



# Healthcare waste from clinical analysis laboratories in São Tomé and Príncipe – Current state and constrains in the framework of least developed countries

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## ARTICLE INFO

Handling Editor: Klaus Kümmerer

### Keywords:

Hazardous waste  
Sustainability  
Dumpsites  
Waste incineration

## ABSTRACT

Laboratories of clinical analysis are essential to the diagnosis of many diseases but also generate waste that is a potential risk to humans and the environment, especially in the context of least developed countries with structural impediments. The main objective of the work was to assess the current state of waste management from clinical analysis laboratories in Sao Tomé and Príncipe (STP) and to propose suggestions to increase environmental and social sustainability.

Data was collected by interviews between March and April 2022. Waste from clinical analysis laboratories reaches 123.7 t/year (0.35% of waste in the country). Critical issues are: pre-treatment to prevent biological contamination is carried out in 50% of the laboratories; at 93% of the sites, the staff does not have proper training; 43% of the laboratories do not have a dedicated space for storing the waste; 79% of the laboratories only segregate sharp-objects, 14% segregate infectious waste and 7% have no source-segregation. Sharp waste is incinerated, while other waste is dumped or buried (93% of laboratories) or is burned in pits on the ground (7%).

Most of the waste produced in clinical analysis laboratories in STP is disposed and treated in an inappropriate manner, likely resulting in soil, water and air pollution that impact on human health. Critical issues that have been identified at STP are likely found also in other least developed countries and need addressing in the path towards sustainable development goals.

## 1. Introduction

Healthcare waste is generated from the treatment, diagnosis and vaccination of human beings and animals at medical and veterinary facilities, research centres on health and clinical analysis laboratories (Yoon et al., 2022). It is estimated that 15% of all healthcare waste is hazardous (WHO, 2023). The hazardousness can be of biological nature (due to the presence of active biological agents), physical nature (due to sharp objects) or chemical nature (due to the presence of reagents and other hazardous chemical substances). Therefore, poor management of this type of waste presents a potential risk to health since these wastes are potential reservoirs of pathogenic microorganisms, contain dangerous chemical, pharmaceutical or radioactive products and can cause injuries

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as they contain sharp materials and can also affect the quality of surface and groundwaters (Abanyie et al., 2021; Eren and Tuzkaya, 2021; Hamadan et al., 2012; Omar et al., 2012).

Worldwide, 5.2 million people, including 4 million children, die every year from diseases caused by unmanaged healthcare waste (Nie et al., 2014). In 2000, it was estimated that sharps injuries to healthcare professionals caused approximately 66 000 cases of hepatitis B (HBV), 16 000 hepatitis C (HCV) and 200–5000 HIV infections. Other diseases that can result from inadequate management of this type of waste are typhoid fever, cholera (Agbere et al., 2021; Hamadan et al., 2012; Oroei et al., 2014), hemorrhagic fever, anthrax, brucellosis and tuberculosis (Qasmi and Khan, 2019). When hazardous healthcare waste is not managed properly, exposure to it can lead to other complications such as infertility, genital deformities, hormone-triggered cancers, mutagenicity, dermatitis, asthma, and neurological disorders in children (Oli et al., 2016). Therefore, while being essential for healthcare and for the diagnosis of many diseases (such as COVID-19, tuberculosis, HIV, malaria, and others) laboratories of clinical analysis, also generate healthcare waste that is a potential risk to humans and to the environment. The recent COVID-19 pandemic added to the problem, by increasing generation of waste due to more laboratory testing (WHO, 2020).

The management of clinical analysis wastes requires specific attention in storage, discarding, collection, transport, treatment, and disposal, to prevent water, soil and air pollution and health risks to humans and other living beings. To help improve hazardous waste management there are several principles such as the “polluter pays” principle; the “precautionary” principle; the principle of “duty of care”; the principle of “proximity” and the “prior informed consent” principle. In addition to these principles, there are international agreements that apply to the management of this waste, such as the Basel Convention (transboundary movements of hazardous waste and its disposal) and the Stockholm Convention on Persistent Organic Pollutants (POPs) (WHO, 2014).

Technologies used for the treatment of healthcare waste are classified into three types: thermal processes (incineration stands out, according to Dave and Joshi, 2010), chemical disinfection (using sodium hypochlorite, calcium hypochlorite, chlorine dioxide) and physical disinfection (autoclave and microwave treatment, according to Dharmaraj et al., 2021). These technologies have advantages and disadvantages that must be analyzed before their implementation for healthcare waste management.

Management of healthcare waste has been challenging and critical in many least developed countries (LDC) (Omoleke et al., 2021), where less attention is given to this waste. The mixing of infectious with non-infectious waste (Agbere et al., 2021; Oroei et al., 2014) and the discarding healthcare waste with common household waste creates a significant risk for all population (Agbere et al., 2021). On the other hand, in LDC the poor management of waste produced is caused by the lack of financial resources and infrastructures, improper segregation, inadequate awareness, inadequate attitudes and practices of professionals working in the area (Oroei et al., 2014) and limitations in options for disposal (Agbere et al., 2021).

In Sao Tome and Principe (STP), currently classified as an LDC, basic obstacles to a well-functioning waste management system have been previously highlighted (Vaz et al., 2015) in particular: waste vehicles are imported and require expensive and considerable maintenance; waste containers and bins are scarce; economic and political leadership are both unwilling to take risks and to make unpopular decisions; and, waste management is strongly dependent on donor countries and agencies (European Union, Agencia Espanola de Cooperación Internacional para el Desarrollo (AECID), Instituto Camões, etc.). Waste littering and burning in ground pits are widely spread practices for household waste and at least 75% of the population does not have access to regular municipal collection service (Fernández-Braña and Dias-Ferreira, 2023), being unknown how the specific waste stream from clinical analysis laboratories is currently being managed.

In Cape Verde, an African island state (such as São Tomé and Príncipe), the availability of data relating to healthcare waste production is limited and the efficient separation of different groups of hazardous waste is difficult (MSSS, 2021). Additionally, there is a lack of trained human resources and of suitable equipment for the transportation of waste. It was also found that the transport to final destination is carried out in most municipalities by the Municipal Chambers. Final disposal is at municipal dumpsites (MSSS, 2021), similarly to STP.

In yet another African country, Angola, current hospital waste management practices include the separation of sanitary waste and its collection by the municipality for final disposal in open dumps (PGRH, 2020).

Given the lack of information on healthcare care waste in LDC in general, and clinical waste in particular, this work aims to fill in the gap and assess the current state of management of waste from clinical analysis laboratories in São Tomé and Príncipe, as an example of an LDC. It is also an objective to identify suitable measures that can be introduced, based on the current state, to reduce the environmental and social negative impact of wastes from clinical analysis laboratories in LDC, targeting UN2030 sustainable development goals.

## 2. Methodology

### 2.1. Methodological approach

A case study approach is used in this work. Management of waste from clinical analysis laboratories in the LDC of São Tome and Principe will be examined to understand the dynamics of waste generation, sorting, collection, treatment, and disposal and to identify the critical issues that need addressing to increase sustainability. Even though the results cannot be generalized to all LDC, some of the findings can, to a certain degree, be representative and valid in other LDC.

### 2.2. Case study

The Democratic Republic of São Tomé and Príncipe (STP) is an archipelago located in the Gulf of Guinea, West Africa, comprising two islands: São Tome Island and Principe Island. The total area is 1001 km<sup>2</sup> and the population is 223 107 (World Bank, 2023).

Most districts fail to collect waste, and collection covers only between 10% and 30% of the population (Vaz et al., 2015).

There is no scientific data on the management of laboratory waste in STP, with data available only for municipal solid waste. The management of municipal solid waste has been challenging for District Chambers (municipalities), as they do not have the means for adequate collection nor treatment. The fact that São Tomé and Príncipe is made up of two small islands increases difficulties in the management of solid waste due, among other aspects, to the high cost of transporting and properly treating waste, associated with the lack of means to carry out awareness raising campaigns among citizens and good practices in this matter. On the other hand, it should be noted that waste management in the country only covers the collection process, which is still very rudimentary and vulnerable, where waste is placed in containers made available by the District Chambers, collected and then transported to the Penha dumpsite and occasionally burned.

In 2017 a Training Manual on the Management of Hospital Waste was prepared by an external consultant at the request of the Directorate-General for the Environment of São Tomé and Príncipe, with the aim of providing training on of hospital waste management for the staff working in this area (Saraiwa, 2017). This manual refers that sharp waste must be disposed of separately, at the place of its generation and immediately after use. Additionally, with the COVID-19 pandemic, an Infection Control and Waste Management Plan was created for São Tomé and Príncipe in 2020, which emphasizes that waste must be separated at the source. These documents aim at the implementation of measures to ensure adequate environmental protection related to healthcare waste.

Although in São Tomé and Príncipe there is no specific law for healthcare waste, it is possible to verify the existence of some laws that establish fundamental principles related to public health, environmental protection and safe management hazardous waste which must be considered in the planning and management of healthcare waste. Furthermore, it is noteworthy that the Constitution of the Democratic Republic of São Tomé and Príncipe of 1990 in its article 10th, establishes in paragraph (d) as one of the four Primary Objectives of the State of São Tomé and Príncipe: “*Preserving the harmonious equilibrium of nature and the environment*”, which reveals the commitment of national authorities to actively promote actions, policies and measures for the protection, conservation and preservation of natural resources. In this sense, Law number 10/1999 (Framework Law on the Environment), of 15 April 1999 and Law number 37/99 (Regulation on the assessment of environmental impacts), establish the foundation of environmental policies for sustainable development in the country.

### 2.3. Data collection

A survey was carried out encompassing all laboratories that were in operation in 2022 at São Tomé and Príncipe. The survey was designed following the guidelines by Carmo and Ferreira (2008), without carrying out a pre-test. It comprised 22 questions grouped in 3 sections. The first section gathered information about the laboratory, namely size, average number of users and number and type of analysis carried out per day. The second section focused on clinical waste generation and disposal practices. Questions in this section included the daily amounts of waste generated, types of waste, sorting and collection practices and final destination of waste. The third section of the survey targeted the perception of the staff about the practices of waste management in clinical analysis laboratories. This last section comprised 2 open-ended questions on the main problems of clinical waste management and suggestions for improvement.

The survey took place in March–April 2022 and each interview took approximately 30 min. All 14 clinical analysis laboratories that were fully operational in STP were surveyed, 13 of which were dedicated to human analysis and one was dedicated to veterinary analysis. To ensure data consistency and the validity of the results, the person within each laboratory who answered the survey was carefully selected (referred by his/her own colleagues as the one most knowledgeable in the laboratory in relation to healthcare waste generation, treatment and disposal). A total of 14 professionals who work in the clinical analysis laboratory responded to the survey, one for each laboratory. In addition, special care was taken when asking about the amounts of waste generated daily: as this is not routinely measured it is expected to be unknown by the respondent, so the respondents were instructed that in their estimate of the estimate the amount of waste produced per day (in kg/day) they should carefully consider the number of waste containers in the laboratory, their volume, how much they weight when filled and the frequency of their emptying. Raw data collected was transferred to a spreadsheet (MS Excel® 2010) and submitted to descriptive analysis and further analysis.

An interview was also carried out to two technicians who work at the São Tomé and Príncipe Health Waste Management Center with the prior authorization of the person responsible for the same Center. Of the interviewees, one is an environmental sanitary engineer and another is the incinerator operator. The goal of the interview was to achieve a deeper understanding of the incineration of healthcare waste in São Tomé and Príncipe, namely the amounts and origin of incinerated waste and available equipment. The interviews took approximately 1h30 m and were supported by a previously elaborated script comprising both open and closed questions, totaling 34 questions. The script was divided into 3 sections, with the first section including questions related to the type and quantities of waste and the operating procedures of the incinerator. The second section included questions related to the logistics of transport to the incinerator (such as how often the incinerator receives waste, who transports the waste, means of transport used, among other). Finally, section three aimed to find out by who and how is the incinerator managed. The interviews took place on March 7, 2023, at the São Tomé and Príncipe Health Service Waste Management Center.

### 2.4. Waste classification into hazardous and non-hazardous

Classification as hazardous or non-hazardous wastes was based on the following considerations.

- **Biological samples** (such as saliva, urine, blood, feces) may contain viable pathogenic micro-organisms or their toxins, in high concentrations, which cause disease. For this reason, such wastes are potentially infectious and constitute a significant risk for humans in particular, and for other living beings, being classified as hazardous. Items that have been in direct contact with biological samples can also be infectious and were also considered hazardous.
- **Sharp objects** (example: syringe’s needles) were considered hazardous because they can perforate the skin.

- **Chemical reagents** are hazardous due to their potentially toxicity, corrosivity, ignitibility, explosivity, carcinogenic, irritability or because of their mutagenic (which may cause a permanent change in the amount or structure of the genetic material in a cell) or sensitizing properties. **The first level of packaging of such chemicals** might also exhibit the same properties, and therefore were considered hazardous as well.
- **Personal protection equipment (PPE)** worn by staff are considered hazardous because they might have come into contact with potentially infectious biological material or hazardous chemical material.
- **Packaging of personal protective equipment and 1st level packaging of sampling materials** that did not come in contact with biological samples or chemical hazardous materials were not considered hazardous. Also not hazardous are **secondary and tertiary packaging** materials that have not been in contact with chemical products or biological material.

### 3. Results

#### 3.1. Characterization of clinical analysis laboratories in São Tomé and Príncipe

There are 14 clinical analysis laboratories in São Tomé and Príncipe, roughly equivalent to 1 laboratory for 16 000 inhabitants. One laboratory is dedicated to veterinary analysis and the remaining 13 to human analysis. The laboratories range from 2 national-level (stand-alone) public laboratories, 2 laboratories associated with public hospitals, 7 smaller laboratories located in local health centres (public) to 3 laboratories in private health clinics (Table 1). 79% of the laboratories are public entities and the remaining 21% are private.

Clinical tests vary from laboratory to laboratory and range from direct observation of samples under a microscope, biochemical tests (triglycerides, hemogram, blood type, hemoglobin, urea, uric acid, etc), to more complex microbiological tests to detect tuberculosis through cell-culture or molecular test for COVID-19 Polymerase Chain Reaction (PCR), which are carried out in 2 laboratories only. 12 out of the 14 laboratories carry out serological exams to detect HIV, Malaria and COVID-19.

#### 3.2. Management of healthcare waste from clinical analysis laboratories

Management of healthcare waste from clinical analysis laboratories was systematized into 7 stages: The first four stages occur within the laboratory's facility and comprise: waste generation (stage 1), source segregation (stage 2), pre-treatment (stage 3); removal and discarding (stage 4). The remaining stages occur outside the laboratory and comprise collection and transport (stage 5), treatment (stage 6) and elimination (stage 7).

The following sections describe each stage in STP's laboratories.

##### 3.2.1. Waste generation (stage 1)

This is the first stage of clinical waste management. Relevant issues within this stage are: (i) types of waste and its hazardousness (ii) amounts generated.

**3.2.1.1. Types and hazardousness of waste.** Healthcare waste generated in clinical analysis laboratories can be divided into two main groups according to the place of origin: wastes generated during the collection of the biological sample from the patient (sampling stage); and, wastes generated during sample processing at the laboratory (analytical stage). Some types of wastes can occur at both stages. Table 2 lists waste items that have been identified in the current works in each category, divided into hazardous and non-hazardous. Classification between hazardous and non-hazardous followed the guidelines laid out in the methodology section.

Based on the survey results, all clinical laboratories in Sao Tomé and Príncipe produce both hazardous and non-hazardous healthcare waste. Fig. 1 systematizes the types of waste produced in clinic analysis laboratories and their hazardousness.

**3.2.1.2. Amounts of waste generated.** Daily waste generation at individual analysis laboratories surveyed varied between 2 and 100 kg/day with 9 out of 14 laboratories (64%) producing 10 kg or less per day (Fig. 2a).

The waste per analysis varied between 20 and 1429 g, with 2 of the laboratories presenting comparatively high amounts, over 1000 g of waste/analysis (Fig. 2b).

This high variability in waste/analysis might be related to the type of analysis carried out. PCR and cell culture-based analysis require more materials and therefore likely generate more waste. The amount of clinical waste generated by facility therefore depends on the number of analysis as well as on the type of analysis carried out.

Considering the amount of waste produced per day at each laboratory, a total daily production of 339 kg/day of healthcare waste from clinical analysis laboratories was estimated for São Tomé and Príncipe, equivalent to 123,7 t/year. This represents a production of clinical waste of 0,562 kg/inhabitant/day.

**Table 1**

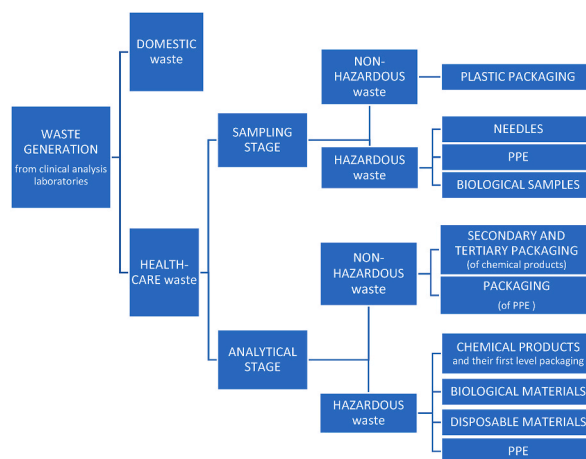
Types of clinical analysis laboratories in operation in São Tomé and Príncipe in 2022.

Type of laboratory	Number of laboratories
Public national-level laboratories	2
Laboratories in public hospitals	2
Laboratories in local health center (public)	7
Laboratory in a private health clinic	3
TOTAL	14

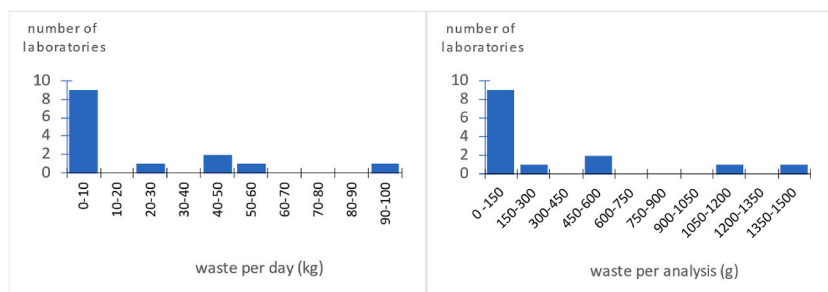
Each laboratory attends between 10 and 120 patients per day and carries out between 10 and 700 analytical tests per day. The average analysis per patient is 3,8, ranging 1–10 analysis/patient.

**Table 2**  
Waste items generated at clinical laboratories during the sampling stage and the analytical stage.

Sampling stage	Analytical stage	At both stages (sampling + analytical)
<i>Hazardous</i>	<i>Hazardous</i>	<i>Hazardous</i>
<ul style="list-style-type: none"> <li>• Syringes</li> <li>• Needles</li> <li>• Needle's cover tips</li> <li>• Cotton used to stop bleeding after blood sampling</li> </ul>	<ul style="list-style-type: none"> <li>• Tubes containing biological samples (saliva, blood, urine, feces)</li> <li>• Disposable pipette plastic tips</li> <li>• Nasal and oral swabs (e.g., COVID testing),</li> <li>• Cell-culture dishes</li> <li>• PCR kits</li> <li>• Diagnose test cartridges</li> <li>• Containers of chemical reagents (1st level packaging)</li> </ul>	<ul style="list-style-type: none"> <li>• Disposable respiratory surgical mask (used)</li> <li>• Head cover (used)</li> <li>• Shoe cover (used)</li> <li>• Disposable gowns/aprons (used)</li> <li>• Disposable gloves (used)</li> </ul>
<i>Non-hazardous</i>	<i>Non-hazardous</i>	<i>Non-hazardous</i>
<ul style="list-style-type: none"> <li>• Syringe's individual plastic packaging</li> </ul>	<ul style="list-style-type: none"> <li>• Outside (2nd level) packaging of chemical reagents used in the analytical procedures (without direct contact with the chemicals)</li> </ul>	<ul style="list-style-type: none"> <li>• Paper box of disposable gloves</li> <li>• Individual wrapping (paper/plastic) of disposable gloves</li> </ul>



**Fig. 1.** Systematization of waste produced in laboratories of clinical analysis.



**Fig. 2.** Frequency distributions of healthcare waste produced within clinical analysis laboratories in São Tomé and Príncipe: (a) amount per day (left); and (b) amount per analysis (on the right).

The estimated production of total waste in the country in 2022 is 30 984 t/year (TESE, 2010), so healthcare waste by clinical analysis laboratories represents 0,4% of total waste in the country. This value is in line with previous findings in other countries (Mota et al., 2004) that refer that healthcare waste (clinical laboratories, but also all other activities related to healthcare, such as hospital, medical offices, clinics, etc.) represents approximately 1% of all generated waste.

### 3.2.2. Source segregation (Stage 2)

Results obtained show that in STP practice to segregate sharp objects (such as needles) and placing these wastes in specific containers, is generalized, with only one out of the 14 laboratories failing to achieve this. This practice is aligned with the training Manual on the Management of Hospital Waste, introduced in 2017 (Saraiva, 2017).

Segregation of sharp objects prevents work injuries and injuries outside the laboratory to those who might come into contact with the waste and is especially relevant since these items are in contact with potentially infectious biological samples and can easily

perforate the skin, increasing the risk of transmission of infectious diseases such as HIV and hepatitis B and C (Agbere et al., 2021).

In addition to sharp objects, there is other hazardous healthcare that is also generated at clinical analysis laboratories, as shown in Fig. 2 and Table 2. Opposite to what happens with sharp objects, separation of these other hazardous waste from non-hazardous waste is not a common practice in STP's laboratories. To better understand the level of separation within the laboratories, we propose a classification system with 4 levels: (i) no separation, (ii) basic separation, (iii) intermediate separation and (iv) advanced separation. The attributes of each level are described in Table 3.

Classification of laboratories in STP according to the source segregation practices showed that 79% of the laboratories in STP are at the Basic Level, 14% are at Intermediate Level, 7% are at Zero Level and there are no laboratories classified at the Advanced Level. Ideally, all laboratories should separate hazardous from non-hazardous waste, because when hazardous waste is mixed with non-hazardous waste, all of it becomes hazardous and recycling of non-hazardous packaging waste is no longer possible. Not segregating hazardous wastes also means that laboratories will have higher amounts of hazardous waste to deal with.

### 3.2.3. Pre-treatment (Stage 3)

Pre-treatment of clinical waste before collection to eliminate biological risk is carried out at 50% of the laboratories by either disinfection (5 laboratories) or autoclaving (2 laboratories). Disinfection is achieved with a solution of sodium hypochlorite (bleach), which has a low cost and is widely available, making it a widespread chemical disinfectant. Autoclave, on the other hand, uses pressure and heat (vapor) to deactivate biological organisms, thus sterilizing samples. The higher acquisition cost of autoclave and the instability of electric energy supply in São Tomé and Príncipe (as well as in other LCD) likely explain why autoclaving is available only at 2 of the laboratories. The results also show that 50% of the laboratories do not eliminate biological risk before discarding the wastes.

### 3.2.4. Removal and discarding (Stage 4)

This stage comprises the removal of waste produced at multiple locations within the facility and discarding of this waste. Critical issues during this stage include.

- staff safety during removal due to the risk of exposure to infectious or chemical material contained in the waste and possible work injuries caused by sharp objects.
- ensuring proper containment of waste while waste awaits collection.

According to Moreschi et al. (2014) staff capacitation for waste management procedures and use of personal protection equipment (PPE) is highly recommended to minimize risks at healthcare facilities.

In the laboratories included in the study, waste is either temporarily stored within the facilities or removed from the facilities and.

- (i) discarded into the common waste container (the same used by the population for household waste) and collected by the municipality.
- (ii) taken to incinerator.
- (iii) taken to municipal dumpsites.
- (iv) directly eliminated (refer to section 3.2.7).

Discarding potentially infectious and hazardous substances in the street containers, sometimes for over a week, in general-use bags or containers, being accessible to people passing-by and to animals; during this period tear and wear of the bags by physical elements (such as rain, or wind) or by people and animals can occur. In addition to the risk of direct contact to hazardous substances, there is also the potential of contamination of soil and groundwater by leaching of hazardous substances from the waste bags and containers.

### 3.2.5. Collection and transport (Stage 5)

As explained previously, there might be 1, 2 or 3 flows of healthcare waste, according to the laboratory: (i) sharp healthcare waste (ii) biological risk waste after autoclaving; and (iii) mixed waste (including healthcare and domestic-like waste). Collection and transport is described individually for each waste flux.

**3.2.5.1. Collection and transport of sharp healthcare waste.** There is not a set schedule for the collection of sharp objects. This operation occurs only when reaching a certain number of filled boxes, which might take a long time in districts with few patients.

Since 2009, and for some years, there was external funding that supported the collection and transport of sharp objects from the laboratories to the incinerator. The operation was at that time under the responsibility of the healthcare waste management center of São Tomé (CGRSS). When the external funding started to decrease, collection also decreased and currently only the sharp objects from central hospital (Dr<sup>o</sup> Ayres de Menezes) are being collected by the Healthcare waste management center of São Tomé, using trained

**Table 3**

Classification of the level of waste separation at analytical laboratories.

ZERO LEVEL (no separation)	BASIC LEVEL (Separation of sharp objects only)	INTERMEDIATE LEVEL	ADVANCED LEVEL
There is only one waste stream: o Mixed waste (all waste, including hazardous waste)	There are two waste streams: o Sharp objects o All other waste	There are three waste streams: o Sharp waste o Biological risk waste o Mixed waste (comprises healthcare and domestic-like waste).	There are four waste streams: o Sharp waste o Biological risk waste o Chemical risk waste o Non-hazardous waste (healthcare and domestic-like waste).

staff and properly equipped vehicles. Transport from the remaining laboratories is carried out by the laboratories own staff without any specific training to handle healthcare waste, namely cleaning personal, stretcher bearers or gardeners, and using general use vehicles that are not adapted to the transport of hazardous waste. This study did not assess if workers use PPE.

**3.2.5.2. Collection and transport of biological risk waste.** In the 2 laboratories where biological risk waste is autoclaved, after sterilization the waste is temporarily stored within the facility and then transported to the dumpsite by the laboratory's staff.

**3.2.5.3. Collection and transport of mixed healthcare waste.** Collection of mixed waste from the laboratories is carried out by the municipality. Collection takes place on a weekly basis in 64% of the laboratories, twice a week (one laboratory), three times per week (3 laboratories) and daily (one laboratory), as shown in Fig. 3.

The low collection frequency in most of the laboratories is due to the lack of vehicles or shortage of petrol. The consequences have already been referred in the previous section and are increased exposure of the general public to hazardous healthcare waste and the possibility of environmental contamination due leachate originating from waste.

### 3.2.6. Treatment (stage 6)

Healthcare waste from clinical analysis laboratories goes directly to elimination without any prior sorting, processing, or treatment.

### 3.2.7. Elimination (stage 7)

The final stage in healthcare waste management is elimination. Elimination depends on the type of waste flux and the laboratory and can be either incineration, discarding in a municipal dump site, *in situ* burning in an open pit in the ground, or *in situ* disposal in a hole dig in the ground.

Most sharp healthcare waste from clinical analysis laboratories is source segregated and is transported to healthcare waste management facilities and incinerated (93% of the labs, Fig. 4); for the one laboratory which does not source segregate sharp objects, this waste is mixed with other wastes and taken to the municipal dumpsite.

Non-sharp waste healthcare waste from clinical analysis laboratories are sent to municipal dumpsites (in 70% of laboratories), buried underground in the vicinity of the laboratory (21%) or burnt *in situ* (7%), as shown in Fig. 6.

**3.2.7.1. Incineration.** There are two incinerators for healthcare waste in São Tomé and Príncipe. One is in the capital (São Tomé) and has a loading capacity of 240 kg (Fig. 5). The other is in the Island of Príncipe and has a loading capacity of 30 kg.

The incinerators were provided by foreign donors and initially it was anticipated that these equipments would be able to handle all healthcare waste produced in the country. However, on arrival it was seen that the capacity was not enough to incinerate all healthcare waste, so it was decided by the entity responsible for this incinerator (The CGRSS) to incinerate sharp objects and placentas, only.

With the purpose of extending the life cycle of the equipment, the entity in charge of the incinerator decided to perform only 1 incineration cycle per day and limit the working load to 210 kg. Each incineration cycle takes between 4 and 5 h and requires electricity supply, petrol (1000 L), water (for cooling and for off-gas treatment system (500 L) and caustic soda for off-gas cleaning (12 kg). The output of the incineration is 25 kg of bottom ash, which are stored underground within the facilities (it was not possible to find additional details about this disposal operation). This represents a production of 11,9% of bottom-ash (percentage of the initial waste) and a reduction of 88,1% (in weight) of the waste during the incineration process.

The operational costs of the incinerators are partially supported by external donors. The incinerators receive healthcare waste from the central hospital, public health centres, private clinics, and public and private laboratories of clinical analysis. Public institutions do not pay for waste incineration and private entities have cooperation agreements. This means that incineration of healthcare waste in STP does not have own fundings and operation relies on external donations. Additionally, at the time of the interview to the manager of CGRSS, it was possible to verify that the incinerator was not in operation on that period due to lack of petrol, to instability in the supply of electricity and to the shortage of water.

All these constrains mean that sometimes healthcare waste is stored for long periods awaiting collection and elimination, both at the point of origin as well as in the incinerator facilities.

**3.2.7.2. Waste dumping and open burning.** "Penha" is the biggest municipal dumpsite in São Tomé Inland, receiving all kinds of wastes from around the island. Waste is discarded not only by the municipality's employees responsible for waste collection but by other public and private entities and by the general population, as well. There are other smaller dumpsites, such as "Neves" dump, in the north (Fig. 6) and others in South part of the island.

The waste is discarded in the dumpsite in a disorganized manner, it is not covered at the end of the way, the dumpsite does not have fences, leachate collection systems and biogas collection system are non-existent, and there are not environmental nor safety control

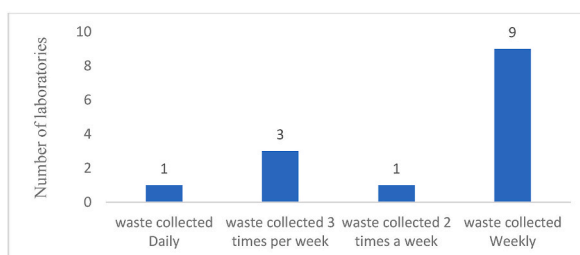


Fig. 3. Frequency of collection of mixed healthcare waste from the clinical analysis laboratories.

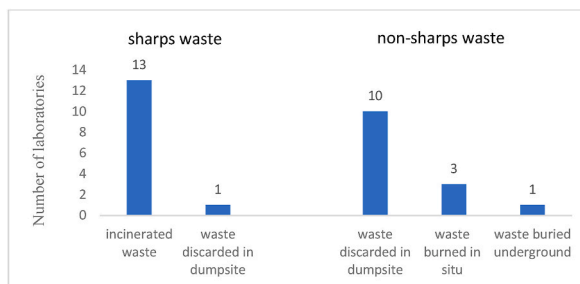


Fig. 4. Elimination of healthcare waste in the 14 laboratories in São Tomé and Príncipe.



Fig. 5. Incinerator at CGRSS, São Tomé island (photo by A. Pereira, 2023).



Fig. 6. Dumping and burning of clinical waste at dumpsite “Lixeira de Neves”, Lembá, São Tomé and Príncipe (photos by I. Andrade, 2022).

measures in place to ensure proper and safe operation.

The waste discarded is burnt almost on a daily basis and there is no control of the combustion fumes, that very often reach nearby communities (Fig. 7). So there is a huge impact of this waste management operation to the nearby communities, to personnel from the municipality and private entities and population who regularly travel to Penha to discard their waste or who live nearby.

Hazardous materials from healthcare waste discarded at the dumpsite present chemical risk (such as chemicals) or biological risk (from infected material that was not pre-treatment at the source laboratory). At the dumpsite these materials may come into direct contact with the population or can leach to the soil and groundwater.

Because the waste is burnt in an uncontrolled manner, it is not possible to ensure the safe destruction of biological or chemical contaminants. Combustion fumes can contain particles of original unburnt material (that maintain its hazardousness), can contain



Fig. 7. Waste burning and air pollution at the Penha dumpsite, on the island of São Tomé (photo by: Sacramento, 2023).

products of incomplete combustion (PIC) due to oxygen-deprived combustion, or can contain vapors of metallic elements present in the healthcare waste, all of which most likely hazardous if inhaled.

The impact of the dumpsites in STP on the local population has not been assessed by any epidemiological study to the best of the authors' knowledge. Healthcare waste represents less than 1% of total waste, but even so, it contributes to the potential impacts of waste dumping at these sites.

#### 4. Discussion

The main problems related to the management of healthcare waste from clinical analysis laboratories that have been identified in the current work are systematized in [Table 4](#). The table is organized according to the stage of waste management and puts forward actions to improve current waste management. Furthermore, the table also identifies the sustainable development goals (SDG) associated to each problem.

#### 5. Conclusion

According to the results obtained, most of the waste produced in clinical analysis laboratories in Sao Tomé and Príncipe is handled and disposed in an inappropriate manner. This is related to lack of general waste management of the area, the most relevant being the lack of separate waste collection services and the lack of suitable infrastructure for waste elimination. Because of these shortcomings, it is difficult for the laboratories to properly manage their own waste. However, unlike general waste, laboratory waste is hazardous and special attention should be given to this waste stream.

Among the critical issues identified in this work is the need to expand source segregation to include hazardous waste other than sharp objects, such as wastes presenting biological or chemical risk. To address it, professionals in the laboratories should be trained and containers suitable for segregation such as buckets and colored bags should be made available. Even though relatively simple to implement, these measures would need to be articulated with changes in the collection and elimination system, which do not depend on individual laboratories, else on the general waste management in STP.

Also important would be to ensure elimination of biological risk at the, prior to discarding waste. Even though autoclaves are expensive, there are more cost-effective chemical disinfection systems that could be set-up in laboratories that do not currently have any disinfection system in place (half of all laboratories).

To overcome problems during the temporary storage of waste, laboratories could build infrastructure or use other physical barriers to prevent waste from being accessible to the public and animals.

There is a need to train professionals who transport hazardous waste on the risks of this waste and the importance of using personal protective equipment. Finally, the incineration capacity must be increased so that other hazardous waste (other than sharp objects) can also be incinerated instead of being deposited in dumpsite, preventing these wastes from coming into contact with the population.

The issues identified in this work are likely to be present in other least developed countries, where there is a lack of regular collection and infrastructures for waste treatment and disposal.

Given the relevant contribution of clinical analysis laboratories for the promotion of health, it is necessary to address the issues here identified so that negative environmental and social impacts from healthcare waste can be reduced in the context of LCD.

#### Author statement

Alzira Pereira: Conceptualization, Methodology, Investigation, Data curation, Writing- Original draft preparation.

Celia Dias-Ferreira: Conceptualization, Writing- Reviewing and Editing, Supervision.

**Table 4**  
Problems regarding the management of healthcare waste from clinical analysis laboratories in STP, improvement suggestions and relevant SDG.

Stage	Problem	Improvement suggestions	Associated SDG
1. Waste generation	339 kg/day (equivalent to 123,7 t/year) of healthcare waste is generated at clinical analysis laboratories. Some of the waste is hazardous, due to either physical risk (can perforate the skin), biological risk (is infectious) or chemical risk.	Promote waste reduction measures at the laboratory (chose materials with less packaging, improve stock management to prevent expired products; select products which can be taken back by the supplier to be refilled, among others)	<b>Goal 12.5.</b> Substantially reduce waste generation through prevention, reduction, recycling and reuse.
2. Source segregation	7% of laboratories fail to segregate sharp waste 86% of laboratories fail to separate biological and chemical risk waste 100% of laboratories fail to separate chemical risk waste	Implement source-segregation procedures at the laboratory by: acquiring containers with distinctive colours and suitable lids/sealing to properly separate chemical, biological and sharp object waste; training staff; implementing new procedures that ensure proper separation	<b>Goal 3.9.</b> Substantially reduce the number of deaths and illnesses from hazardous chemicals, soil air and water contamination and pollution.
3. Pré-Treatment	50% of laboratories do not disinfect nor sterilise biological risk waste	Each laboratory has an autoclave or means to perform chemical disinfection.	<b>Goal 6.3</b> improve water quality by reducing pollution, eliminating dumping and minimizing releases of hazardous chemicals and materials, halving the proportion of untreated wastewater, and substantially increasing recycling and safe reuse globally.
4. Removal and discarding	At 43% of laboratories temporary storage of hazardous healthcare waste is inappropriate because: - the waste is accessible to people passing by (including children) and to animals (insects, dogs, rodents, etc) - the waste is placed in general-use plastic bags, which might be torn apart, release content and pollute nearby soil and water.	Construction or assigning a closed space for temporary storing the waste whilst awaiting collection. Ensure proper bags/containers are used for temporary storage. Prevent any leachate being released from the bags/containers from reaching the nearby soil or water.	<b>Goal 9.a.</b> Facilitate the development of sustainable and resilient infrastructure in developing countries, through increased financial, technological, and technical support to African countries, least developed countries, landlocked developing countries and small island developing States.
5. Collection and transport	In 93% of the laboratories, transport of sharp-objects waste to the incinerator is not done using suitable waste collection vehicles nor trained staff In 64% of the laboratories, the frequency of collection of mixed healthcare waste (hazardous and non-hazardous) is low (weekly); when there is lack of petrol, staff, or vehicles, collection frequency is even lower. In all laboratories, a percentage of hazardous healthcare waste is collected and transported together with residential waste.	Introduce dedicated collection of hazardous healthcare waste	<b>Goal 8.8.</b> Protect labor rights and promote safe and secure working environments for all workers, including migrant workers, in particular migrant women, and people in precarious employment.
6. Treatment	100% of potentially recyclable waste from clinical analysis laboratories goes directly to elimination without any prior sorting, processing or treatment Treatment to eliminate biological risk is decentralized (and only in 50% of the laboratories) There is no treatment of chemically hazardous waste	It might be possible to sort recyclable materials from the non-hazardous waste fraction. Other additional centralised treatment technologies might be considered (eg: disinfection/sterilization of biological risk waste; neutralization of chemical waste);	<b>Goal 12.5.</b> Substantially reduce waste generation through prevention, reduction, recycling and reuse.

(continued on next page)

Table 4 (continued)

Stage	Problem	Improvement suggestions	Associated SDG
7. Elimination	<p>7% of laboratories discards sharp waste in municipal dumpsites</p> <p>71% of laboratories discard non-sharp healthcare waste in municipal dumpsites, where it can come into contact with the population</p> <p>21% of laboratories discard non-sharp healthcare waste by burying it in the ground without any leachate control nor ensuring that the waste will not be dig up again</p> <p>7% of the laboratories eliminate non-sharp healthcare waste by burning it in a pit in the ground; this solution does not prevent toxic fumes from being emitted nor is able to control combustion conditions to a point where full combustion is ensured and biological and chemical risk is eliminated.</p> <p>The capacity of existing incinerators is not enough to incinerate all healthcare waste produced in the country.</p> <p>The incinerators are often out of order due to lack of water, electricity, petrol or caustic soda.</p>	<p>Provide laboratories with alternatives to eliminate hazardous waste in a safer manner.</p>	<p><b>Goal 11.6.</b> Reduce the per capita negative environmental impact of cities, including by paying special attention to air quality, municipal and other waste management.</p> <p><b>Goal 12.4.</b> Achieve environmentally sound management of chemicals and all wastes (...) and significantly reduce their release to air, water and soil, to minimize their negative impacts on human health and the environment.</p> <p><b>Goal 15.1.</b> ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and arid lands.</p>
ALL stages	<p>Staff at clinical analysis laboratories has doubts on whether wastes sent for incineration will in fact become incinerated</p> <p>Lack of national regulations specific for the management of healthcare waste</p>	<p>Ensure proper environmental awareness and capacitation of professionals working in the clinical analysis laboratories regarding waste management.</p> <p>Publish a national regulation on healthcare waste management and create a team to oversee its implementation</p>	<p><b>Goal 12.8.</b> ensure that people everywhere have relevant information and awareness for sustainable development and lifestyles in harmony with nature.</p>

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Alzira Pereira reports a relationship with Direction of Livestock, Ministry of Agriculture Fisheries and Rural Development that includes: employment.

## Data availability

Data will be made available on request.

## Acknowledgements

The authors would like to acknowledge CERNAS Research Center from the Portuguese Fundação para a Ciência e a Tecnologia (UIDB/00681/2020).

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