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Investigation of Practices and Procedures of Chemical Waste Management in Educational Institutions: The Case of Secondary Schools and Higher Institutions Located in Tigray, Ethiopia

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ABSTRACT

Mismanagement of laboratory hazardous waste presents a profound challenge to the environment and occupational health within educational sectors. This paper evaluates chemical waste management dynamics in secondary schools and higher education institutions in Tigray, Ethiopia. The objectives of the study were twofold: to assess the institutional practices governing the handling, storage, and disposal of chemical waste; and to quantify the types and volumes of waste generated across diverse educational strata. Employing a mixed-methods framework, the study utilized multi-stage stratified sampling involving 120 individual school personnel respondents, qualitative observational audits, and a granular review of laboratory manuals and curricula. A mixed-methods approach was adopted where quantitative data were gathered via a specific structured questionnaire instrument, while qualitative insights were obtained through direct observation and comprehensive document analysis. Quantitative findings were synthesized through a dual-axis Pareto analysis, which revealed a significant statistical concentration of waste; governmental secondary schools are accounting for approx. 78% of the total waste (n=93). Despite more robust upstream infrastructure, higher education institutions exhibited a technical-operational disconnect where technical capacity was undermined by downstream failures, including routine sink decanting and the absence of comprehensive lifecycle traceability documentation. One-sample t-tests confirmed that deficits in waste segregation ($t=216.089$, $p<0.001$) and staff training ($M=3.90$, $p<0.001$) are systemic constants. The document analysis identified 82 environmentally blind experimental designs that normalize hazardous disposal through pedagogical omission. It is concluded that the regional risk is driven by the corrosive acid & base effluents in the governmental sector and complex organic solvents in universities. The results advocate for a Point-Source Concentration Model, prioritizing bulk neutralization for high-volume contributors and specialized recovery systems for research-oriented environments.

Keywords: Chemical Waste Management, Hazardous waste, Higher Education Institutions, Secondary Schools, Waste minimization, Ethiopia.

1. INTRODUCTION

Chemical waste management has become a critical issue in educational institutions, particularly in secondary schools and higher education institutions in the developing countries, due to the

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increasing use of chemicals in various educational and research activities. Improper handling and disposal of chemical waste can pose significant environmental and health risks, including soil and water contamination (Haddis et al., 2014). Research indicates that academic laboratories are often more hazardous than industrial ones due to lower safety standards and resource constraints (Omer, 2024). Academic institutions recognize the importance of chemical management and laboratory safety; however, their implementation in educational and research settings is often limited. Academic laboratories are reported to be 11 times more hazardous than their industrial counterparts because of lower safety standards and regulations (Langerman, 2009; Lestari et al., 2019). This not only compromises the quality of education but also endanger laboratory staff handling hazardous substances (Wu et al., 2007). For instance, laboratory safety issues have led to fire incidents in three Malaysian colleges and 16 cases of mercury spills in Ethiopian school laboratories (Draman et al., 2010; Nurul et al., 2017).

Despite the critical importance of safety in chemical laboratories (Hill, 2007), academic institutions often neglect regular inspections due to resource constraints and a lack of safety awareness (Marendaz et al., 2013). Accidents often result from negligence, inadequate training, and insufficient safety measures (Su and Hsu, 2008). Unfortunately, the methods for investigating and analyzing these accidents lack standardization across universities, and the lessons learned are not widely disseminated (Fukuoka and Furusho, 2022). However, it is important to note that laboratory errors are not inevitable. Many of these incidents can be prevented by implementing chemical safety management practices (Babinakova et al., 2020).

A study was conducted to investigate the practice of chemical waste management in secondary schools and higher education institutions located in the Tigray region, northern Ethiopia. The region hosts numerous educational institutions, from secondary schools to universities. The objective of the study is to provide valuable insights into the broader challenges and best practices in Ethiopia (GIZ, 2023, Proclamation No. 1090/2018), which can inform policy and interventions to improve chemical waste management in the country.

1.1. Composition of Chemical Waste from Educational Institutions

Educational institutions such as universities, colleges, and high schools often generate a variety of chemical waste. It can be complex and diverse, and understanding the composition of this waste is essential for developing appropriate waste management strategies and ensuring the safety of the campus community and the surrounding environment.

The chemical waste from educational institutions will be in different categories. 1. Inorganic Chemicals (include acids, bases, salts, and heavy metals. Examples include hydrochloric acid, sodium hydroxide, copper sulfate, and lead nitrate); 2. Organic Chemicals (include organic solvents, reagents, and compounds used in experiments and laboratories like acetone, ethanol, toluene, and formaldehyde etc); 3. Radioactive Materials (include small amounts of radioactive isotopes like ^{14}C, ^{3}tritium etc; 4. Biological Waste (includes biological samples, cultures, and materials contaminated with biological agents, such as bacteria, viruses, or cell lines).

Apart from the type, quantity also can vary significantly depending on the size and focus of the institution, as well as the specific activities and courses offered. A study conducted in the Brazil found that the average amount of chemical waste generated per institution can range from 20,000 to 25,000 Kg/Yr (Magriotiset al., 2021). Proper disposal of this waste is crucial to minimizing environmental and health risks. Educational institutions typically follow strict guidelines and regulations for the handling, storage, and disposal of chemical waste, which may include on-site treatment, off-site transportation to licensed waste management facilities, or specialized disposal methods for certain types of waste (EPA, 2022).

1.2. Chemical Waste Generated Educational Institutes in Different Countries

1.2.1. Africa

In many African countries, the management of chemical waste in secondary schools and higher institutes remains a challenge. A limited published literature is available on African countries regarding Chemical Inventory Management type and quantity of hazardous waste generation in educational institutions (Mogopodi et al., 2015). A study conducted across several sub-Saharan African nations found that the most common types of chemical waste generated in educational institutions include organic solvents, acids, bases, heavy metals, and flammable substances (Kihampa and Hellar-Kihampa, 2015). The specific quantities and compositions vary widely depending on the size and nature of the institution. However, the scientific research centers and educational activities commonly produce a wide variety of hazardous waste in relatively small volumes including new materials of unknown toxicity and hazards. The generated chemical waste is estimated to be around 5000kg per year which includes the most prevalent waste streams like spent acids, bases, and organic solvents (Abou-Elela and Ibrahim, 2014). Mmereki et al, (2014) have reported that the chemical waste from higher education institutions in Ghana is

mainly from chemistry and biology laboratories which included acids, bases, heavy metals, and persistent organic pollutants. According to Engida (2011), the problem is widespread where many schools and universities lack the necessary infrastructure, resources, and expertise to manage the waste streams effectively.

1.2.2. Europe

In European countries there is a well-established systems and practices are in place for managing chemical waste in secondary schools and higher institutes. A study conducted across several European Union member countries found that the most common types of chemical waste include organic solvents, acids, bases, oxidizing agents, and heavy metal-containing compounds (CHESS-E, 2023). In the United Kingdom, a survey of secondary schools revealed that the average annual chemical waste generation was approximately 200 liters per institution, mainly comprised of organic solvents, acids, and bases (CLEAPSS, 2018). Similar study on universities in Spain found that the chemistry and biology departments were the primary sources of chemical waste, about 1,500 liters per institution per year (Freese et al., 2024).

To address the management of chemical waste, European countries have developed comprehensive regulatory frameworks and guidelines. For example, the European Union's Waste Framework Directive (2008/98/EC) and the Hazardous Waste Directive (2008/98/EC) provide a comprehensive set of rules and standards for handling, storage, transportation, treatment, and disposal of chemical waste, including specific provisions for educational institutions (European Commission, 2022). Many European countries have also implemented initiatives to promote the safe and sustainable management of chemical waste in schools and universities. These include the development of centralized waste collection and disposal services, the provision of training and guidance to laboratory staff, and the implementation of waste minimization and recycling programs (CHESS-E, 2023).

2. RESEARCH METHODOLOGY

In Tigray region as of 2020 there were 294 secondary schools (280 governmental and 14 private) and 6 higher education institutions (Fig 1) (TSVERA 2024). This study investigated secondary schools and higher education institutions in the Tigray region and excluded primary schools (Grades 7 and 8) due to their lack of standardized laboratory infrastructure. To balance statistical rigor with logistical feasibility, a multi-stage sampling strategy was employed using a mixed-

methods approach. Quantitative data were gathered via structured questionnaires, while qualitative insights were obtained through direct observation and document analysis.

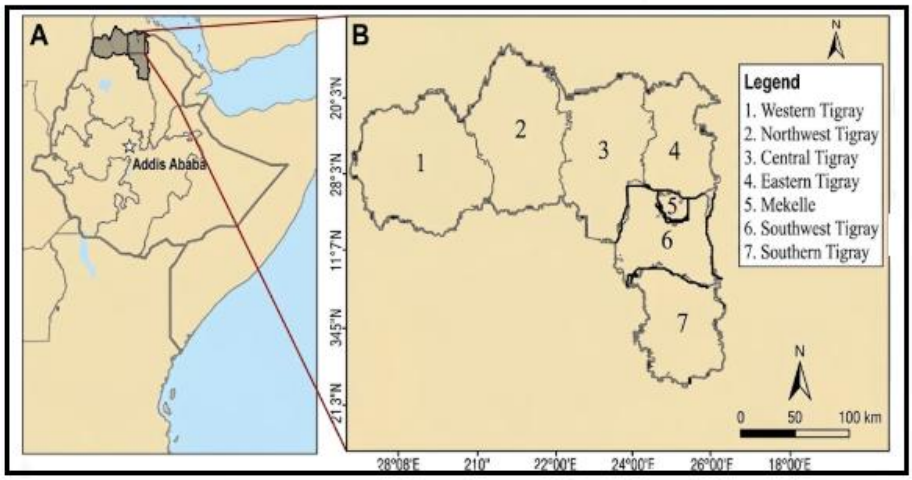


Figure 1. Map of Tigray with inserted Ethiopian map.

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2.1. Sampling Strategy

2.1.1. Purposive (Intentional) Sampling

Educational institutions were selected based on the availability of laboratory infrastructure, institution type, and regional security considerations to ensure a representative cross-section of the Tigray region. But the Western Zone was completely excluded due to security concerns.

2.1.2. Stratified Sampling

The institutional population was stratified by management type—private secondary, governmental secondary, and higher education institutions—to enable comparative analysis.

2.1.3. Random Sampling

A random sampling technique was applied across selected *weredas* and strata to minimize selection bias. The final sample comprised of 18 *weredas*, 60 governmental secondary schools, 8 private secondary schools, 2 universities, and 1 college.

2.1.4. Participants and Sample Size

Survey and interview participants included college deans, department heads, school principals, chemistry instructors, and laboratory assistants. The quantitative survey sample size was determined using a power analysis considering expected effect size, statistical power, and significance level (Cohen, 1988). For the qualitative interviews, the final sample size was

governed by the principle of data saturation, concluding when no new themes or insights emerged (Saunders et al., 2018).

2.3. Instrument Development and Validity

The research instruments were developed following a comprehensive literature review and consultations with subject-matter experts to ensure content relevance and construct validity. Prior to full-scale administration, a pilot study was conducted to evaluate the clarity and comprehensiveness of the items. Based on the pilot data, the instruments were refined and revised. The internal consistency of the quantitative scales was verified using Cronbach's alpha, yielding a reliable coefficient value of 0.78.

3. RESULTS AND DISCUSSION

3.1. Analysis of Observational Findings

3.1.1. Infrastructure and Safety Protocols

Empirical assessments of secondary school laboratories reveal a landscape of systemic fragility. While institutions exhibit superficial regulatory compliance—such as displaying safety signage and maintaining active chemical inventories—these efforts are severely undermined by profound infrastructural deficiencies. The most critical operational failure is the absence of standardized chemical storage, which compromises reagent stability and poses an immediate threat to institutional security.



Figure 2. Environmental degradation.

This environmental contamination directly impacts the surrounding community, including its educated members, who report acute health complications. Specifically, students and teachers with pre-existing asthma experience severe symptom flare-ups during hot, sunny

days when ambient temperatures rise. While these immediate respiratory effects are evident, the long-term health and toxicological consequences remain fully undetermined and will require comprehensive, experimental investigation by health professionals.

The Tigray study advances the regional academic discourse by directly linking these behavioral safety gaps to systemic infrastructure deficits. Study across Ethiopia and East Africa primarily attributed to safety failures, lack of PPE and safety training (Degavi et al., 2021). However, the data in the present study clarifies a deeper structural reality: environmental negligence—such as the ad-hoc discharge of toxins directly into the soil—is often a forced necessity driven by a lack of specialized containment systems and disposal infrastructure, rather than a mere lack of awareness. By documenting this complete absence of waste tracking, the study confirms a critical regional traceability gap (Omer, 2024). It proves that without a fundamental shift toward a circular life cycle model, these laboratories will remain dangerously disconnected from both national safety regulations and international environmental standards. The empirical data gathered from site observations confirms a profound departure from established laboratory safety protocols (Fig 3). The visual evidence underscores a state of storage paralysis, where infrastructural neglect has transformed necessary reagents into high-risk legacy hazards. Evidence from the sampled laboratories reveals the utilization of porous, combustible materials—specifically corrugated cardboard—as primary storage vessels (Fig 3a Storage Paralysis). This represents a dual hazard: cardboard acts as a capillary wick for liquid leaks, facilitating the mixing of incompatible reagents, while simultaneously providing a high-fuel-load matrix that would accelerate a chemical fire. This violates the fundamental principle of using non-combustible, chemically resistant secondary containment.



Figure 3. Evidence of legacy chemical stocks, a) storage paralysis; b) unventilated legacy chemicals.

A significant percentage of the inventory exhibits accumulation of particulate matter and chemical crystallization (efflorescence) on the closures and shoulders of the vessels. Such phenomena are symptomatic of chronic gas-off and cap-seal failure. These conditions present acute physical risks; pressurized containers or frozen caps (due to chemical welding) necessitate high-torque removal, which significantly increases the probability of vessel rupture or peroxidizable compound detonation. The audit identified a pervasive loss of legibility on original manufacturer labels due to chemical fumes and environmental moisture. In a professional chemical lifecycle model, a container lacking a clear Globally Harmonized System (GHS) label is classified as an unknown hazard. The presence of these unidentified substances creates a significant traceability gap, as they cannot be safely neutralized, transported, or disposed of without cost-prohibitive forensic analysis.

As illustrated in figure 3b (unventilated legacy chemicals), the use of unventilated wooden cabinetry with insufficient vertical clearance prevents the implementation of a First-In, First-Out (FIFO) inventory management system. This dead storage configuration encourages the accumulation of legacy chemicals, where reagents are relegated to the rear of the cabinet and remain stagnant.

3.2. Institutional Sophistication Vs Downstream Lapses in Higher Education

The higher education institutions demonstrate a more robust infrastructure regarding the upstream procurement and storage of chemicals. However, this sophistication does not extend to downstream waste management despite the availability of PPE and standardized storage facilities, waste-handling remains primitive.

The audit identified a significant lack of dedicated hazardous waste receptacles, leading to the routine decanting of effluents into laboratory sinks. While these facilities are occasionally equipped with catchment or interceptor systems, observational data confirms frequent mechanical failures in these systems, resulting in the seepage of toxic substances into the external environment. Much like the secondary schools, the absence of waste-disposal documentation highlights a systemic failure to implement a cradle-to-grave management policy, despite higher technical capacity.

The findings from both the secondary and higher education sectors in Tigray illustrate a systemic failure to move beyond a linear waste economy, where the institutional mandate focuses heavily on procurement while neglecting the critical **cradle-to-grave** management of

chemical by-products. In secondary schools, the presence of multi-decadal **legacy chemicals** and ad-hoc soil discharge reflects the end-stage of this model, mirroring broader sub-Saharan trends where a lack of disposal infrastructure transforms schools into hazardous repositories (Mogopodi et al., 2015). Even in universities, which possess significantly higher technical capacity, the audit reveals mechanical failures in interceptor systems and the routine decanting of effluents into sinks facilitate the seepage of toxic substances into the environment,

The physical state of the laboratory drainage infrastructure serves as a tangible manifestation of a linear waste economy (Fig 4).



Figure 4. Degradation of Laboratory Sanitation Infrastructure.

The observed corrosion and localized staining are not merely aesthetic failures but diagnostic indicators of chronic chemical mismanagement and structural vulnerability. The laboratory wash basins suffer severe surface corrosion and enduring discoloration point to the regular dumping of reactive effluents that have not been neutralized. The wash basin surfaces chemical etching indicates repeated exposure to strong oxidizing chemicals and mineral acids. The material fatigue that results from these plumbing systems' conventional design for domestic-grade gray water rather than hazardous laboratory discharge is a systemic failure to supply specialized containment gear.

The obvious buildup of secondary precipitates and chemical residues attests to the complete lack of point-of-origin neutralization. Before going into the drainage system, acidic or hazardous byproducts need to be stabilized or adjusted in pH according to a specified chemical hygiene framework. . The presence of these residues implies that the sink has been repurposed as an ad-hoc disposal site for legacy chemicals, effectively bypassing the chemical lifecycle and shifting the burden of treatment to the local ecosystem.

The level of staining indicates that any catchment systems, acid-neutralizing sumps, or interceptors that may have been in place have either been completely removed or made inoperable. This gives pollutants a direct hydrological route from the lab bench to the local

groundwater and soil or, more importantly, to the city sewage system. According to the regional discourse, these "ad-hoc discharge" activities turn the laboratory from a regulated learning environment into a localized source of anthropogenic environmental toxicity. A secondary concern is the encrusted debris inside the drainage opening. When more incompatible substances are put down the same drain, these leftovers may serve as catalysts for erratic reactions. This accumulation creates a persistence risk, where toxic vapors (such as NO_x or Cl_2) may be liberated into the breathing zone of the students and faculty long after the initial disposal event has occurred.

3.3. Analysis of Document Findings

3.3.1. Gaps in curriculum Chemical Waste Management

A critical analysis of the curriculum of both secondary and higher education in Tigray reveals serious gaps related to modern chemical waste management. The pedagogical frameworks including syllabi, textbooks, and laboratory manuals are entirely devoid of structured guidance on the essential hierarchy of waste management minimization, reuse/recycling, safe storage, and environmentally sound disposal. The textbooks and laboratory manuals mainly focus exclusively on the sequential procedures for conducting the experiments in detail, stepwise and remain completely silent on the post-experiment protocols like guidance on how to safely store or properly dispose the chemical waste. Thus, the textbooks and laboratory manuals are not taking the principles of Green Chemistry into consideration which could help to replace hazardous reagents with more environmentally benign chemicals without compromising the experimental results. Thus, minimizing the environmental pollution. For example, replacing the reactive and hazardous reagents (HCl, $AgNO_3$ etc.) with safer, greener alternatives like Sodium Carbonate (Na_2CO_3) and Calcium Chloride ($CaCl_2$). This would achieve the same pedagogical objectives while significantly mitigating risk to students and the environment.

A critical review of the advanced laboratory manuals specifically the *Lab Manual for Practical Organic Chemistry for Undergraduate Students Organic Chemistry-1)* and the college-level *Analytical Chemistry-1* manual—reveals a significant pedagogical and safety oversight. Both these manuals completely overlook the post-experimental protocols. Notable deficiencies include, failing to address the lifecycle of the chemicals used, these manuals miss a crucial opportunity to foster a culture of safety and environmental responsibility. Integrating green

alternatives at the secondary level and establishing clear waste management protocols at the undergraduate level are essential steps toward a modern, sustainable chemistry curriculum.

3.4. Educational Design as a Root Cause

Improper chemical handling is not merely a failure of individual practice but is rooted in a fundamental flaw in the educational design itself. By failing to provide the necessary theoretical knowledge and practical competence, the curriculum abdicates its responsibility to equip educators and students with vital environmental and occupational safety standards. Consequently, this instructional vacuum normalizes unsafe disposal habits at the foundational level of science education.

3.5. Alignment with the Regional Linear Waste Economy

The findings align closely with broader research across sub-Saharan Africa, which characterizes the educational sector as a linear waste economy that prioritizes chemical procurement and experimental execution over end-of-life management (Mogopodi et al., 2015). By failing to integrate waste minimization, recycling, and traceable disposal into the core curriculum, the pedagogical framework effectively perpetuates a cycle of institutional negligence, leaving academic laboratories disconnected from modern environmental standards.

3.6. Analysis of Laboratory Procedures

A granular review of laboratory manuals identified a high frequency of "environmentally blind" experimental designs. 70 secondary school experiments and 12 higher education laboratory courses prescribe the use of hazardous reagents such as heavy metal salts, volatile organic solvents, and strong corrosives without accompanying disposal protocols. By providing no instructions for waste treatment, these documents implicitly normalize hazardous behaviors. They suggest, through silence, that dilution into public sewage systems or mixing with general solid waste is an acceptable endpoint for chemical by-products.

This implicit normalization of hazardous behavior mirrors findings in other developing regions, where laboratory manuals often lack specific treatment instructions, leading to the routine "dilution-to-drain" approach .Such document-level omissions function as a form of implicit non-compliance, suggesting that the discharge of toxins into public sewage or solid waste systems is an acceptable endpoint. This lack of specialized documentation is a primary driver of the traceability gap identified in broader regional studies, where the absence of waste-disposal logs renders the chemical lifecycle essentially untraceable (Omer, 2024).

3.7. Quantitative Analysis of Chemical Waste Distribution

The following section examines the institutional distribution of chemical waste through a dual-axis Pareto analysis (Fig 5). By integrating a stacked bar chart with a cumulative frequency curve, the study identifies the Vital Few contributors to waste volume, providing an empirical basis for targeted environmental intervention.

3.8. Institutional Predominance and the Pareto Concentration

The data reveals a significant statistical concentration of waste generation within Governmental institutions. As evidenced by the cumulative percentage trajectory, the governmental sector alone accounts for approximately 78% of the total waste volume across the four surveyed categories.

This finding validates the application of the Pareto Principle within this context, the vast majority of environmental risk is localized within a single institutional sector (Fig 5). From a policy perspective, this suggests that the governmental laboratory system acts as the primary lever for regional waste reduction. Consequently, specialized protocols tailored to this sector would yield the highest efficiency in mitigating total environmental impact, as opposed to broad-spectrum, uniform policies.

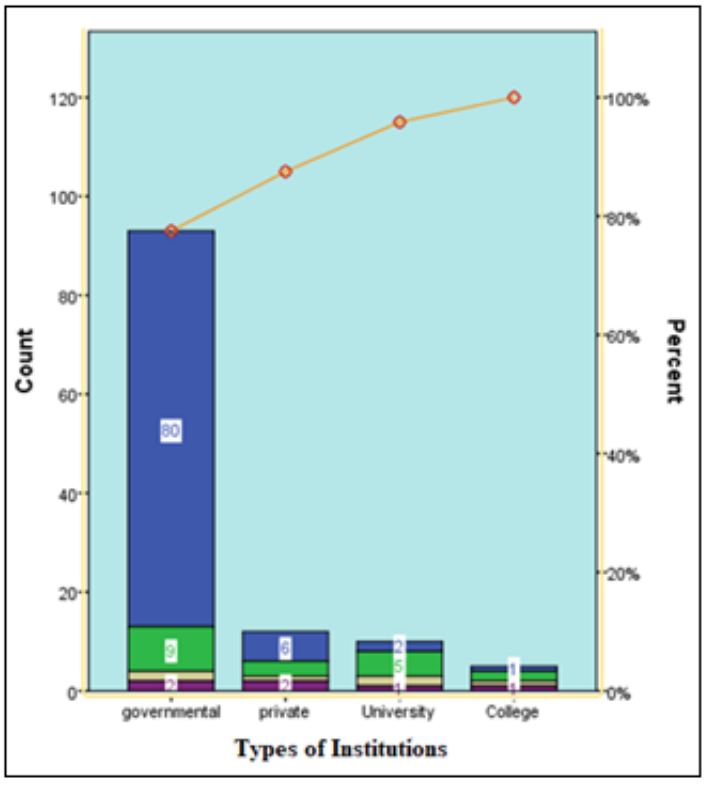


Figure 5. Pareto chart.

3.9. Chemical Composition and Sector-Specific Heterogeneity

A granular analysis of the stacked bar segments provides insight into the chemical profiles of the effluents generated.

3.9.1. Dominance of Acid and Base Constituents

Across all institutional tiers—most notably within the governmental sector Acid & Base compounds constitute the primary categorical volume. The recorded count of 80 units in governmental labs signifies that the management challenge is twofold: it is defined not only by the *source* (institutional) but also by the specific chemical nature (corrosive) of the waste stream.

3.9.2. The University Deviation

While corrosive waste remains prominent globally, the University **sector** exhibits a unique, heterogeneous distribution. In this sector, Organic Solvents account for 50% of the institutional total. This suggests that research-oriented environments possess a more complex chemical footprint than high-volume testing facilities, requiring distinct recovery and distillation protocols rather than simple neutralization.

3.10. Cumulative Impact and Strategic Mitigation

The cumulative frequency curve illustrates a sharp elbow after the primary data point, where the line levels off significantly through the Private, University, and College categories. Collectively, these sectors represent the Trivial Many—numerous in quantity but marginal in their cumulative contribution to the total waste count.

3.10.1. Stratified Resource Allocation

The precipitous decline in volume between the Governmental schools (n=93) and the Private schools (n=12) identifies a critical threshold for regulatory focus. This data supports a stratified management approach, where resources and oversight are disproportionately allocated to high-volume point sources to address the bulk of the Acid and Base volume.

3.10.2. Point-Source Governance Model

From table 1 the findings suggest a transition away from diffuse environmental oversight toward a Point-Source Concentration Model. In this framework, the governmental sector is recognized as the strategic pivot point for achieving national or regional waste reduction targets.

3.11. Quantitative Synthesis

As described in table 1, the total population (n=120) of waste incidents is heavily skewed toward the governmental schools. The researcher would frame this using the concept of Statistical

Concentration. The delta between the highest contributor (Governmental, n=93) and the lowest (College, n=5) represents an eighteen-fold difference in waste frequency. This suggests that type of institution is a statistically significant predictor of waste volume.

Table 1. Distribution of Chemical Waste by Institutional Category and Type.

Institutional Category	***Acid and Base***	***Organic Solvents***	***Heavy Metals***	***All (Mixed)***	***Total Count (n)***	***Cumulative %***
Governmental	80	9	2	2	93	77.5%
Private	6	2	1	3	12	87.5%
University	2	5	1	2	10	95.8%
College	1	2	1	1	5	100%
Total	89	18	5	8	120	

3.12. Qualitative Nuance: The University Exception

While the Pareto line emphasizes volume, my elaboration should highlight the qualitative shift in the University sector. Unlike other categories where Acid and Base is the undisputed leader, the universities show a unique spike in Organic Solvents relative to their size (50% of their school's total) (Table 1). This deviation is critical.it suggests that while governmental labs are high-volume, university labs may present a higher complexity of waste streams due to diverse research activities.

3.13. Strategic Implementation

- Based on these data, a proposed waste management framework should follow a Hierarchical Intervention Model:
- Level 1 (Primary): Bulk neutralization protocols for Acid/Base waste in Governmental facilities.
- Level 2 (Secondary): Solvent recovery systems specifically targeted at University environments.
- Level 3 (Tertiary): General education and simplified disposal streams for the Trivial Many (Private and College sectors).

3.14. Statistical Interpretation of the One-Sample t-Test

The One-Sample t-test was conducted on six critical variables related to chemical waste management in Tigray's educational institutions (Table 2). All variables demonstrated high statistical significance, suggesting that the laboratory practices and institutional profiles identified are not random but represent distinct, systemic patterns.

Table 2. One Sample t-test.

	Test value=0					
	T	***df***	***Sig. (2-tailed)***	***Mean Difference***	***95% Confidence interval Difference***	
					Lower	***Upper***
Types of institution	18.759	119	0.00	0.392	1.24	1.54
How often is chemical waste Segregated according to its type	216.089	119	0.00	3.958	3.92	3.99
How is chemical waste disposed of from your institution	98.281	119	0.00	3.142	3.08	3.20
Are there documented procedures for handling chemical waste	21.938	119	0.00	1.783	1.62	1.94
What type of training is provided to staff on chemical waste handling	97.503	119	0.00	3.900	3.82	3.98
What type of treatment ,if any is applied to chemical waste before disposal	49.362	119	0.00	4.208	4.04	4.38

3.14.1. General Significance and Confidence Levels

Across all tested parameters, the p-values (Sig. 2-tailed) are recorded as .000, which is well below the standard alpha threshold of alpha = 0.05. This confirms that the data provides a statistically significant answer to the research questions for every category. Furthermore, the 95% Confidence Intervals (CI) are remarkably narrow (e.g., for Chemical waste segregation, the CI is 3.92 to 3.99), indicating a high degree of precision in the mean estimates across the N=120 sample size (df=119).

3.14.2. Analysis of Primary Waste Management Indicators

The Mean Difference values provide a quantitative score for each practice. Given that these are likely based on Likert-type scales or categorical coding, the following highlights emerge:

Chemical Waste Treatment (M = 4.208, t = 49.362)- this variable exhibits the highest mean difference. In the context of the observational findings which noted a lack of standardized treatment—this high mean likely represents a high frequency of no treatment or unsafe disposal (depending on the numerical coding used), reflecting the systemic discharge of waste into the environment.

Segregation Practices (M = 3.958, t = 216.089)- the exceptionally high t-statistic (216.089) indicates that the lack of proper chemical segregation is a nearly universal trait across the sampled institutions. This aligns with the observational data regarding the "routine decanting" of various effluents into laboratory sinks.

Staff Training (M = 3.900, t = 97.603)- this mean confirms a significant and consistent gap in occupational health education. The statistical strength here underscores the curricular deficiency found in the document analysis, suggesting that staffs are operating without the necessary competence for environmental stewardship.

3.14.3. Procedural Documentation and Institutional Type

Documented Procedures (M = 1.783, t = 21.938)- though statistically significant, this variable shows a lower mean difference compared to others. This suggests that while documented procedures are largely absent, there is slightly more variability here than in training or treatment practices likely due to the sophisticated infrastructure noted in higher education institutions compared to secondary schools.

Types of Institution (M = 1.392$, t = 18.759$)- this validates that the distribution of institutional types (Governmental, University, etc.) in the sample is statistically stable, providing a reliable foundation for the Pareto analysis.

The findings of this research, synthesized through qualitative observations, rigorous document analysis, and multi-dimensional statistical evaluations, reveal a critical failure in the chemical waste lifecycle within Tigray's educational institutions. A cohesive picture emerges: unsafe laboratory practices are not merely behavioral lapses but the direct output of a deficient pedagogical framework and systemic infrastructural neglect. The document analysis provides the explanatory foundation for the operational failures noted in observations; specifically, the 82 identified environmentally blind experimental designs are quantitatively confirmed by the one-sample t-test result for Staff Training (M = 3.900, t = 97.603, p < .001). This statistical significance suggests that the curricular omission of waste management principles translates directly into a measurable deficit in occupational competence, confirming that educators and students are operating within a system that fails to define safety protocols. Building on this systemic failure, the Pareto analysis identifies a "Vital Few" phenomenon where governmental institutions account for approximately 78% of the total waste volume. This concentration was triangulated by the one-sample t-test for Types of Institution (M = 1.392, t = 18.759), validating the institutional distribution as a stable and significant predictor of waste frequency. This reveals a Sophistication Paradox in higher education; while these institutions possess more robust upstream infrastructure, the observational data regarding sink decanting and interceptor failure is reinforced by the high t-test mean for Waste Treatment (M = 4.208). This high mean statistically

represents the routine nature of unsafe disposal, proving that higher technical capacity does not mitigate environmental risk when coupled with the cradle-to-grave documentation gap (M = 1.783) observed across all sectors. Finally, triangulating the Pareto stacked-bar analysis with qualitative audits uncovers a critical distinction in chemical heterogeneity. While Acid and Base waste dominates the high-volume governmental sector, the university sector exhibits a unique spike in Organic Solvents, accounting for 50% of its institutional total. This nuance suggests that while the governmental sector is the primary target for volume reduction, the university sector requires specialized complexity management. Furthermore, the observation of Legacy Chemicals—reagents aged 20 to 40 years—highlights the Trivial Many (Private and College) as potential hotspots for high-toxicity, low-volume risks. These risks remain unregulated and untraceable due to the total absence of hazardous waste logs, highlighting an urgent need for a transition toward a point-source concentration model for regional environmental governance.

4. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

The synthesis of qualitative observations, curricular audits, and multi-dimensional statistical evaluations reveals a critical fracture in the chemical waste lifecycle within Tigray's educational landscape. This study concludes that the prevalent mismanagement of laboratory hazardous waste is not merely a byproduct of individual negligence but is a structured output of a deficient pedagogical framework and systemic infrastructural neglect. The high t-statistic recorded for staff training gaps (t=97.603) serves as a quantitative indictment of the current curricula, which abdicates environmental responsibility by failing to integrate the waste management hierarchy into experimental protocols.

A central contribution of this research is the identification of the Vital Few Vs Trivial Many distribution of environmental risk. The Pareto analysis confirms that regional environmental impact is disproportionately localized within governmental institutions, providing a strategic lever for policy intervention. However, the qualitative nuance found in the university sector—characterized by high-complexity organic effluents and the presence of legacy chemicals (aged 20–40 years) in secondary schools, highlights a dual-threat environment of high-volume corrosives and high-toxicity stagnant reagents.

To rectify these lapses, a move toward a Point-Source Governance Model is imperative. Resource allocation must be stratified: Level 1 interventions should focus on bulk neutralization in governmental labs, while Level 2 should implement specialized recovery systems for the heterogeneous waste streams of higher education. Ultimately, bridging the cradle-to-grave documentation gap and revising environmentally blind laboratory manuals are essential steps to ensuring that educational progress does not come at the cost of long-term ecological and occupational toxicity.

4.2. Recommendations

- The Sophistication Paradox: Emphasize that having PPE and nice labs (Universities) didn't lead to better waste management compared to poor schools; it just changed the *type* of waste.
- Curricular Silence: Argue that by not teaching disposal, the Ethiopian education system is "implicitly normalizing" environmental pollution.
- Prioritize and implement comprehensive waste minimization strategies at the source, including detailed inventory management, purchasing chemicals in appropriate quantities, promoting chemical exchange programs, and integrating micro scale chemistry into the curriculum wherever feasible.
- Policy Efficiency**:** Use the Pareto data to argue that the government doesn't need to fix every school at once; fixing the Governmental Secondary sector alone solves nearly 80% of the volume problem.

5. ACKNOWLEDGMENTS

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6. CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

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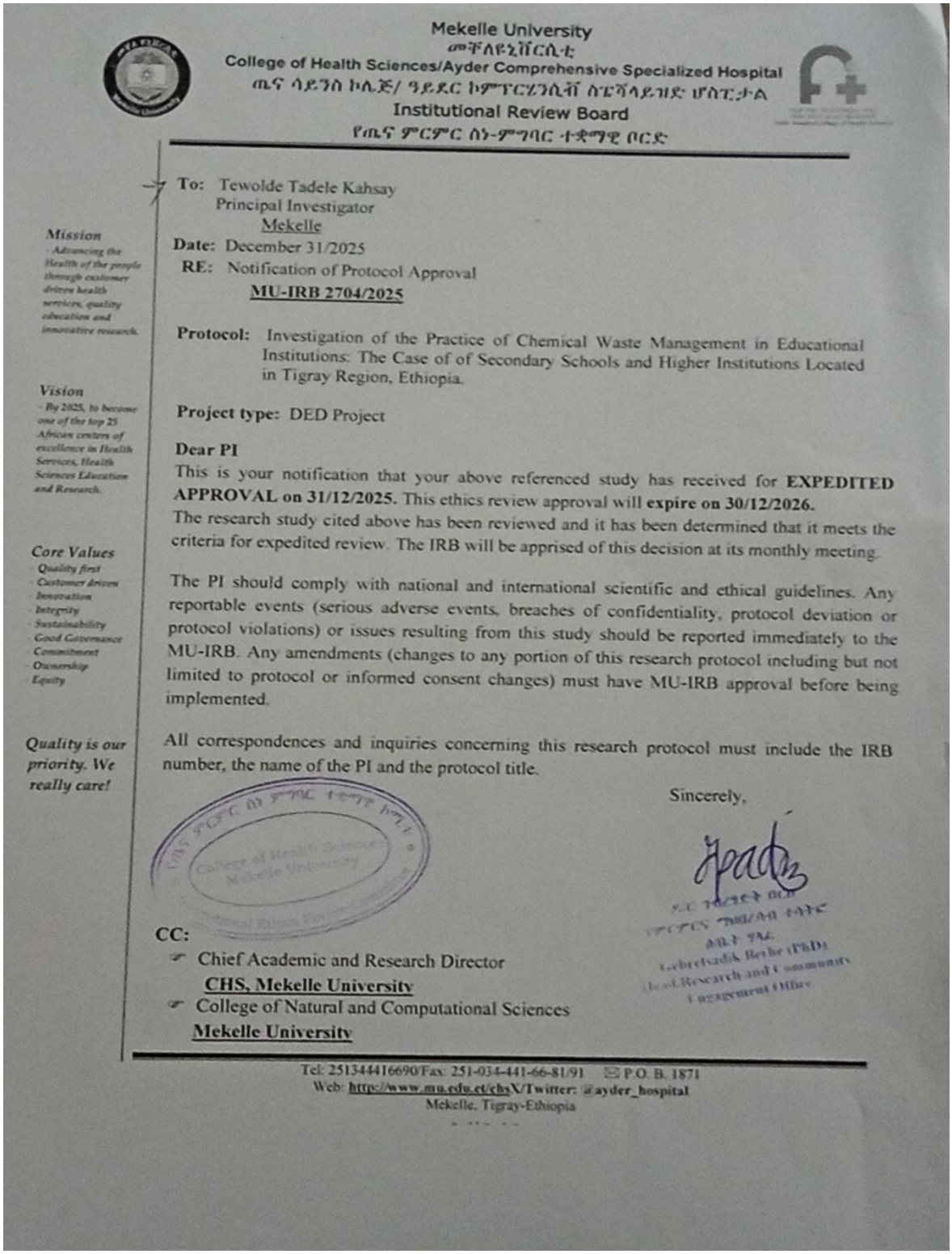
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***Appendix**-1 Notification of Protocol Approval.*



Mekelle University
መቐለዩኒቨርሲቲ
College of Health Sciences/Ayder Comprehensive Specialized Hospital
ጤና ሳይንስ ኮሌጅ/ ዓይደር ኮምፕርሂንሲቭ ስፔሻላይዝድ ሆስፒታል
Institutional Review Board
የጤና ምርምር ስነ-ምግባር ተቋማዊ ቦርድ

To: Tewolde Tadele Kahsay
Principal Investigator
Mekelle

Date: December 31/2025

RE: Notification of Protocol Approval
MU-IRB 2704/2025

Protocol: Investigation of the Practice of Chemical Waste Management in Educational Institutions: The Case of of Secondary Schools and Higher Institutions Located in Tigray Region, Ethiopia.

Project type: DED Project

Dear PI

This is your notification that your above referenced study has received for **EXPEDITED APPROVAL on 31/12/2025.** This ethics review approval will **expire on 30/12/2026.** The research study cited above has been reviewed and it has been determined that it meets the criteria for expedited review. The IRB will be apprised of this decision at its monthly meeting.

The PI should comply with national and international scientific and ethical guidelines. Any reportable events (serious adverse events, breaches of confidentiality, protocol deviation or protocol violations) or issues resulting from this study should be reported immediately to the MU-IRB. Any amendments (changes to any portion of this research protocol including but not limited to protocol or informed consent changes) must have MU-IRB approval before being implemented.

All correspondences and inquiries concerning this research protocol must include the IRB number, the name of the PI and the protocol title.

Sincerely,

CC:
- Chief Academic and Research Director
  CHS, Mekelle University
- College of Natural and Computational Sciences
  Mekelle University

Mission
- Advancing the Health of the people through customer driven health services, quality education and innovative research.

Vision
- By 2025, to become one of the top 25 African centers of excellence in Health Services, Health Sciences Education and Research.

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Mekelle, Tigray-Ethiopia

Appendix-2. *Research questionnaire related to chemical waste management.*

Research questionnaire

Mekelle University, Department of Chemistry

Dear Sir/madam, I am a PhD/DED Student of the Department of Chemistry, Mekelle University.

This questionnaire aims to collect data on secondary school and higher institution teachers' practices and procedures on chemical waste management.

Instructions: Please complete the following questionnaire regarding practices and procedures related to chemical waste management at your institution. Your responses will remain confidential and will be used for research purposes only..

Make A tick (✓) mark on the provided box

Section A: Socio-demographic characteristics

Type of the Institution/ School (Governmental ☐ Private ☐, University ☐ College ☐)

Position of the respondent Dean ☐ Department head ☐ principal ☐

Chemistry teacher ☐ Laboratory technician ☐

Gender (M ☐ , F ☐)

Educational level (Diploma ☐ , Degree ☐., Masters ☐, PhD ☐)

Years of Experience in Current Role: (1-5 years ☐, 6-10 years ☐, 11-15 years ☐ ,More than 15years ☐)

Instructions: Please select the most appropriate answer for each question by making circle

1. Which of the following types of chemical waste is most frequently generated in your laboratories?
   a) Acids and bases b) Organic solvents c) Heavy metals d) Other, please specify:_____
2. Approximately how often are chemical waste disposal procedures carried out?
   a) Daily b) Weekly c) Monthly d) As needed e) not at all
3. Of the total waste generated above, which specific chemical waste is estimated to be disposed of in the largest quantity?
   a) Acid and Base b) Organic solvents c) Heavy metals d) other please----------
4. Which of the following is the most common container used for storing liquid chemical waste?
   a) Plastic bottles b) Glass bottles c) Metal containers d) Original chemical containers
   e) nothing is storing
5. Which of the following is the most common container used for storing solid chemical waste?
   a) Plastic bags b) Cardboard boxes c) Metal bins d) Original chemical containers
   e) nothing is storing
6. Which of the following is the most common method of initial chemical waste storage?
   a) Dedicated storage cabinets b) Under lab benches c) In fume hoods d) In open area
   e) Other, please specify:_____
7. How often is chemical waste segregated according to its type?
   a) Always b) Often c) Sometimes d) Never

8. How is chemical waste disposed of from your institution?

   a) On-site treatment b) Off-site disposal by a licensed company

   c) Discharged into the sewage system d) Local landfill e) other

9. Are there documented procedures for handling chemical waste?

   a) Yes, and they are regularly reviewed b) Yes, but they are rarely reviewed

   c) No, but staff have informal knowledge d) No, there are no procedures e) I do not know

10. What type of training is provided to staff on chemical waste handling?

    a) Formal training sessions b) On-the-job training

    c) Written guidelines d) No training provided

11. What type of treatment, if any, is applied to chemical waste before disposal?

    a) Neutralization b) Incineration c) Dilution d) No treatment e) I do not know

For each statement, indicate your level of agreement using the following scale: by making tick (✓) mark on the provided box

1 - Strongly Disagree, 2 – Disagree, 3 – Neutral, 4 – Agree, 5 - Strongly Agree

no	Section A: Waste Treatment and Minimization	1	2	3	4	5
01	The higher institution implements waste minimization techniques, such as inventory control and recycling.					
02	On-site chemical waste treatment methods (e.g., neutralization, precipitation) are used when feasible.					
03	The higher institution explores opportunities to substitute hazardous chemicals with less-toxic alternatives.					
04	Waste reduction and proper disposal are considered in the procurement of new chemicals.					
	Section B: Safety and Training					
05	Appropriate personal protective equipment (PPE) is available and used when handling chemicals waste.					
06	Staff and students have received training on chemical safety, waste handling, and emergency response.					
07	The institution conduct waste audits					
	Section C: Waste Handling and Disposal					
08	Chemical waste is collected and stored in designated, labeled containers.					
09	Different types of chemical waste are segregated for appropriate disposal methods.					
10	The institution has access to licensed, reputable chemical waste disposal services.					
11	I can dispose waste chemicals by knowing it's physical and chemical properties					
12	Chemical waste (especially expired chemicals) is disposed of regularly and in compliance with local and EPA regulations.					
13	The types of chemical waste generated are well documented					
14	There is a designated individual or team responsible for the management of chemical waste at my institution.					
15	Chemical waste containers are picked up and the waste disposed of regularly at the laboratory premises.					
16	Chemical wastes generated in the laboratory are disposed of into the sink					
17	Chemical stocks are rotated (first in, first out) in the laboratory to help avoid expiration.					

***Appendix-3**. Research Observation checklist.*

Observation checklist

No	Availability of chemical storage facilities	1	Remark
1	Presence of a designated chemical storage room/area		
2	Condition of the storage facilities (e.g., ventilation, shelving, labeling)		
3	Accessibility of the storage facilities (e.g., restricted access, security measures)		
	Waste disposal practices		
4	Presence of a designated chemical waste disposal area (Open drain, Septic tank or other alternative)		
5	Availability of appropriate waste containers (e.g. labeled, leak-proof)		
6	Proper segregation of different types of chemical waste		
7	Frequency and method of chemical waste disposal		
	Personal Protective Equipment (PPE) usage		
8	Availability of PPE (e.g., gloves, laboratory coats, goggles)		
9	Proper use of PPE by laboratory staff and students		
	Safety and emergency preparedness		
10	Presence of safety equipment (e.g., fire extinguishers, eyewash stations, first aid kits)		
11	Availability of emergency response plan and procedures		
12	Visibility of safety signage and instructions		
	Waste management records and documentation		
13	Presence of chemical inventory records		
14	Availability of waste management records (e.g., disposal logs, manifests)		
15	Compliance with relevant regulations and guidelines		
	Overall cleanliness and organization		
16	Cleanliness and orderliness of the chemical storage and waste disposal areas		
17	Proper labeling and identification of chemicals and waste containers		