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Laboratory Waste Management: Challenges and Sustainable Solutions

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ABSTRACT: *The production of various types of waste in laboratories is inevitable, and undoubtedly, the lack of sufficient attention to this issue can have a great impact on the destruction of the environment and nature. In this regard, laboratory waste management, as one of the fundamental pillars of safety and sustainable development, requires special attention. This study was conducted with a descriptive-analytical method and through the distribution of questionnaires to laboratory elites and stakeholders, which was analyzed and analyzed with SPSS software, which examined the challenges and provided effective solutions. For laboratory waste management, the findings show that three main challenges, including lack of employee awareness, financial and support limitations, and lack of sufficient equipment and tools, have made the management of this waste difficult. On the other hand, the proposed solutions, including the implementation of intensive training programs, the use of appropriate reuse and recycling methods, and the development of detailed separation instructions, can reduce the volume of hazardous waste by up to 70 percent. The results indicate that the implementation of these solutions, in addition to increasing workplace safety, will reduce waste management costs by 60 percent. This research emphasizes the need to pay attention to technical, human, and economic aspects in the sustainable management of chemical waste.*

KEYWORDS :*Chemical safety, chemical waste, laboratory management, recycling solutions*

I. INTRODUCTION

In recent years, waste management has become a vital and challenging issue in many industries and places, especially in chemical laboratories, which are sensitive environments containing hazardous materials. Due to the use of chemicals and complex experiments, these laboratories are faced with the production of large amounts of hazardous waste, which requires appropriate approaches and solutions to manage and control it.

Although the substances are used in small amounts in the laboratory, with volumes measured in parts per million (ppm) and milliliters, these amounts of substances are extremely hazardous to human health and the environment(Sadat, S. A. A., Ilbeigi, V., Valadbeigi, Y., & Soleimani, M. (2020). A variety of chemicals are used in the laboratory, which are harmful to human health and the environment in various ways (Danishyar, A. S., Karimi, M. N., & Sadat, S. A. A. (2023).

In these environments, many challenges require proper attention and management(Hegering, H. G., Küpper, A., Linnhoff-Popien, C., & Reiser, H., 2003, October). These challenges include issues such as collection, separation, disposal, recycling and disposal of waste, and use of hazardous materials, ensuring employee safety, and protecting the environment. To solve these challenges, we need to provide sustainable and efficient solutions(Jonathan, G.K., & Mbogo, R. W., 2016).

One of the main obstacles in this field is the high diversity of chemical compounds and the need for specific methods for each type of waste (Demirbas, A., 2011). For example, the disposal of radioactive

materials, organic solvents, and acidic wastewater each requires separate protocols, the non-compliance of which can be disastrous. In addition, the lack of unified standards at the national level and weak regulatory laws have made the management of these wastes difficult.

Modern solutions in this area are based on the principles of green chemistry and the circular economy. Reducing the consumption of raw materials, using low-waste synthesis methods, recovering valuable materials from waste, and employing advanced purification technologies are among the effective measures in this field. Also, continuous training of laboratory personnel on waste classification, safe packaging, and proper disposal plays a key role in preventing accidents (Sheldon, R. A. (2016).

In this study, we examine the challenges of waste management in laboratories and provide sustainable and economical solutions for optimal waste management (Kurul, F., Doruk, B., & Topkaya, S. N. (2025). This research aims to promote the improvement of waste management processes, reduce negative impacts on the environment, and increase safety and health in these environments (Sheldon, R. A., & Norton, M. (2020). In the continuation of this research, we will delve deeper into the challenges and sustainable solutions in waste management in laboratories to help improve processes and reduce the negative impacts of waste in these environments) Anastas, P., & Eghbali, N. (2010). Laboratory waste management is a topic that has attracted the attention of researchers, policymakers, and environmental experts in recent decades (Nwobi, N. L., Anetor, G. O., Nwobi, J. C., Igharo, G. O., Adeyemi, A. V., Badrick, T., & Anetor, J. I. (2025). Several studies have examined the challenges, disposal methods, and sustainable solutions in this field, the most important findings of which are mentioned below.

Studies show that laboratories, such as those in chemistry, biology, and medicine, face numerous challenges in waste management. Abdollahi et al. (2020), Salman, R. A. S., Beller, E., Kagan, J., Hemminki, E., Phillips, R. S., Savulescu, J., ... & Chalmers, I. (2014). concluded in a study concluded that the lack of integrated systems for separating and disposing of chemical waste leads to increased safety risks and environmental pollution. Tsydenova, O., & Bengtsson, M., 2011). On the other hand, they have pointed out that the high costs of safe disposal of hazardous materials are one of the main obstacles to implementing waste management policies. Shekdar, A. V. (2009). They also showed in their research that the lack of sufficient awareness of laboratory personnel about safety guidelines increases the likelihood of chemical accidents.In response to these challenges, researchers have proposed various solutions. In a report, it has been emphasized that the principle of waste minimization can significantly reduce the volume of hazardous waste through the optimization of laboratory methods. It has also introduced the use of solvent recycling methods as a cost-effective and sustainable solution. In addition, it has emphasized the need to develop international standard guidelines for chemical waste management.

Recent research has addressed the role of advanced technologies in improving waste management systems. They have considered the use of electrochemical treatment technologies to be effective for neutralizing acidic and alkaline wastewater. Also, in their study, they showed that intelligent waste storage systems can automatically identify and classify hazardous materials.

Despite the progress made, there are still gaps in this area. Many studies have focused on large industrial laboratories, while educational and small laboratories have received less attention. Also, limited research has been conducted on the circular economy in laboratory waste management.

Although several solutions have been proposed for chemical waste management, their implementation requires collaboration between different sectors, investment in new technologies, and continuous training of sectoral staff. Building on previous research, this study seeks to provide practical solutions for improving waste management systems in laboratories in Afghan universities.

II. RESEARCH METHOD

This research is applied in terms of purpose and descriptive survey in terms of data collection method, which analyzes the challenges and solutions of waste management in laboratories using quantitative and qualitative methods. The statistical population of this research is 20 laboratory assistants, 150 chemistry professors in Afghan universities, and 120 science students in universities, with a total of 290 respondents. The data

collection tool includes a researcher questionnaire that includes closed questions (Likert scale) and open questions in three axes (awareness and knowledge, analysis of existing challenges, providing sustainable solutions and methods).

III. RESEARCH FINDINGS

I. DEMOGRAPHIC CHARACTERISTICS (EDUCATION LEVEL, WORK EXPERIENCE, TYPE OF ORGANIZATION)

TABLE 1. GENERAL CHARACTERISTICS OF RESPONDENTS

General Characteristics	Category	Percentage (%)
Gender	Male	93.9%
	Female	6.1%
Level of Education	Baccalaureate	19.2%
	Post-Baccalaureate	5.6%
	Bachelor	57.6%
	Master	10.6%
	Doctorate	7.0%
Work Experience	Less than 5 years	36.4%
	5 to 10 years	30.3%
	10 to 15 years	27.3%
	20 years and above	6.0%

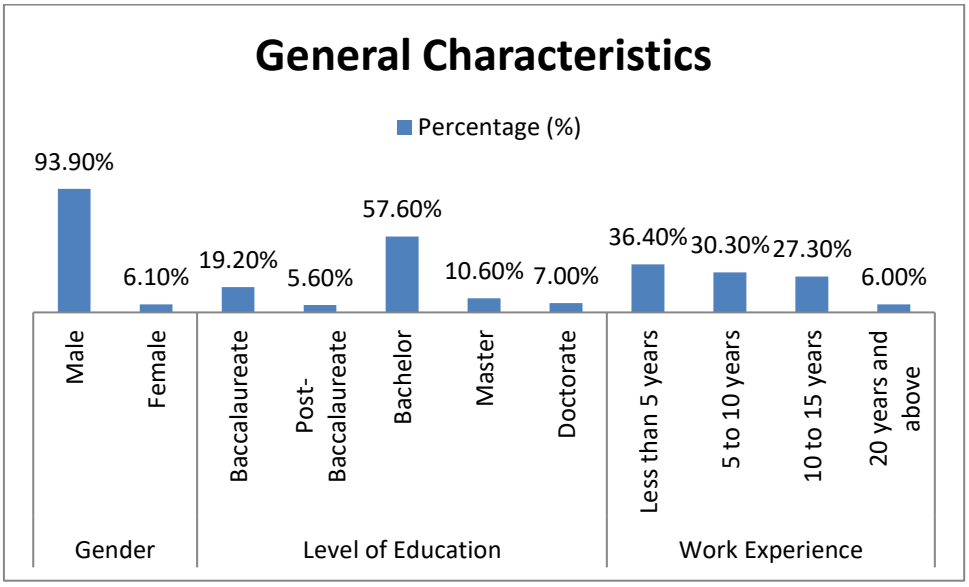

Chart (1) General characteristics of respondents

Considering the above table and Chart, most respondents were male, with the highest level of education being a bachelor's degree, the lowest level being a doctorate, and the lowest level of work experience being more than twenty years. Therefore, it is proven that all participants in this study were literate.

INDICATOR 1: LEVEL OF AWARENESS AND KNOWLEDGE OF EMPLOYEES ABOUT LABORATORY WASTE

Table 2: Employees' Awareness and Knowledge

Evaluation Questions	Very Low	Low	Medium	High	Very High	Average
How familiar are you with the concepts of laboratory waste?	15%	25%	35%	20%	5%	2.75
To what extent are you familiar with the	10%	30%	40%	15%	5%	2.85

environmental impacts of laboratory waste?						
To what extent do you have sufficient information about proper methods of laboratory waste disposal?	20%	35%	30%	10%	5%	2.45
How aware are you of the impacts of laboratory waste on human health?	5%	20%	45%	25%	5%	3.05

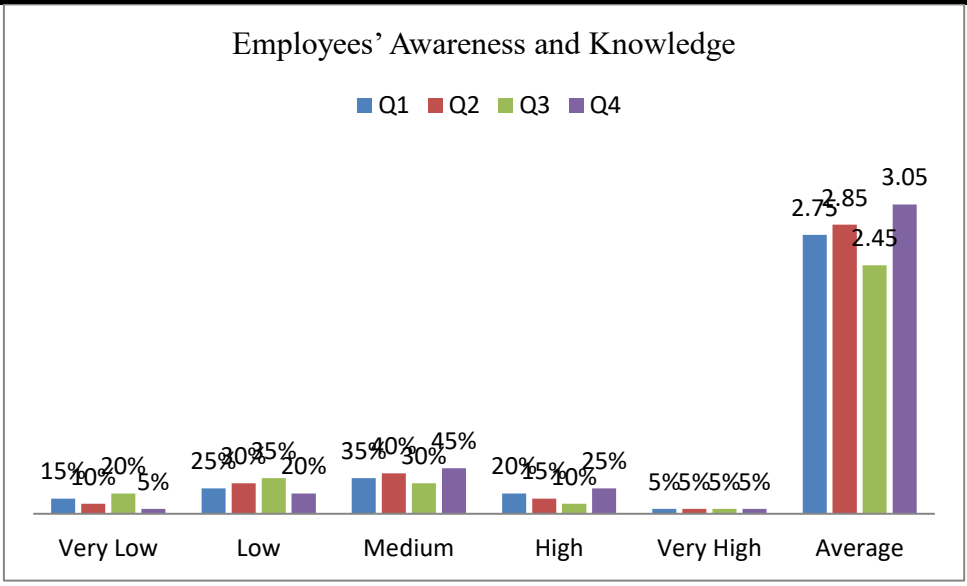

Chart (2) Employees' Awareness and Knowledge

The diagram and table (2) above show that Based on the results of the table, employees' level of awareness regarding laboratory waste is at a moderate level. The highest mean score (3.05) relates to awareness of the impacts of laboratory waste on human health, indicating a relative sensitivity of employees toward health-related consequences. In contrast, the lowest mean (2.45) concerns proper methods of waste disposal, highlighting a significant weakness in their practical and applied knowledge. Awareness of general concepts (2.75) and environmental impacts (2.85) is also at a moderate level. These findings emphasize the necessity of implementing targeted training programs to enhance employees' knowledge.

INDICATOR 2: WASTE MANAGEMENT CHALLENGES IN LABORATORIES

Table 3: Challenges of Waste Management in Laboratories

Evaluation Questions	Very Low	Low	Medium	High	Very High	Average
To what extent do you face problems in the segregation and management of laboratory waste?	5%	15%	30%	35%	15%	3.40
Does your laboratory have sufficient systems for controlling laboratory waste?	10%	20%	40%	20%	10%	3.00
In your opinion, to what extent is the lack of financial resources for waste management one of the main challenges in laboratories?	5%	10%	25%	40%	20%	3.60

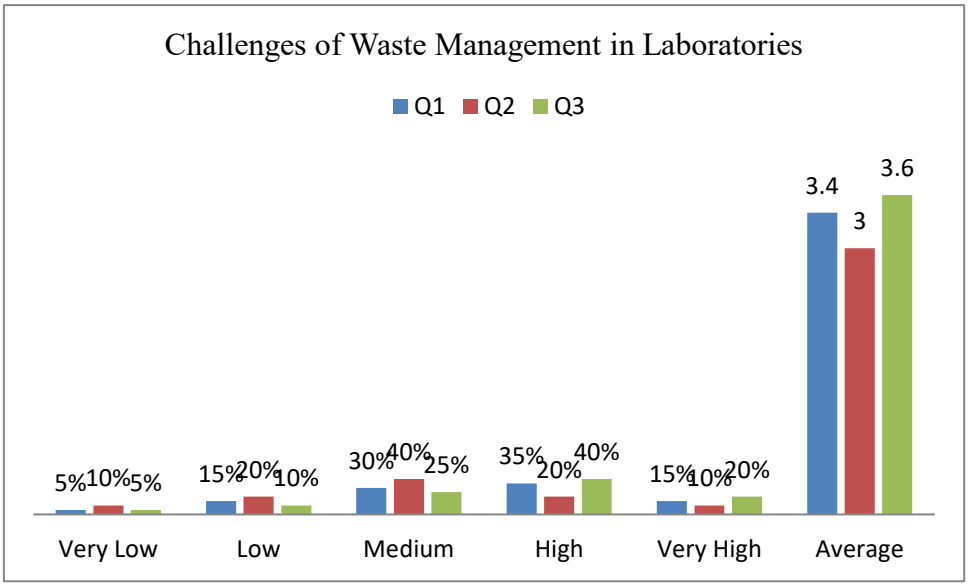

Chart (3) Challenges of Waste Management in Laboratories

The results of the challenges of waste management in laboratories showed that waste management in laboratories faces several challenges. The most important challenge is the lack of financial resources, with an average of 3.60, which was given the highest importance among the respondents. The lack of funds reduces the ability of laboratories to provide safe and up-to-date equipment for waste disposal or recycling and is recognized as a major obstacle in sustainable waste management.

In second place, problems related to waste separation and management were raised with an average of 3.40. More than 80% of the participants assessed this challenge at the "medium to very high" level, which indicates a weakness in the standardization of the separation process and a lack of practical guidelines in this area.

Also, the inadequacy of control systems, with an average of (3.00), shows that although some infrastructure exists, they do not have the necessary efficiency for effective waste management. In contrast, challenges such as a weak waste management culture among employees (2.80) were less important compared to financial and technical factors.

Overall, it can be concluded that lack of financial resources and failure to separate waste are the main obstacles to laboratory waste management, and their elimination can help improve safety and environmental protection.

INDICATOR 3: PROPOSED SOLUTIONS FOR SUSTAINABLE MANAGEMENT OF LABORATORY WASTE

Table 4: Challenges of Waste Management in Laboratories

Suggested Solutions for the Sustainable Management of Different Waste Types

Questions	Very Low	Low	Medium	High	Very High	Average
There are suitable training programs for laboratory staff on laboratory waste management.	25%	30%	25%	15%	5%	2.45
Using proper methods for reuse and recycling	30%	40%	20%	8%	2%	2.12
You believe that improving recycling equipment is effective for improving waste management.	5%	15%	25%	35%	20%	3.50
Proper waste control can help reduce environmental pollution.	0%	5%	15%	40%	40%	4.15
Improving waste management can lead to a reduction in the laboratory's operational costs.	5%	15%	30%	35%	15%	3.40
Constructing a suitable location for the laboratory, separate from the municipal sewage system.	10%	20%	35%	25%	10%	3.05

The use of modern methods, with an average of 2.12 (40% low + 30% very low), indicates the lack of modern equipment in laboratories. Only 20% of respondents confirmed the existence of adequate training programs (average 2.45). Only 15% considered management improvements to be very effective in reducing costs, indicating the need for initial investment. The improvement of the public image, with an average of 3.60, indicates that waste management is seen more as an administrative requirement than a moral value. A specific location for laboratories should be created for each university, school, and center that has a laboratory. The gap between the current situation (averages below 3) and the effectiveness of the proposed solutions (averages above 3.5) indicates that the main problem is in implementation, not in identifying the solutions. This study confirms the need to create incentive mechanisms and allocate targeted budgets to convert potential solutions into tangible results.

RESULTS BASED ON ACADEMIC QUALIFICATIONS

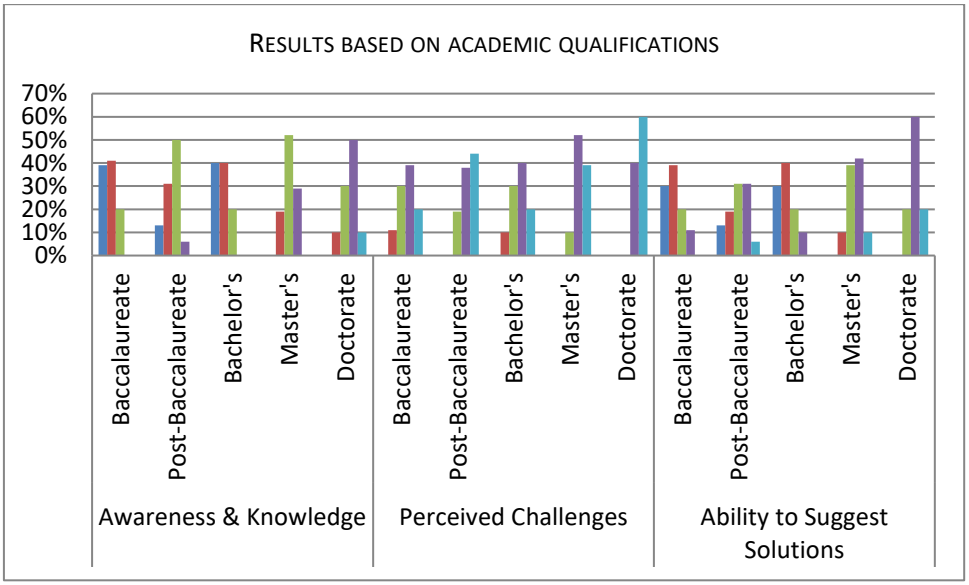

chart (4) Findings chart based on academic degree

The findings based on educational qualifications show that, based on the survey results, there is a significant knowledge gap among individuals with different educational levels. About 80% of diploma and bachelor's degree holders rated their awareness of laboratory waste as low or very low, while around 60% of PhD holders reported high awareness. This highlights the urgent need for general training and tailored educational programs for personnel with lower qualifications.

Across all groups, the challenges of waste management were widely acknowledged; notably, 59% of diploma holders and 91% of specialists rated these challenges as high or very high, indicating a consensus on the existence of the problem and the need for immediate action.

Moreover, 70% of bachelor's degree holders considered their ability to provide sustainable solutions as low, whereas 80% of PhD holders described themselves as highly or very highly capable. This demonstrates that specialized human resources are a key but underutilized asset.

IV. DISCUSSION

Laboratory waste management in Afghan schools and universities faces several technical challenges. The lack of a designated location in laboratories, the high diversity of chemical compounds, and the need for specific methods for each type of waste complicate management systems. For example, waste containing heavy metals such as mercury and lead requires special treatment streams Also, the risks arising from unwanted chemical interactions when mixing materials are considered one of the most important technical challenges

The high costs of safe disposal of chemical waste are a major obstacle to economic and efficient management. (Bierma, T. J., & Waterstraat Jr, F. L. (1999). indicate that the cost of disposing of hazardous waste in laboratories is up to 40% higher than that of conventional waste. Many educational and research

institutions in developing countries are unable to implement complete waste management protocols due to budget constraints (Demirbas, A. (2011). Other important challenges include deficiencies in monitoring and management systems and the lack of uniform standards (Wilkinson, G., & Dale, B. G., 1999). A study in Asia showed that only 30% of countries in the region have comprehensive laws for laboratory waste management (Khan, B. A., Cheng, L., Khan, A. A., & Ahmed, H., 2019). In many cases, weak implementation of existing laws is also observed.

Lack of awareness and training of relevant staff is a major obstacle to safe waste management. The aforementioned study showed that more than 60% of chemical accidents in laboratories are due to human errors and mistakes, and failure to comply with safety protocols. This problem is more severe in schools.

Lack of proper facilities for collecting, storing, and transporting hazardous waste is a major challenge, especially in deprived areas. Many laboratories in Afghanistan lack special containers and safe places for the temporary storage of waste.

V. Conclusion

The results of this study show that waste management in laboratories in Afghanistan faces several challenges, including a lack of appropriate infrastructure, a lack of standard guidelines, limited financial resources, and poor professional awareness. The findings indicate that current approaches are inefficient in many cases and have led to increased safety risks and environmental pollution. On the other hand, the present study suggests practical solutions that are tailored to local conditions, including three levels: immediate, medium-term, and long-term. In the short term, training staff and students and developing simple protocols have the greatest impact, while in the long term, investing in sustainable technologies and reforming curricula seems essential. Successful experiences in some laboratories have shown that even with minimal facilities, both safety and costs can be increased and reduced through smart management. This study emphasizes the need for national commitment and cross-sectoral cooperation to establish an integrated waste management system, as addressing these challenges will not only ensure the health of personnel and the environment but will also lead to improving the quality of education and research in the country. Finally, continuing applied research in this area and benefiting from the experiences of countries with similar conditions can help Afghanistan achieve acceptable standards in laboratory waste management..

VI. Recommendations

- Prepare waste management guidelines appropriate to the conditions of Afghanistan and implement them by educational and training institutions
- Establish laboratory waste collection centers in the center and provinces
- Build simple, safe containers with local construction materials
- Use durable plastic containers with tight lids to collect waste
- Designate separate shelves with natural ventilation for hazardous materials
- Neutralize acids and alkalis with available materials before disposal
- Controlled evaporation of organic solvents in the open air while observing safety
- Form a simple safety committee consisting of professors and students
- Prepare solutions in the required amount to reduce waste,
- Separate and recycle simple solvents such as acetone and ethanol,
- Prepare posters and visual guides in local languages in laboratories
- Include basic concepts of waste management in school and university curricula

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