot be considered fully representative of all clinical laboratories in Pakistan. The low response rate may reflect factors such as survey fatigue among laboratory professionals or limited institutional interest in sustainability, both of which could have influenced participation. Consequently, the sample may be biased toward laboratories already engaged in sustainability initiatives, potentially overestimating the adoption of green practices. Despite these limitations, the study provides valuable initial insights and highlights critical areas for policy development and future research.

While this study provides important baseline insights, future research should focus on developing context-specific strategies for implementing sustainability initiatives in Pakistan. Practical next steps could include pilot programs in large public and private laboratories to test the feasibility of water-saving technologies, energy-efficient equipment upgrades, and structured waste recycling systems. Establishing multi-institutional collaborations between laboratories, government agencies, and environmental organizations could facilitate shared learning and resource optimization. Research should also explore the cost-effectiveness of different green interventions in the Pakistani context, helping to build an economic case for sustainability. Finally, incorporating sustainability metrics into laboratory accreditation frameworks and national health policies would provide a structured pathway for scaling up successful initiatives across the country.

Conclusion

This study underscores the urgent need for structured sustainability policies, financial incentives, and educational programs to enhance green laboratory practices in Pakistan. While some progress has been made, significant gaps remain in energy efficiency, waste management, and regulatory compliance. Overcoming these challenges requires strong institutional leadership, stakeholder collaboration, and supportive regulatory frameworks. By integrating sustainable practices into routine laboratory operations, the healthcare sector can contribute to environmental conservation while improving long-term operational efficiency and cost-effectiveness.

Competing interests

None declared.

Ethical Approval

Approval was sought from the institutional ethical review committee of the Aga Khan University (2025-11186-33468).

Author Statement

Sibtain Ahmed conceived the idea, designed the study, and wrote the first draft. Alizeh Sonia Fatimi contributed to writing, data compilation, and questionnaire development. Imran Siddiqui conceived the idea, assisted with study design, questionnaire development, and final draft review. Ghazanfar Abbas, Sahar Iqbal, Mohsin Shafi, Khushbakht Arbab, Rizwan Uppal, Asma Shaukat, Muhammad Dilawar Khan, Muhammad Qaiser Alam Khan, Adnan Mustafa Zubairi, Syed Haider Nawaz Naqvi, and Junaid Mahmood Alam were involved in data collection, assisted with figures, reviewed the first draft, and suggested revisions. Tomris Ozben contributed to questionnaire design, reviewed the final draft, and provided improvements.

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Supplementary

Survey Instrument

Sustainability Practices in Clinical Laboratories

This survey aims to gather insights into the current sustainability practices, barriers, and future goals of clinical laboratories. Your valuable input will help identify trends and opportunities for improving environmentally friendly practices in laboratory settings. The survey is designed to take approximately 10–15 minutes to complete. All responses will remain confidential and will be used solely for research purposes.

Thank you for considering participation in this survey. By proceeding, you acknowledge that:

1. Your participation is voluntary.
2. The information you provide will remain confidential and be used only for research purposes.
3. No identifiable data will be collected or shared.

Section 1 of 13

I. General Information

This section collects basic details about your laboratory, including its size, location, and organizational affiliation.

- What is the size of your laboratory? *
- Which city is your laboratory located in? *
- What type of organization is your laboratory part of?
- If your answer was "Other," please specify:

Section 2 of 13

II-A. Current Green Practices – Energy Efficiency

The following sections (II-A – II-I) explore the sustainability measures currently in place at your laboratory, covering energy efficiency, water conservation, waste management, and more. Your responses will provide valuable insights into the implementation of green practices and areas for potential improvement.

- Does your laboratory track energy consumption and implement strategies to reduce it? *
- Does your laboratory use energy-efficient lighting (e.g., LED)? *
- Are automated light sensors or timers installed to reduce energy usage? *
- Are energy-efficient laboratory equipment or appliances used? (e.g., low-power centrifuges, freezers) *
  - If your answer was "Yes," please specify which energy efficient equipment is used:
- Are laboratory devices turned off or placed in energy-saving modes when not in use? *
  - If your answer was "Yes," please specify which devices are turned off or placed in energy-saving modes when not in use:
- Does your laboratory frequently clean filters and condensers? *

Section 3 of 13
II-B. Current Green Practices – Water Conservation

- Does your laboratory monitor water consumption? *
- Have any water-saving technologies been implemented? (e.g., low-flow faucets, closed-loop systems) *
  - If your answer was "Yes," please specify which water-saving technologies have been implemented:
- Are water-intensive processes periodically reviewed for efficiency improvements? *

Section 4 of 13
II-C. Current Green Practices – Material and Resource Optimization

- What actions has your laboratory taken to reduce single-use plastics? (Select all that apply) *
- If you selected "Replacing single-use plastics with reusable alternatives," please specify which items have been replaced and with what alternatives:
- Does your laboratory identify and reuse items such as plastic specimen bags or 24-hour urine bottles within safe limits? *
- Are laboratory consumables, such as pipettes and gloves, reused where safety permits? *
- Does your laboratory consolidate samples to minimize the use of collection tubes and reagents? *
- Does your laboratory conduct regular audits to identify and eliminate outdated or unnecessary tests? *
- Are test requests reviewed to reject unnecessary or duplicate test orders? *

Section 5 of 13
II-D. Current Green Practices – Waste Management

- Does your laboratory separate waste into categories such as hazardous, recyclable, and general waste? *
- Are recycling programs in place for the following items? (Select all that apply) *
- If your answer was "Other," please specify:
- Are hazardous wastes disposed of by certified waste contractors? *
- Does your laboratory conduct regular waste audits to evaluate and improve separation practices? *
- Does your laboratory collaborate with suppliers to return and reuse packaging materials like Styrofoam, paper, or cardboard? *
- Are electrical and electronic wastes (e.g., fluorescent tubes, batteries, phones, computers) recycled in compliance with local regulations? *

Section 6 of 14
II-E. Current Green Practices – Digital and Paperless Operations

- Does your laboratory use electronic reporting to reduce paper consumption? *
- Are staff encouraged to use double-sided printing or avoid printing altogether? *
- Have digital technologies, such as electronic medical records (EMRs), been implemented to streamline processes? *

Section 7 of 13
II-F. Current Green Practices – Chemical and Biological Sustainability

- Are environmentally friendly or less hazardous chemicals used in your laboratory? *
  - If your answer was "Yes," please specify which environmentally friendly or less hazardous chemicals are used:
- Are chemical inventories optimized to minimize overstocking and waste? *
- Are biological samples or reagents reused for educational or research purposes where applicable? *
- Has your laboratory replaced mercury thermometers with safer alternatives? *
- Has your laboratory replaced the use of ethidium bromide for gels? *
- Does your laboratory recycle organic solvents like xylene and formalin on-site? *
- Has your laboratory invested in a solvent recycler? *

Section 8 of 13
II-G. Current Green Practices – Green Certifications and Policies

- Does your laboratory have green certifications (e.g., ISO 14001)? *
- Is there an internal sustainability or environmental policy guiding operations? *
- Does your laboratory have a green purchasing policy in place? *
- Are suppliers and contractors informed of the laboratory's green purchasing policies? *
- Do your suppliers provide environmentally friendly reagents or equipment (e.g., energy-efficient, water-saving, or

biodegradable)? *

Section 9 of 13

II-H. Current Green Practices – Sustainability Training and Awareness

- Are staff trained on sustainability practices and their importance? *
- Are there ongoing initiatives or campaigns to promote environmental awareness among staff? *

Section 10 of 13

II-I. Current Green Practices – Additional Practices

- Does your laboratory use carbon offset programs or renewable energy sources? *
- Have any innovative green practices been adopted that are unique to your laboratory?

Section 11 of 13

III. Barriers to Implementing Green Practices

- What are the main barriers your laboratory faces in adopting more green practices? (Select all that apply) *
- If your answer was "Other," please specify:
- How significant are these barriers in preventing further adoption of sustainable practices? *

Section 12 of 13

IV. Environmental and Cost Impact

- The implementation of sustainability initiatives in your laboratory has led to: (Select all that apply) *
- What environmental impact have you observed due to sustainability practices? (Select all that apply) *
- If your answer was "Other," please specify:
- Has your laboratory experienced any measurable cost savings from green practices? *

o If yes, please specify which areas you have experienced cost savings:

Section 13 of 13

V. Future Goals and Improvements

- What additional sustainability practices would you like to see implemented in your laboratory? (Select all that apply) *
- If your answer was "Other," please specify:
- Are there any other sustainability challenges or ideas you would like to share regarding your laboratory's operations?