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The environmental price of diagnostic scale-up—addressing a toxic trade-off we cannot afford

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The scale up of diagnostic service in many Low-Income Countries (LIC) has greatly improved health outcomes of the populations being served by 21st century laboratory platforms like those seen in High Income Countries (HIC). A challenge because of this scale up is the contribution of increased volume of plastic and hazardous chemical waste that needs to be properly managed with limited options as compared to what is available in HIC. Guanidinium thiocyanate (GTC), as an example, a widely used component of extraction reagents used in Polymerase Chain Reaction (PCR) testing, when inappropriately disposed of can cause harm to animals and the environment because it contains a toxic cyanide compound. While environmental short term disposal methods exist that would improve the practices and offer alternative waste treatment options, challenges in availability of required infrastructure and sustainability remain, thereby limiting their impact. While testing generates revenue, waste associated with testing is a cost that is not adequately funded hence unsustainable in the current environment. The availability of alternative compounds that are less toxic yet can achieve the required actions may provide a lasting solution. Developing platforms geared towards microchemistry as well as the recyclability of the materials used for testing would steer waste/material management in a new direction. We call on diagnostic manufacturers to consider these options upstream of the product lifecycle in the long term that are in line with their internal corporate commitment to sustainability beyond the manufacturing process.

KEYWORDS

waste management, waste disposal, GTC, guanidinium thiocyanate, hazardous waste and management

Introduction

Every diagnostic test conducted has the potential to save lives- but improper disposal of the waste streams (personal protective equipment, blood drawing needles, tubes of blood, pipette tips, platform analyzer tubes, plastic pasture pipettes, Point of Care (POC) cartridges, chemical used in diagnostics platforms of varying hazards) emanating from these tests can result in environmental pollution (Poor air emissions from inappropriately operated incinerators, contaminated/toxic waste water, solid residues from poorly or partially treated wastes) posing a danger to both humans and animals. The scale up in diagnostics while intended to reduce the gap in diagnostic access, must be paralleled with implementation of fit for purpose (versus fit for budget) and sustainable waste management innovations and interventions such as bioremediation and retrofitting incinerators with

FIGURE 1
Viral Load lab waste waiting to be treated and destroyed.

fluid injectors to manage fluid treatment. The scale up of molecular tests to address the diagnostic gaps has the potential to improve health outcomes especially in sub-Saharan Africa, where the unmet need accounts for up to 81% (Fleming et al., 2021). However, we must not ignore that this scale up is accompanied by an increase in the generation of infectious waste, toxic plastics components, and chemicals from the testing platforms (Figure 1). For example, guanidinium thiocyanate (GTC), a strong protein denaturant and a chaotropic agent is an essential component in the functionality of molecular viral load, COVID-19 and other molecular diagnostics. Yet when improperly disposed of, especially when mixed with bleach, it releases cyanide gas potentially posing serious health and environmental hazards (Paik and Wu, 2005; Welch et al., 2020). Options for treatment and disposal are discussed below.

Waste burden and inappropriate practices

Deducing from the estimates by Sleeman et al., over 36 million HIV viral load (VL) tests were conducted globally in 2024, generating approximately 1.1 million litres of effluent chemical waste and 2.5 million kilograms of solid waste annually (Sleeman et al., 2018). The COVID-19 testing surge magnified this issue, with over 140 million supplied kits producing around 2.6 million kilograms of plastic waste and 731,000 L of chemical waste (WHO, 2022). This risk is not theoretical, as demonstrated in a 2020 survey of liquid waste management practices conducted by the African Society for Laboratory Medicine (ASLM) across 11 African countries participating in the laboratory systems strengthening community of practice. The survey reported disposal of GTC-containing liquid chemical waste into the sewer in most viral load testing laboratories thereby creating substantial environmental risks to both humans and animals. Additionally, the 11 countries self-assessed their HIV viral load testing cascades (Odhiambo et al., 2021). Waste management emerged as the weakest domain due to systemic gaps related to lack of national waste management policies and guidelines, insufficient biosafety infrastructure, and the absence of sustainable waste solutions. Only 2 out of 11 countries had the requisite national waste management and biosafety policies and guidelines document (Odhiambo et al., 2021). There is a lack of understanding of the principles of healthcare waste management along with a lack of understanding of the principles of operating and maintaining treatment technologies for the waste streams to be processed. The issue is particularly acute in laboratories using molecular platforms, where chemical handling is more complex and often overlooked. Most lacking is addressing the financial needs associated with healthcare waste management with encompasses maintenance of the appropriately selected equipment as well the cost operating the equipment (staff salaries, fund spare parts, and required utilities). Waste management is a cost center and not a revenue generator like laboratory testing. Opportunities for cost avoidance do exist that need to be explored on a case-by-case basis in collaboration with platform vendors.

Initiative to support short term solution

To urgently address this challenge, the U.S. Centers for Disease Control and Prevention and the ASLM launched a targeted initiative: a waste management sub-community of Practice. This initiative brought together subject matter experts, country teams and technical consultants from Waste Not, Want Not (WNWN) to co-develop solutions. Together, we raised awareness about GTC toxicity, assessed disposal practices, and explored sustainable alternatives to incineration, in the short term. During this initiative, several promising alternatives to the widespread practice of discharging to sewer or incinerating GTC-containing waste were identified (ASLM, 2025). These include: a)

mixing liquid waste with sawdust or charcoal dust to create material more suitable for thermal combustion, (Potentially low cost based on sawdust or charcoal dust availability) b) encapsulation of liquid waste with cement, (Low cost for small volumes) c) Use of chemicals to precipitate the guanidine thiocyanate as cuprous thiocyanate thereby greatly reducing the liquid fraction to a non-hazardous waste, (Medium cost) d) Use of cement kilns that are amenable to liquid and solid fractions of the waste streams, e) Use of UV light and hydrogen peroxide to break down the thiocyanate fraction of GTC (High cost initially for setting up equipment/most appropriate for large volumes of liquid (>100 L per day), f) bioremediation using bacteria capable of breaking down thiocyanate, (Moderate cost to set up but self-sustaining once established) and g) incinerator fluid injection systems that sprays/mists the liquid waste into the primary chamber of an incinerator (High cost for injector/suitable for large incinerators (>100 kg/h processing capacity). Additionally, many facilities used incinerators that were sub-optimally functional as well as not designed for liquid waste disposal, and in some instances, basic burning chambers mistakenly identified as incinerators. These findings demonstrated there are a range of treatment options available. It also pointed to the need to budget for these as well as other waste management practices. Without appropriate funding, none of these options are sustainable.

Overall, there has been an improvement in waste management practices across the 11 countries exemplified by the increased number of countries with at least a draft of the national waste management and biosafety policies and guidance documents (n = 9) from the last round of self-assessment exercises conducted in October 2024. Despite the availability of policies and guidance documents and the improvement of waste management practices in molecular testing laboratories, there are still lingering questions on the sustainability of these initiatives.

Innovations for long term sustainability

While the waste management alternatives mentioned above can apply in the short term to reduce environmental pollution across sub-Saharan African countries, there is need for more sustainable solutions particularly targeted upstream in diagnostic manufacturing. Some successful innovations have been demonstrated, e.g., in eliminating the use of GTC for nucleic acid extraction in molecular testing. For example, Abbott and Hologic diagnostic manufacturers uses Guanidine Hydrochloride and sodium hypochlorite for their mPima and Panther VL tests, respectively as the nucleic acid extraction agent (WHO, 2017, WHO, 2019; WHO, 2021). The use of environmentally friendly material components could allow for less reliance on virgin petrochemical materials that contribute to increasing the carbon footprint through green house gas emmissions. Ongaro et al. provided a review of alternative environmental-friendly materials that can be used to replace commonly used materials in the manufacturing of point-of-care tests (Ongaro et al., 2022). These include the use of recyclable plastics, bio-derived and bio-degradable plastics, natural fibrous materials, among others. Availability of these alternatives should inform advocacy efforts to manufacturers to consider re-designing existing tests to include these environmentally friendly options in the production process. Global laboratory stakeholders like the Global Fund need to enforce the requirement for environmentally friendly alternatives in newer products in addition to stronger legislations and regulations at country level, all contributing to actualizing the 'polluter pays' principle (Gorun, 2018). A holistic approach must be considered by all stakeholders for these waste streams–the application of 10 Rs of waste management would be a good place to begin from most to least effective, Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover (Munoz et al., 2024).

Call to action

In conclusion, we call upon the waste management stakeholders, including ministries of health, donors, and diagnostic manufacturers to act now, before the sector is flooded with a large numbers of kits produced without environmental considerations. National procurement guidelines must include the requirement for safe disposal of diagnostic products. Target Product Profiles should be put to good use by policymakers and must incorporate quantitative limits to the packaging proportion in testing kits, as well as minimize plastic use, especially in standard kits such as lateral flow tests (Wöhrle et al., 2025). Annual procurement forecasting exercises should include anticipated waste volumes for accurate cost of disposal. Infrastructure investments should prioritize biosafety and meet the requirements for safe waste disposal—not just throughput. Diagnostic manufacturers must take greater responsibility for end-of-life management of their products and reagents including consideration for sustainable, less toxic, and potentially recycled, alternative raw materials.

While championing equitable access to diagnostics to meet the needs of the African continent, we must also champion the right to safety—for healthcare workers, communities, and the environment. Diagnostic access without safe, effective treatment and disposal of these waste streams is a toxic trade-off we can no longer afford.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

CO: Conceptualization, Writing – original draft, Writing – review and editing. BV: Writing – review and editing. EK: Writing – review and editing. AM: Writing – review and editing.

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Author EK was employed by Waste Not Want Not inc.

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