BIOMEDICAL SOLID WASTE MANAGEMENT IN LOW-INCOME CONTEXTS: THE CASE OF BEIRA, MOZAMBIQUE

ADA CASTELLUCCI[1,2], MARCO RAGAZZI[1], FEDERICO BERGHI[3], DARIO GUIRRERI[3] & ISACCO RAMA[2]
[1]Environmental and Mechanical Engineering, University of Trento, Italy
[2]Consortium of Associations with Mozambique Onlus (CAM), Italy
[3]Progettomondo NGO, Italy

ABSTRACT

The lack of adequate waste management practices is one of the most critical and common challenges in a low-income urban context. In this sense, the environmental release of biomedical solid waste without proper treatment is a serious risk for the city of Beira in Mozambique. The present work is developed in the frame of the LimpaMOS MOÇambique project (co-financed mainly by the Italian Agency for Development Cooperation) and SIRSU project (Italian Agency for Development Cooperation). These projects involve Italian and Mozambican actors from the public, private, and non-profit sectors. One of the aims of the projects is to strengthen the proper management, separation, and disposal of biomedical solid waste. The present study investigates two main aspects: (a) the separation and collection of hospital waste in the health units distributed throughout the city; and (b) the centralised treatment in the Beira Central Hospital carried out by an incinerator. Concerning the first point, the case study of the Ponta-Gêa Health Centre shows how it is possible to improve waste sorting, which is currently problematic mainly due to the lack of plastic bags, central for a safe collection and transport but not economically nor environmentally sustainable. Concerning the second point, the Beira Central Hospital incinerator presents significant problems in terms of environmental impact, health, and safety. Using weighing, estimates, and official documentation from the Municipality of Beira, the total production of biomedical solid waste in the city was assessed. The short-term aim of this study is an efficient distribution of the biomedical solid waste between the incinerator and a new electric sterilizer. Finally, the possibility of opening new and more sustainable plants is being evaluated, with the long-term aim of closing the incinerator.

Keywords: biomedical solid waste, hospital waste, low-income countries, Mozambique, management, segregation, incinerator, sterilizer .

1 INTRODUCTION

Of the total amount of waste generated by healthcare activities, about 85% is general, non-hazardous waste. The remaining 15% is the so-called biomedical solid waste (BSW) and it is considered hazardous material that may be infectious, toxic, or radioactive [1]. Low-income countries generate on average 0.2 kg of BSW per hospital bed per day, 0.3 kg less than high-income countries [1]. However, without good practices for healthcare waste separation and management, the effective amount of BSW mixed with all kinds of hospital solid waste (HSW) becomes much higher, thus increasing the possibility of spreading infections [2]–[4].

Mozambique ranks low on the human development index (HDI) at 0.456, or 181 out of 189 countries [5]. Since its recent independence from Portugal in 1975, Mozambique has been affected by numerous natural disasters. Violent tropical cyclones like Idai (Beira, March 2019) or Eloise (Beira, January 2021) strike a vulnerable population, creating circumstances that exacerbated poverty levels, food insecurity, and spread of diseases among the affected people [6]. In this complex and fragile climatic, historical, social, and economic context, a deep crisis is affecting the entire public health sector, where the already precarious economic

WIT Transactions on Ecology and the Environment, Vol 257, © 2022 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/WMEI220091

conditions are further aggravated by onerous interventions following the various natural disasters and the COVID-19 emergency [7]–[9]. Correct and safe collection of biomedical solid waste is a frequently underestimated aspect of hospital management, aggravated by weaknesses in collection, transport, and final disposal.

Beira is the capital and largest city of Sofala Province in central Mozambique and has a population of 673,685 [10]. In an area of 633 km^2 there are 16 health units of the National Health Service, including a central hospital, a provincial hospital, 12 health centres and two health posts, plus several private clinics. 1,779 people are employed as health personnel, of which 745 are in the Central Hospital, which is the largest in the city [10].

This study aims to lay the foundations for an improvement in the management of HSW in Beira. To do it, the starting point was to analyse the current municipal solid waste (MSW) and biomedical solid waste management system and also the differences between the various health units in the city. MSW management is at the beginning stage and most of this waste is disposed in open dumps [11]–[13]. This is a normal practice in low-income and developing countries [13]–[16].

The health centres are halfway between small hospitals and doctors' surgeries. They do not have the capacity to admit patients, except for maternity wards in only a few of the larger health centres, which are able to admit women for up to 72 hours. Only a few departments, such as the maternity ward and the emergency room, operate on a 24-hour basis, but they are not organised to deal with complications or surgeries, which can only be managed at Beira Central Hospital (the biggest one in the city). Consequently, even the management of the HSW differs according to the type and the size of the health unit. Some health centres are included in waste collection and transport routes, which are followed by centralised treatment (an incinerator) at the Central Hospital, others treat it locally, others do not treat it at all. This study focuses on Ponta-Gêa Health Centre (one of the biggest health centre in the city) and the Central Hospital. Proper waste sorting in health centres is essential for its subsequent correct treatment. Incineration, sterilisation, and dumping will be the three possible BSW management solutions in Beira in the coming years, and each cannot be disconnected from the initial waste sorting.

2 MATERIALS AND METHODS

The Mozambique Environment Programme started in 2018 thanks to the two Italian NGOs "CAM Consorzio Associazioni con il Mozambico" and "ProgettoMondo MLAL" and the municipalities of Beira and Nampula. This 5-year programme operates in a rapidly evolving context of municipal solid waste management, whose problems are many and varied, due to the quantity, variety and distribution of waste produced. Funded mainly by the Autonomous Province of Trento, the European Union Delegation in Maputo and the Italian Agency for Development Cooperation, this programme includes the LimpaMOS MOÇambique and SIRSU projects. Both projects are still ongoing.

One of the many objectives of the LimpaMOS MOÇambique project is to strengthen the proper management, segregation, and disposal of the BWS in at least two urban health units. The LimpaMOS MOÇambique team produced important research on HSW management in the Ponta-Gêa Health Centre. In 2020, they analysed the HSW produced and the results of the 9-day waste weighing indicate an average daily waste production of 55.7 kg. Of this, 32.6 kg is BSW of which 83% is infected waste, 8% is sharps waste, and 9% is anatomical waste. After discovering the daily waste streams and the internal management of HSW, one of the actions of the project involves the construction of a temporary storage facility for HSW, separate from the other buildings of the centre and protected from atmospheric events and unwanted access.

The SIRSU project (Local Enterprise Development for Solid Waste Disposal) involves the creation of a service company specialising in the collection of BSW, which not only aims to protect citizens of Beira and the environment by properly treating hazardous waste, but also to empower local people by creating specialised staff. By donating an NW15 electric sterilizer from the Italian company Newster Group, the project will make an active contribution to the disposal of BSW from the Central Hospital, the public health centres, and at least from five private clinics, and will reduce the total amount of waste sent to the incinerator installed in the Central Hospital.

Working with Beira Municipal Council, CAM developed and improved the new Hospital Solid Waste Collection Plan for the collection and transport of HSW from 15 urban health centres of the National Public Service and four private clinics. This document also contains estimated date of HSW streams produced by health centres. Through the analysis of the collection routes and field visits, it was verified that the entire HSW management chain in the city of Beira is critical, starting from the first sorting in hospital rooms to the final disposal.

Unlike what is stated in the Hospital Solid Waste Collection Plan, Beira Municipal Council oversees HSW collection and transport only in nine health centres and in five private clinics. all the health centres should be required to implement their waste sorting, but this is not happening both because of a deep crisis in the health sector and because of a deficiency in risk perception. HSW is not always correctly sorted into the categories of infectious, anatomical, sharps, pharmaceutical (the four categories of BSW) and common. Collection and transport carried out by the municipal operators are very inadequate: the vehicle is a tractor with a flatbed trailer, loaded manually, and the waste collectors are not equipped with all the personal protection equipment (PPE). When waste is unpacked and mixed in the temporary storage containers of a health centre, these are emptied directly into the tractor trailer. Even if waste is correctly sorted and packaged (plastic bags containing infective, anatomical, or common waste and carton boxes containing sharps waste) it is not handled safely, and several operators have already been involved in accidents involving needles. In general, the entire transport system does not always guarantee either the separation of the waste nor the safety of the operators and of the community.

The final destinations for HSW are the Central Hospital incinerator for BSW, and the dumpsite for common waste. The incinerator is currently (February 2022) the only BSW treatment site for the city of Beira. Designed to incinerate only the BSW from the Central Hospital by working 3 days a week, the incinerator is used every day except Sunday to burn waste from the majority of the city's health centres, both public and private. Such frequent operation is necessary due to the large quantities of waste and because the cold storage room has not been in operation for about 2 years. The plant uses obsolete technology, resulting in a very high environmental impact. The waste is manually loaded by the operator into a combustion chamber without the closing door. There are two engines for powering the incinerator. The first and only one currently in operation drives a fan that sprays fuel into the combustion chamber, contributing to the increase in temperature for load cycles with high humidity (mainly due to the presence of anatomical waste). The second engine, which has been out of use for several years, is the one used to operate the filter for the smoke generated by combustion. As there are no filters, the only environmental measure should be the chimney, which is too short to provide any real benefits (less than 10 m). Residents living close to the hospital often complain about the smoke from the chimney and the bad smell and are consequently unable to open their windows all morning. The incinerator has other technical problems. The room where it is located has a sheet metal roof, which is often removed by wind during the rainy season. Water falls on the plant and, over time, the outer

metal layer has corroded and even has holes in the top. The protective layer inside the combustion chamber is also deteriorating badly, deforming the walls themselves.

Once the main criticalities of the HSW management chain were identified, a second phase of field investigation and subsequent analyses was carried out, due to the absence of data or information. First, it was not clear why the waste on the tractor trailer of the municipal collection and transport service arrived mixed and unpacked at the incinerator, thus denying the operators the possibility to unload and incinerate it. This waste therefore follows the final deposition of the common fraction of HSW and is transported to the dump, despite its hazardous nature. Second, it was not clear how much waste the health units and the Central Hospital produce on average each day.

3 RESULTS

Although a more technologically advanced treatment plant for BSW is indispensable in Beira, first a good waste sorting at the base of the chain of HSW management is needed. This makes it possible to load the two plants correctly, avoiding energy and economic waste, with the aim of reducing the current high environmental impact and the risk to the workers and to the entire community.

The visits and discussions with waste management staff revealed the main criticalities of the system of collection, storage, and transport of HSW in Ponta-Gêa Health Centre, and are listed below:

- Many departments of the hospital complain of a lack of bins, which are therefore insufficient to cover all classes of waste to be sorted;
- The health centre often suffers from a severe lack of disposable plastic bags to collect and separate common, anatomical, and infectious waste. On such occasions, the few available are used primarily for anatomical waste, and only occasionally for infectious waste;
- The wards are not efficiently organised: some rooms have not enough bins, others have many but not clearly classified. This makes collection by waste management staff difficult;
- Many doctors and nurses are not trained in how to carry out efficient waste sorting, which has a very negative effect on the quality of separation;
- Common waste should be taken to the appropriate container outside the health centre and be collected by municipal solid waste service, but the container isn't always available;
- The location for the temporary storage of the BSW was not appropriate before the construction of the new building by LimpaMOS project. It was an open space with a few 240 litres containers, some with lids and wheels and some without. Waste was therefore exposed to weather phenomena and unauthorised access (vandalism, animal attraction, children attraction);
- The municipal operators who empty the containers into the tractor trailer to transport them to the incinerator have little PPE and in very bad conditions;
- The tractor is not a good vehicle for transporting hazardous waste;
- In general, waste sorting is not efficiently carried out. Very often hazardous waste is mixed with common waste and ends up in dumps without any treatment.

To improve waste sorting three potential scenarios were discussed with the chief of waste management staff. The common waste produced represents almost 42% of the total and it is essential that in all scenarios it remains separated from the BSW.

1. **Adequate supply of plastic bags.** The Service for Health, Woman and Social Action of Beira District (SDSMAS) is the institution to which the health centres refer for the supply of new plastic bags. Often the delivery of these materials, as well as of PPE, does not take place or only in very small quantities. For its part, the health centre could start recording the average consumption of bags over a given period and they must ensure that plastic bags are used correctly, without theft or misuse. Due to the crisis in the health sector, there is a tendency not to give proper economic and organisational importance to waste management, but with better budgeting the District Service could improve the supply of plastic bags.
2. **"Plastic-free" management.** The tractor picks up the 240 litre containers from the health centre's temporary storage facility filled with pre-sorted waste. Anatomical waste is the only waste that still needs a plastic bag. By transporting the containers, the waste is not loose and does not risk mixing between different classes. The tractor, loaded with the containers, arrives at the Central Hospital. There, once the new sterilizer is in operation, the containers of infectious waste are emptied directly into it.
3. **Intermediate solution.** An intermediate solution between the previous two is to place 240 litre containers in each department, one for common waste and one for infectious waste. Only the container for infectious waste has a large plastic bag. Each room or examination room has its own 10 or 20 litre bins (three or two depending on the production of anatomical waste) which can be left without a bag (except for the anatomical waste bins) and washed when emptied. They are emptied as needed or at least once a day by the collection staff into the 240 litre containers located at a strategic point on each floor or department. Only at the end of the day the plastic bag is closed and taken to the temporary storage.

To have a better knowledge about waste streams, every day for two weeks the quantities of anatomical, sharps, infectious and pharmaceutical waste were measured, divided by origin: Beira Central Hospital, health units subject to Municipal Council collection, private clinics transporting their own BSW. The daily fuel consumption of the incinerator was also tracked. Table 1 shows the average daily quantities of BSW, while Table 2 shows the incinerator's consumption. In Fig. 1 more data about the average daily amounts and percentages of BSW treated by the incinerator are reported.

The weighing activity showed a significant deficit of HSW compared to previous reports (HSW Collection Plan, an internal CAM report on the initial information gathered at the Central Hospital). The reasons may be either a reduction of patients due to the COVID-19 pandemic or the inability to weigh and treat part of the BSW as it is not packed. For these

Table 1: Average daily amounts of BSW treated by the incinerator sorted by type and place of production: Beira Central Hospital (BCH), health centres (HC), private clinics (PC).

Type of waste	Place of production			
	BCH	HC	PC	TOTAL
Anatomical	20.08 kg	28.75 kg	1 kg	49.83 kg
Sharps	20.42 kg	8.67 kg	0.66 kg	29.75 kg
Infectious	223 kg	7 kg	23.67 kg	253.67 kg
Pharmaceutical	26.08 kg	0 kg	0 kg	26.08 kg
TOTAL	289.58 kg	44.42 kg	25.33 kg	359.33 kg

Table 2: Current and average incinerator consumption.

Type	Quantity
Total amount of biomedical solid waste weighed	4,312 kg
Total amount of fuel used	225 l
Number of days for weighing	12 days
Average diary amount of fuel used	18.75 l
Average monthly amount of fuel used	487.5 l
Average amount of fuel used to burn 1 kg of waste	0.052 l

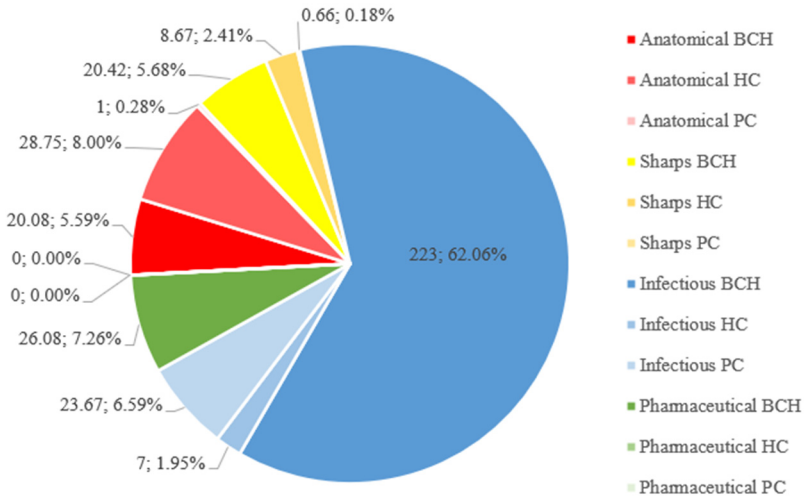

Figure 1: Average daily amounts and percentages of BSW treated by the incinerator expressed in kg, sorted by type and place of production (Beira Central Hospital (BCH), health centres (HC), private clinics(PC)).

reasons, and because of the inaccuracies that could arise from a short weighing period (only two weeks), it would be ill-advised to use the data in Table 1 to assess the load of the two plants. This consideration also stems from an optimistic scenario of an improved collection and transport system. Currently, most of the waste that remains in the tractor trailer as unpackaged (and therefore delivered to the dump) is infectious waste, estimated at 40 kg per day. The average daily amount of BSW produced at the three different sites is reported to be around 550 kg, so the final quantities by category are estimated as in Table 3.

Table 3: Estimate of the average daily production of BSW in the city of Beira, sorted by type.

Type of waste	Weighed and estimated	Percentage	Average daily production
Anatomical	50 kg	12.5%	69 kg
Sharps	30 kg	7.5%	41 kg
Infectious	294 kg	73.5%	404 kg
Pharmaceutical	26 kg	6.5%	36 kg
TOTAL	400 kg	100%	550 kg

NW15 sterilizer can process a maximum of 30 kg of BSW per cycle, which lasts between 30 and 50 minutes. Considering an optimistic scenario in which the machine operators work two seven-hour shifts each, the number of daily cycles can be estimated at 14 and the quantities treated daily at about 420 kg, less than the total 550 kg. Furthermore, to allow optimal treatment and delay the deterioration time of the sterilizer, it is not allowed to be loaded with all BSW fractions, and many types of waste have maximum weight percentages for each load. First of all, the inclusion of even small amounts of common waste (especially organic waste) must be avoided. Ordinary waste should not arrive at the two plants, but if it does because of inaccuracies in separate collection, it is essential to direct it to the incinerator. Thus, it would be unwise to think of treating all BSW exclusively with the sterilizer and not also turning on the incinerator. The main considerations on flow diversion with regard to different types of waste are given below.

- **Anatomical waste.** The large amount of moisture contained in the anatomical waste is a major problem for both types of plant. In the incinerator, the anatomical waste requires large additions of fuel to be incinerated; in the sterilizer this amount must be below 25%–30% of the total load. The amount of anatomical waste is 69 kg, which represents about 16.4% of the total 420 kg that can be treated daily. This is a significant achievement, as it would considerably reduce the use of fuel for burning in the incinerator;
- **Sharps waste.** The sterilizer can process spent syringes that the incinerator cannot destroy. The only caution is how to load the carton boxes containing the syringes: it is advisable to place them at the bottom of the sterilisation chamber, near the blades;
- **Pharmaceutical waste.** Similar to common waste as it is mainly composed of paper boxes, blisters, or in general paper and/or plastic material, it is not recommended to be treated in the steriliser. As it is a material that burns well it can continue to be incinerated;
- **Glass medicine bottles.** This pharmaceutical waste is currently problematic, as incinerator operators have to shred them manually before placing them in the incinerator. Smaller quantities of glass can instead be processed in the sterilizer, thus avoiding further risks to operators.

4 DISCUSSION AND CONCLUSION

The previous paragraph shows that the use of the sterilizer will significantly reduce the load on the incinerator. However, this is a good objective in the short to medium term. The primary long-term objective is necessarily to close the incinerator, a worn-out and problematic plant, but the start-up of a single NW15 steriliser does not allow this objective to be achieved. Considering the weighing carried out and a daily production of about 360–400 kg of BSW, hypothetically the NW15 would be able to treat all the city waste every day. But because of the pandemic period, which discourages patients from going to hospitals, the continuous increase in population and the possibility of breakdown and/or maintenance of the steriliser, it is not prudent to consider that all BSW could be treated with the steriliser in the short future. In this sense, its first year of use will be crucial to confirm or disprove this assumption.

The possibility of closing the incinerator in Beira and some solutions are reported below. However, each proposal will require feasibility studies, interviews, and in-depth research. Studying the city and its current waste management, the following options were considered:

1. **Increasing the operating shifts of NW15 from two (14 hours) to three (21 hours).** The change to three shifts, each of 7 hours, would ensure the daily processing of approximately 630 kg of BSW, thus covering the planned total of 550 kg. This solution would involve a night shift and the employment of at least one other person but would have the great advantage of not having to purchase any additional plant. The main

problem is the centralisation of processing, which would continue to be carried out in one place. This would violate one of the key principles of waste disposal, which is to treat waste as close as possible to its place of production.

2. **Starting up a NW5 steriliser.** The Newster5 sterilizer is an equivalent machine to the NW15, with the difference that its load does not exceed 15 kg per cycle. This means that the sterilizer is capable of processing 210 kg of BSW (over two shifts, totalling 14 hours), which, when added to the 420 kg of the NW15, would cover the total planned quantity. The advantage of this proposal is that it would be possible to decentralise the BSW treatment site, by choosing to locate NW5 in one of the city's major health centres, so that it would treat the waste produced there every day, as well as waste from some neighbouring clinics. This would involve the creation of new waste collection routes, one for the Central Hospital and one for the new health centre where the plant would be located.
3. **Starting up an autoclave.** A similar argument can be made for an autoclave to the NW5 sterilizer. This machine can treat about 50–70 kg in a 35-minute cycle [17]. Considering loading, unloading, and cleaning operations, the indicative treatment of 50 kg per hour can be assumed, ensuring total coverage of the daily BSW quantities. However, the effectiveness of autoclaving as a method of treating hospital waste has not been fully demonstrated, and its use is preferred for the sterilisation of medical instruments [18].
4. **Starting up small incinerators.** Not an environmentally sustainable solution, the installation of small furnaces for incinerating BSW are very common in developing countries. Compared to the current incinerator, small furnaces would have a much smaller load, leading to lower and decentralised emissions. If well designed, with a good filter and sufficient chimney height, small incinerators can be an acceptable solution, considering the context, given the lower costs compared to a sterilisation plant. Of course, an adequate management of residues must be guaranteed.

For both the Ponta-Gêa Health Centre and the evaluation of new waste treatment plants, it is difficult to define an optimal solution. The choices are complicated by a wide fragmentation of management responsibilities and a severe economic crisis in the health sector. However, health centres in Beira already prioritise the use of plastic bags for waste packaging in certain departments or for certain fractions, and the intermediate solution of reducing their number in everyday use could be a valid effort to implement waste collection without a high economic impact. Assessing which new plant could permanently replace the incinerator is inseparable from a review of the entire Hospital Solid Waste Collection Plan.

The increase in NW15 shifts, although the best solution in terms of emissions and costs, has the double disadvantage of the absence of plants running in parallel (essential in case of breakdowns) and the maintenance of very long transport routes for the BSW collected. Of the decentralisation proposals, the inclusion of an NW5 could be more effective in terms of bacterial removal than an autoclave, but not necessarily less expensive.

The construction of small incineration furnaces is the option that should be discouraged the most, but at the same time it may prove to be the one with the fewest economic and acceptance obstacles. Further analysis, availability of technical expertise and economic availability will be the key discriminators in understanding which project proposal is the most suitable for the Beira context.

The safe and environmentally friendly management of the BSW is an issue that could become more relevant after the consolidation of the use of the sterilizer, when the benefits of reducing the use of the incinerator will be more evident to both hospital technicians and administrators.

ACKNOWLEDGEMENTS

This paper was written within the project "Limpamos Moçambique" (AID code 011891), implemented with the contribution of the Italian Agency for Development Cooperation (AICS). The responsibility for the content of this publication lies with the authors and the project partners and does not necessarily represent the views of the AICS funding body.

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