Thesis for the Degree of Doctor of Philosophy

Assessment of management practices from generation to final disposal for solid medical wastes in Bujumbura, Burundi

by

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Pukyong National University

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부룬디 부줌브라의 의료폐기물 관리 실태 평가

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Abstract

Solid medical wastes (SMW) that are not properly handled and disposed of can cause a risk to human health and environmental. Thus, it is very important to deal with it properly from generation to final disposal. This study examined SMW management practices in 12 health care facilities (HCFs) in Bujumbura, Burundi from generation to final disposal (i.e, separation, collection, measurement, transportation inside of HCFs, storage, transportation at on-site and off-site, and final disposal). Rapid risk assessment was conducted to identify potential hazards and degree of risk, and to provide control measures for reducing risk from current SMW management system. Three treatment methods (low-temperature incinerator,

organic pit, and landfill) currently used to treat SMW in Bujumbura were also comparatively evaluated using emergy methodology focused on the cost-efficiency.

The results showed that current classification system of SMW in the national guidelines was not appropriate for safe collection and disposal. Pathological wastes, pharmaceutical wastes, and discarded medical plastics, and absorbent cotton and placenta were the main types of SMW, accounting for 14,308 tons (84.38%) from the HCFs. Public HCFs were responsible for 92.8% of SMW generated in which 88.8% were generated by three public HCFs.

Burundi national guidelines do not fully comply with WHO guidelines and there are no guidelines for final disposal at all. No HCFs followed the national guinidelines completely, and most medical wastes have not been properly managed from the source separation stage. Storage of medical wastes was the least managed step in the HCFs. 92.8% of SMW (15,736 ton) from all 12 HCFs were inappropriately disposed of through uncontrolled landfill and incineration. Most types of waste were treated by using the low-temperature incinerator. The rapid risk assessment (RRA) conducted in the study suggested that all SMW, HCFs, and environment, as well as peoples involved during SMW management in 12 HCFs were at high risk. The results from the emergy analysis show that organic pits has the lowest emergy and monetary costs among the three methods. The emergy cost of uncontrolled landfill was 1.27 times and 7.4 times higher than those of low-temperature incinerators, and organic pits, respectively. Not much difference in emergy costs were observed between the emergy costs of sanitary landfill and high-temperature incinerators used in other countries and those of the uncontrolled landfill and low-temperature incinerators used in Bujumbura, Burundi. In consideration of both emergy cost and safety, uncontrolled landfills and low-temperature incinerator should eventually be replaced with the high-temperature incinerator.

Thre results showed that strict implementation of government policies and proper guidelines from generation to final disposal, revision of waste classification system, regular training and education for waste workers and medical staffs, construction of safe storage system, safe transportation of wastes, and adequate treatment methods (high-temperature incinerator with air pollution control system and sanitary landfills) are priority steps for the safe management of medical wastes in Burundi. It is important for Burundi government to improve the safety management system by introducing the radio frequency identification (RFID) based on medical waste treatment tracking system.

To control risk and reduce it to a safe low risk level, additional measures such as disinfection of infectious wastes and medical sharps and the implementation of safe and detailed guidelines for toxic chemicals and radioactive wastes can be considered. The Burundi government should first focus on improving SMW management of public HCF that produce most of SMW.

This study can be used to help the Burundi government to improve SMW management from generation to the final disposal and minimize their potential risks to health and ecosystems by revealing problems and priority areas for the SMW management. It is also important to ensure financial resources first to implement these policies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I.INTRODUCTION

1.1. Overall background information

Solid medical waste (SMW) is defined as a health care waste, hospital waste, or biomedical waste that are generated during various medical services, such as diagnosis, treatment, immunization of humans or animals, and biological testing (WHO, 2000). 10% ~ 25% of medical wastes are considered to be hazardous (WHO, 2014). In general, medical wastes are segregated, collected, transported, stored, and disposed of after they are generated. Incorrect management at one stage will affect the overall subsequent processes and could cause high risks arising from inappropriate management of the waste from generation to final disposal processes (Jang et al., 2006; Lee et al., 2002). When pathogenic wastes are mixed during waste management stream, the entire waste can be infectious or when toxic wastes are mixed, the amount of hazardous waste increases and making in more difficult to dispose of safely. Since improper management practices of hazardous SMW (HSMW) could potentially result in serious health risks and environmental problems (e.g., the spread of infectious diseases, direct/indirect human exposure to toxic materials), it is extremely important to properly manage and dispose of the waste (Babanyara et al.,2013;Mohee,2005; Mmereki et al.,2017; Rao,2008).

The health risks, environmental concerns, and safety risks associated with medical wastes in developing countries have been reported through many scientific studies (Babanyara et al., 2013; Rao, 2008). Therefore, for resolving the issue, it is important to set up the proper guidelines for safe management of SMW from their generation to final treatment in which all stakeholders involved in management processes in health care facilities (HCFs) should follow (ICRC, 2011). In addition, accurate data on SMW generation and its properties are required in order to systematically manage solid medical wastes. When SMW is treated safely and properly in HCF services, following guidelines, the negative impacts on the people in HCFs as well as a surrounding community could be effectively reduced.

Because safe management of SMW directly relates to the health of the people, developed countries, such as the United States, European Union, and Canada, have specific guidelines for medical waste management practices and medical wastes are highly regulated (Insa et al., 2010; Walkinshaw, 2011). In developing countries, however, SMW management practices have not received sufficient attention. Some countries do not have the proper guidelines for SMW in HCFs and even others that have guidelines do not follow them appropriately during SMW management practices (Awodele et al., 2016; Diaz et al., 2005).

The waste policy, strategy and plan were provided by WHO for helping the developing countries to adopt their own waste policy, strategy and plan, Burundi established national guidelines for SMW management practices in 2008 and all HCFs should follow them (MOH, 2008;ICRC, 2011). A recent study conducted in 10 laboratories of HCFs in three provinces in Burundi, however, showed that 78.8% of laboratories did not follow the national guidelines (Godefroid and Jean, 2013). Furthermore, the report on assessment of the health policy of SMW management revealed that most HCFs in the country failed to follow the national guidelines during SMW management (Joseph and Nina, 2010). Even the guidelines were established by Burundi government do not cover all steps of management practices, because no guidelines are available for the final treatment (MOH, 2008). Furthermore, the accurate generation properties of SMW have not been properly analyzed. SMW management practices in Burundi, therefore, must be regulated properly to reduce risks to public health. The management of SMW requires different treatment methods depending on the characteristics of waste types. Because it could contribute to reduce a high risk to human health and surrounding environment, it is important to choose a safer disposal method. However, the economics of the methods cannot be ignored, especially for developing countries like Burundi.

In this study, the generation properties of SMW were analyzed to provide quantitative data for systematic solutions for safe management of SMW (Chapter 2). The status of SMW management practices during all management steps in HCFs from generation to final treatment was analyzed (Chapter 3). Rapid risk assessment was also conducted to identify potential hazards and degree of risk, and to provide control measures for reducing risk from current SMW management system in Bujumbura, Burundi (Chapter 3). The SMW disposal methods currently used in Burundi were compared using emergy evaluation methodology, an analysis method of ecological economics (Chapter 4). Emergy, with an “m”, is an accounting methodology used to assess the amount of energy that needed to make a product. Emergy evaluation methodology has not been applied to SMW treatment methods but for the municipal solid waste treatment (Liu et al., 2017). It can be a meaningful tool for evaluating the best options of treatment systems of waste (Odum, 1996).

Although data regarding the quantities of medical waste generated from HCFs are often readily available in the literature, little is known about the detailed SMW characteristics generated by such facilities. Since a comprehensive analysis of Burundi’s SMW management practices has not been performed, the current status and associated risks of SMW management in Burundi that can be identified through this study will help establish a safe and appropriate SMW management policy for the future. This study can also help the Burundi government to improve

SMW management practices, to operate safe and economic disposal methods and minimize their potential risks to health and ecosystems by revealing problems and priority areas for the SMW management.

1.2. Research Methodology

The research framework used in the study were shown in Figure 1-2. It illustrates three study area divided into different sections. The first section concerns the generation properties of SMW in twelve HCFs by types of waste and their quantity. The main steps assessed in this section type are the following: the quantity by type of waste, the amount generated by the type of waste, the comparison of public HCFs and private HCFs, as well as districts, and the assessment of generation per kg/bed/day and kg/patient/day. The second section shows the steps related to the management practices from generation to final treatment in all 12 HCFs. This part illustrates in the first position the current management practice steps from the separation of wastes inside of facility to the storage area. Secondly, it shows the management related to the transportation of wastes at the final disposal as well as the different treatment methods used in Bujumbura. The last stage of this second section focuses on the rapid risk assessment (RRA) related to the current management of SMW from generation to final disposal. The third section concerns the emergy analysis of three treatment methods such as incineration, organic pit, and landfill methods.

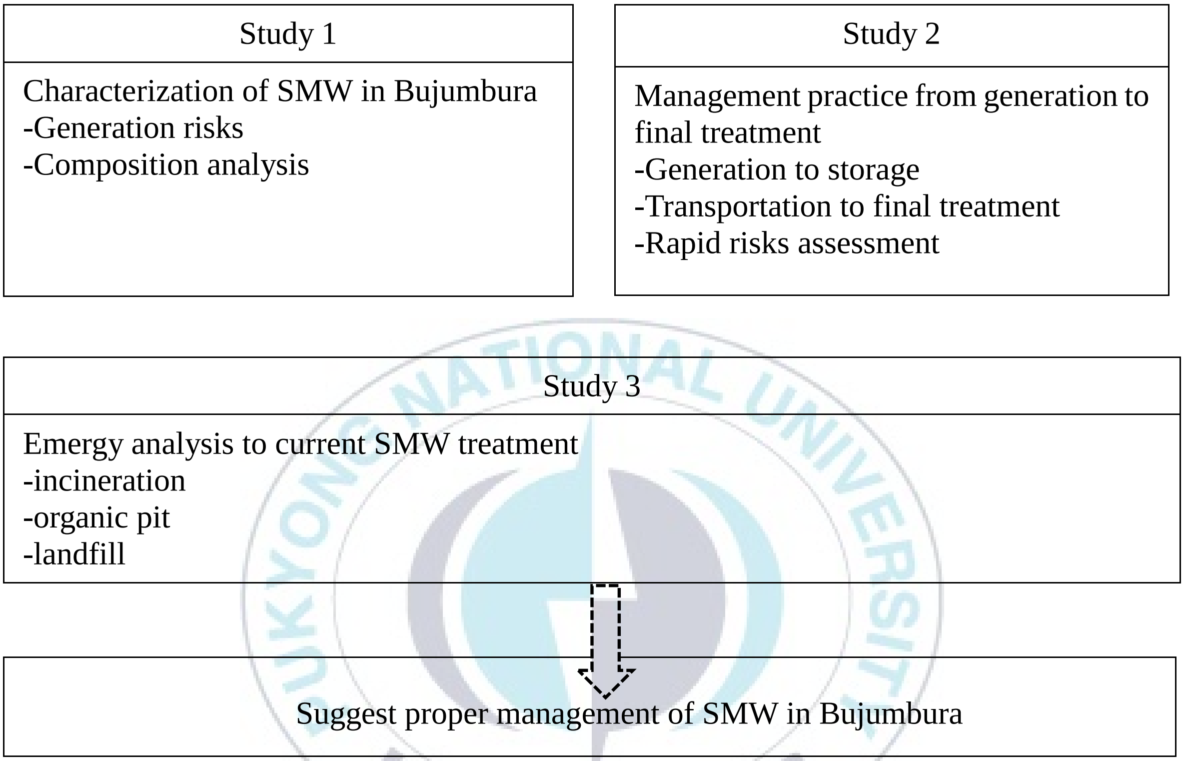

Figure 1- 1. Research framework for the study

1.3. Scope

The national guidelines for SMW management practices are divided into three parts, and each part has specific management steps (Figure1-2). The first part of the guidelines covers practices that are conducted inside the services of HCFs, from the generation of SMW to their separation and collection. The wastes are separated in coded (A1), colored containers (A2) in accordance with the SMW classification (A3). SMW should be collected safely in covered containers and placed in a designated area (B1), and the workers should be protected during the separation and collection steps (B2). The quantity of SMW should be measured before being transported to a storage area (C). The second part of the guidelines deals with practices conducted outside of the services. SMW should be transported to a storage area safely, using covered wheelbarrows (D1), and treated according to the national guidelines (D2). In the storage area, SMW should be stored separately and managed safely.

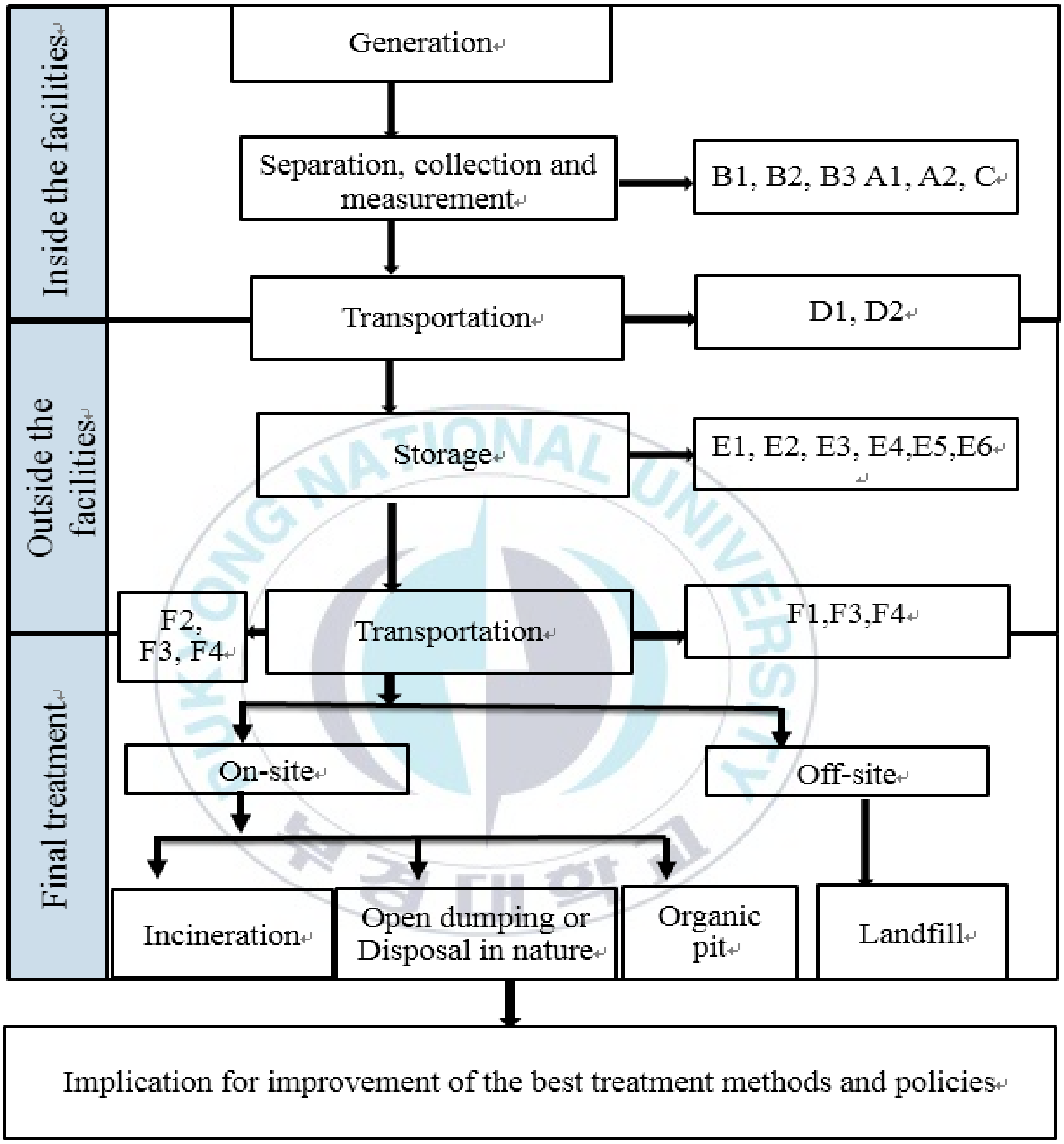

Figure 1- 2. Workflow of solid medical wastes management practices in health care facilities of Bujumbura, Burundi. (A: Separation, B: Collection, C: Measurement, D: On-site transportation, E: Storage, F: On-site and Off-site Transportation)

Sharp objects are separated from other types of SMW (E1) and the closed container arranged according to SMW types (E2). To manage infectious wastes safely, the proper temperature must be maintained no higher than 3℃ to 8℃ (E3) and SMW should be stored for no longer than 5 days (E4). The storage area needs to be protected by fence and roofing (E5) and should be constructed as directed by the national guidelines (E6). During offsite transport the truck needs to be protected (F1), wheelbarrow covered (F2), waste workers protected (F3) and regular transport (F4).

1.4. Study Area

Burundi has an area of 27,834 km² and is located in central Africa between 2 ° 45 'and 4 ° 25' latitude south, 28 ° 50 ' and 30 ° 53'30' ' longitude east. It is bordered north by Rwanda, west by the Democratic Republic of Congo, and east-south by Tanzania. Its population is estimated to 8.05 million in 2008 with 50.8% female and 49.2% male, annual population growth is 2.4%, and density is 310 persons per km². Burundi is ranked among the African countries most densely populated which the fertility rate is 6.4 children per woman (ISTEBU, 2008). The average temperature is 23℃ and annual precipitation is 1,274 mm (IGEBU, 2015). Burundi’s gross domestic product (GDP) per capita in 2017 is $ 343.39, ranking 187th in the world. Current Health Expenditure per Capita is $ 24 in 2015 and health capital expenditure is less than 1% of GDP (IMF, 2017; WHO, 2017). The climate is tropical with four seasons, such as a short rainy season (October to December), a short dry season (January to February), and the long rainy season (March to May), and the long dry season (June to September). Bujumbura is the capital city of Burundi and has three districts with a total area of 11,000 km^2. The population of the northern, central and southern districts in 2008 was 187,046, 172,120, and 138,000, respectively (ISTEBU, 2008; MOH, 2015a). Bujumbura has primary and secondary health care services, with three levels of administration of health care systems at the national, provincial, and district levels (MOH, 2011). Out of 15 HCFs with inpatients in Bujumbura, twelve HCFs were selected for this study to assess the generation properties, management status, and emergy evaluation of SMW treatment methods, considering their district and operational levels (Figure1-3).

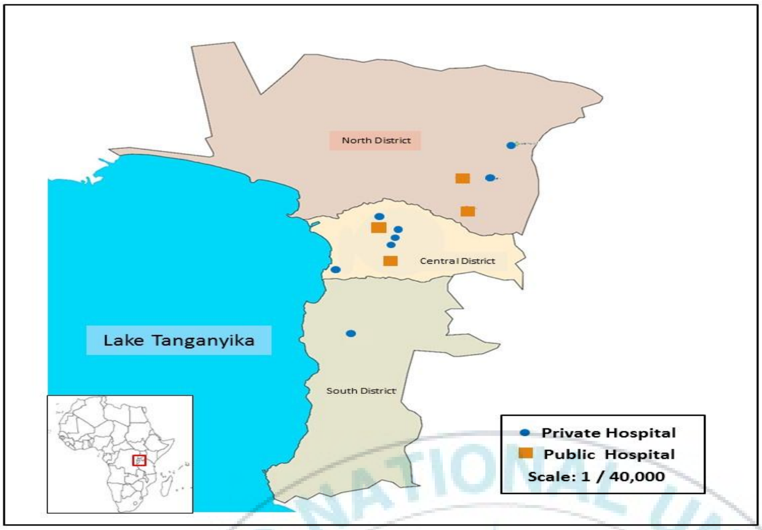

Figure 1- 3. Map showing the health care facilities selected to assess the generation and management status of HSMW in Bujumbura, Burundi (MOH, 2015b)

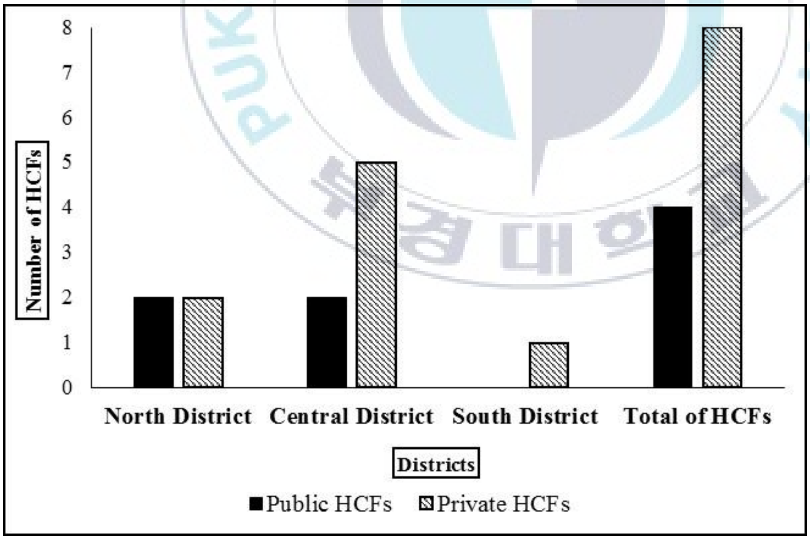

Figure 1- 4.Health Care Facilities in the study area

II.CURRENT STATUS OF GENERATION PROPERTIES

2.1. Introduction

SMW is divided into different types of wastes according to their characteristics and is generated from different services of HCFs after medical services (WHO, 2014). The separation of SMW inside of services into their specific containers with identification (code and color) contribute for determining the quantity of waste generated according to each type of waste. The quantity of SMW generated in each HCF is depending on the operational levels or the status of HCF (WHO, 2014). The amount daily or annually generated is the best indicator to assess the waste generated in each HCF (ICRC, 2011). Moreover, kg/bed/day and kg/patient/day are considered by WHO as the main indicators that determine the amount generated in each HCF (WHO, 2014).

Developed countries, such as Canada and USA, due to their modern facilities and good services observed in their HCF; the generation rates are high with 4.3-5.8 $kg.bed^{-1}.day^{-1}$and 4.1-4.4 $kg.patient^{-1}.day^{-1}$, respectively (Nemathanga, 2008; Sawalen, 2009). Moreover, most the developed countries do have classification referring to WHO recommendation (Department the health of Australia, 2016; Joan, 2016; MOH of Canada, 2011; Royal College of Nursing, 2014; USA, 1992). The proper management practices should respect the classification of SMW from generation to final disposal (Sefouhi et al., 2013). In some developing countries, like Tanzania, South Africa, and Ethiopia, however, the generation rates are low at 0.08 $kg.patient^{-1}.day^{-1}$and 1.24 kg. $patient^{-1}.day^{-1}$, 2.31 $kg.bed^{-1}.day^{-1}$, respectively (WHO, 2014). Most developing countries their classification system do not respect totally WHO recommendation and others do not have it (Abugri, 2014; Asante et al, 2014; Joshua et al., 2014; Longe and Williams, 2006; MOH of Uganda, 2009; MOH of Rwanda, 2016; Sawalem et al.,2009; Tadesse and Kumie, 2014).

Burundi, the classification doesn’t follow totally WHO recommendation because some types of SMW are classified together (WHO, 2014). Moreover, the quantity of waste could be wrong separated and collected together in the containers. In addition, the wrong classification also could impact negatively all process of SMW management practice from generation to final disposal all the more the waste are mixed. Therefore, the amount of SMW could be wrong reported daily or annually. The classification of SMW in developing countries, including Burundi still a big issue to be resolved. Burundi, no studies related to the generation properties of SMW carried out in HCFs. It is important to conduct the studies related to the SMW generation properties for understanding how much generated in each HCF of Burundi.

Considering this, the classification of SMW based on their characteristics is necessary for Burundi. It is important to compare the findings of this chapter with the data of the studies carried out in different countries. Relatively, practices studies conducted by some authors have shown that the quantity of pathological waste was more generated in HCFs (Nemathanga et al., 2008). Although data regarding the quantities of medical wastes generated from HCFs in Burundi are often readily available in the literature, little is known about the detailed mass composition of the waste generated by such facilities. This is not just Burundi's problem. There is a lack of detailed quantitative data on healthcare waste management in many developing countries (Joseph and Nina, 2010). In this Chapter, the objective is to compare the current classification of SMW by referring to WHO recommendation and to analyze the generation properties of SMW in twelve HCFs of Bujumbura. Through the findings, this chapter suggests how the SMW can be generated properly in twelve HCFs.

2.2. Literature review

2.2.1. Classification of SMW

SMW is classified according to different types of waste based on their characteristics, nature, risk, and origin of waste and management purpose or the final disposal method. Depending on the nature of waste, type of risk, management purpose, or the final disposal method, it may vary from country to country but should be reasonably classified for safety reasons. In general, it is classified as infectious waste, pathological waste, sharps, pharmaceuticals, genotoxic waste, radioactive waste, and non-hazardous waste or general wastes in the WHO guidelines (ICRC, 2011; WHO, 2014; WHO, 2005; WHO, 2004; WHO, 1999). The Table below details clearly the types of SMW and their codes, colors, definition and potential diseases that correspond to each type of SMW (WHO, 2014).

Table 2- 1.Classification and potential diseases of hazardous solid medical by WHO

Type	Codes	Colors	Definition	Potential diseases
Sharps waste	1	Green	Anything that could cause a cut or puncture leading to wound. (needles, syringes, infusion sets, pipettes, scalpels, knives, broken glass, etc.)	AIDS, viral hepatitis A, B, and C.
Infectious waste	2	Yellow	Waste that contains pathogens or contaminated with blood and other bodily fluids in sufficient quantity and can cause diseases of exposed persons.	Gastroenteritis infection, respiratory infection, ocular infection, genital infection, anthrax, and skin infection.
Pathological waste	3	Blue	Waste that contains human tissues, organs and other body parts from an operation, autopsy, and birth. (human tissues, organs or fluids, body parts, fetuses, placenta, unused blood products etc.	AIDS, viral hepatitis A, B, and C, hemorrhagic fevers, septicemia, bacteraemia and candidemia.
Pharmaceutical waste, cytotoxic waste	4	Orange	Expired or unused drugs, items contaminated by or containing pharmaceuticals, vaccines, and other products used in chemotherapy which may be cytotoxic, genotoxic, mutagenic,	Skin infection, gastroenteritis infectious, respiratory infection and cancer.

Chemical waste	5	Yellow	genotoxic chemicals, teratogenic or carcinogenic. Chemicals products. (Acid, alkali, film developer, organic substances, solvents etc.)	Cancer.
Radioactive waste	6	Red	All solid, liquid or pathological contaminated with radioisotopes of all kinds.	Skin infections, respiratory infections, and cancer.

2.2.2. Generation of SMW in HCFs

SMW is generated from different services of HCF according to the types of care offered to the patients and its quantity is depending to the types of waste according to their classification (ICRC, 2011; WHO, 2014; WHO, 2005; WHO, 2004; WHO, 1999). The quantity of waste is reported based on the types of waste by using daily data-collection according to the following information: date, number of data collector, name of HCF, number of occupied beds, department or services, type of wastes, weight, volume and notes or comments related to the current generation into service. This information contributes for the improvement of medical wastes management in HCF, worker awareness, the potential for reducing waste, the weights by a number of patients or beds in use and allow to constitute the report based on the evidence (ICRC, 2011; WHO, 2014).

2.2.3. Potential risks and pathways

During the management practice, all individuals coming into the close with SMW are susceptible at high risk from the hazards; most of them are susceptible to develop the infectious diseases by direct or indirect contact (ICRC, 2011; WHO, 2014). Among the people in charge of SMW management in HCF, the main groups exposed at high risk are medical staffs (doctors and nurses), waste cleaners, patients, visitors, and the general public. The literature reports show that hazards from infectious waste and sharps contain the pathogenic microorganisms and may enter the human body through several routes such as puncture, abrasion or cut in the skin, mucous membranes, and ingestion. In fact, the hazards from chemical, genotoxic and pharmaceutical waste can cause the intoxication to the persons through the skin, mucous membranes, inhalation or ingestion, and the radioactive waste can cause a high risk of infectious diseases through the inhalation (Banyara et al., 2013; ICRC, 2011; WHO, 2014). In another hand, improper management of SMW can cause a high risk of diseases to the personal staff and waste workers when they handle it. It was revealed that over two millions of workers are exposed to percutaneous injuries with infected sharps and infectious wastes every year. The United States, an annual report in 1993 showed that a large number of nurses between 12,600 to 22,000 and 500 to 7,300 have contacted the viral hepatitis B (HBV) (WHO, 2014).

Even if there is no scientific document that showed the number of health care workers that contract the diseases from the chemical waste and pharmaceutical waste, however, the literature shows that some groups of health care workers like pharmacists, anesthetists, nurses, waste workers, and maintenance personnel may be at risk of respiratory diseases caused by these types of SMW. Many studies conducted in Finland, Canada, and the United States have shown some that the improper SMW was the cause of infectious diseases or spontaneous abortions during pregnancy and malformations especially the female children (WHO, 2014). Moreover, several accidents related to the radioactive wastes were reported in HCFs of Brazil, where the carcinogenic caused by the radioactive waste have impacted negatively on the health of the general population (WHO, 2014). In another hand, pathological wastes not well treated contribute to the high risks of diseases to the general public. In most of the HCFs of developing countries, the personal staff, waste workers and visitors are exposed at high risk caused by the SMW wrong managed in HCFs. Besides these negative impact observed to the different medical teams, the risk is also high to the environment following to the improper SMW managed (Banyara et al., 2013; Nemathange et al., 2008; Muhwezi et al., 2014). The figure below shows the pathways of exposure depending on the infectious waste types (Figure 2-1).

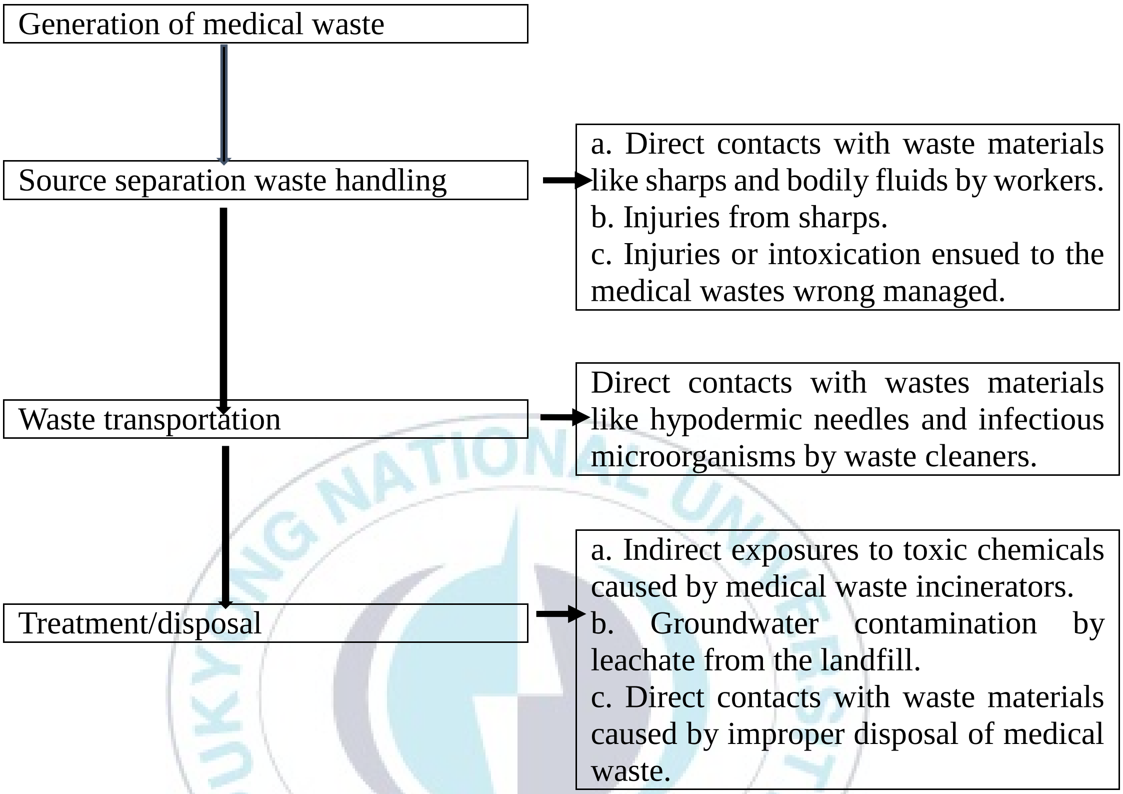

Figure 2- 1.Potential hazards and pathways of exposure to infectious materials in medical waste (Jang, 2011)

2.3. Materials and Methods

2.3.1. Data collection and analysis

Data for the generation and SMW management practices were collected from reports produced by the Ministry of Health of Burundi for 2011-2014, using questionnaires on generation (MOH, 2014). The questionnaire contains the status of waste generation in each service of HCF. The amount of waste generated from HCFs was reported as annual data classified by waste type after daily measurement.

The SMW was weighed using a 50 kg spring balance before moving from the HCF service to the storage area. In this study, unit generation rates, based on beds (kg $bed^{-1}day^{-1}$) and patients (kg $patient^{-1}day^{-1}$), were used to assess SMW generation characteristics in Bujumbura. Waste generated by district, in public and private HCFs was compared in this study. Waste amount handled by a worker (kg. $worker^{-1}.day^{-1}$) was also calculated in this study. Moreover, the amount of wastes generated in each HCF was calculated in this study. One-way analysis of variance (ANOVA) was used to determine whether there is a difference in waste generation by HCF types. All statistical tests were performed using the R 3.32 program at the 95% significance level. To understand the main problem of SMW classification system in Burundi, WHO classification and other countries were compared with Burundi SMW waste classification.

2.3.2. Characteristics of HCFs and SMW management

Twelve HCFs selected for this study are four public and eight private HCFs, which have different attributes, such as general, university, military, and clinic. Two public and two private HCFs are located in the northern district, two public and five private HCFs are in the central district, and one private HCF is located in the southern district (Fig. 1-3). Among the four public HCFs, HCF1 is a university HCF where medical students are trained and more advanced care is delivered. HCF 3 and

HCF 6 are general HCFs to which, most small primary HCFs in Bujumbura transfer their patients. HCF 6 has a high accommodation capacity and treats the largest number of patients. HCF 8 is a military HCF and reserved for the army. The eight private HCFs are all clinics and provide similar services, except for HCF10 that treats patients with mental illnesses (Table 2-2).

Table 2- 2**.** Characteristics of 12 HCFs in Bujumbura studied (MOH, 2014)

Name	**Status**	**Operation Type**	**Location District**	**Number of Beds**	**Number of Inpatients**
HCF1	Public	University	North	1,536	50,927
HCF2	Private	Clinic	Center	188	898
HCF3	Public	General	Center	626	34,040
HCF4	Private	Clinic	South	243	2,697
HCF5	Private	Clinic	Center	206	1,761
HCF6	Public	General	Center	2,099	63,707
HCF7	Private	Clinic	Center	130	1,290
HCF8	Public	Military	North	710	26,132
HCF9	Private	Clinic	Center	85	1,187
HCF10*	Private	Clinic	North	294	1,718
HCF11	Private	Clinic	North	143	818
HCF12	Private	Clinic	Center	112	999

*mental illness

2.4. Results and Discussion

2.4.1. Comparison of classification of SMW in Burundi to WHO and other countries

The comparison between the classification of SMW in Burundi, WHO, and other countries are presented in Table (2-3). Burundi, its classification system doesn't follow completely WHO recommendation because some types of wastes are classified together such as chemical waste and radioactive waste, pharmaceuticals and discarded medical plastics (MOH, 2008). By comparing the Burundi classifications system and WHO recommendation, the results of this study show how the improvement of SMW classification system in Burundi is an emergency situation. Therefore, in Burundi, some types of waste should be separated first and classified in their specific group in accordance with their characteristics and mode of final disposal. For this, discarded medical plastics may be classified in the group of non-hazardous SMW because it can be disinfected and recycled. Because the chemical waste and radioactive waste have different characteristics and disposal methods, they must be separated into different groups. The absorbent cotton may be classified in the infectious waste when it is contaminated. The placenta that has recently been used for medical purposes can be classified in the pathological waste. A good and systematic medical waste classification system is the basis for efficient and safe SMW management (Wen et al., 2014). Better classification and separation of medical wastes enable the Burundi government to establish and implement more effective management policies for SMW and to adopt appropriate treatment methods based on physical and chemical characteristics of specific SMW. As mentioned in the Table (2-3), a similar situation was developed in Uganda where the Chemical waste was classified together with pharmaceutical waste (MOH of Uganda, 2009). In another hand, Rwanda has followed completely WHO recommendation for all types of SMW (MOH of Rwanda, 2016). Developed countries, however, like US and Republic of Korea have followed WHO recommendation by establishing their own classification based on their local situation (Table 2-3) (Oh, 2006, USA, 1992; WHO, 2015).

Table 2- 3. Comparison of classification of SMW in Burundi to WHO and other countries

WHO	Developing countries			Developed countries		Difference	Improvements
	Burundi	Uganda	Rwanda	USA	Republic of Korea		
1.Infectious waste	1.Infectious waste	1.Infectious waste	1.Infectious waste	1.Infectious waste a. Cultures and stocks of infectious waste ｂ.wastes contaminated with blood, excretions.	I. Isolated high-risk medical waste	Burundi classification doesn't consider all items related to infectious waste.	Burundi classification should consider the absorbent cotton item in the case it is contaminated.
					II. Hazards medical waste:		

2.Pathological waste	2.Pathological waste and tissue	2.Pathological waste	2.Pathological waste	2.Pathological waste: a. Human tissues, organs, body parts, body fluids. b. Animal waste contaminated	1.Pathological waste 2.Tissue and body waste 3.Blood contaminated waste	a. Burundi classification considers tissue as a part of the pathological waste. b. It doesn't consider animal and blood-contaminated waste.	Burundi government should improve the classification system by including the animal and blood contaminated waste in the SMW classification system.
3.Sharps waste	3.Sharps waste	3.Sharps waste	3.Sharps waste	3.Sharps waste	4.Sharps waste	Same classification	Well followed
4.Pharmaceutical waste, cytotoxic waste	4.Pharmaceutical waste and discarded medical plastics	NC	4.Pharmaceutical waste, cytotoxic waste	NC 4.Antineoplastic: cytotoxic,	NC NC	Pharmaceutical waste is mixed with discarded medical	Pharmaceutical waste should be separated with discarded medical

				cytostatic, drugs		plastic.	plastic.
5.Chemical waste	5.Chemical waste and radioactive waste	5.Chemical, pharmaceutical, genotoxic waste	5.Chemical waste	5.Small volumes of chemical hazardous waste	5.Biochemical waste	Radioactive waste and chemical waste are classified together in Burundi system.	Burundi classification should classify separately the chemical waste and radioactive waste.
6.Radioactive waste	NC	6.Radioactive waste	6.Radioactive waste	6.Low-level radioactive waste	NC		
	6.Absorbent cotton and placenta					Burundi classification system considers the absorbent cotton and placenta as a type of SMW.	Absorbent cotton should be classified as an item of infectious when it is contaminated, another hand it is considered as an item of general waste.

		The placenta should be classified in the pathological waste group.
3.General wastes	Burundi SMW classification system doesn't consider the general wastes	Burundi SMW classification system should take account of general wastes for ensuring the proper management practices.

NC: Not consider

Considering the classification system in developed countries, Burundi government should improve its classification system by revising the current classification accordance to WHO recommendation while basing itself on the local situation of the country especially on the economy in order to contribute for the best management practices of SMW based on the evidence.

2.4.2. Overview of SMW generated in 12 HCFs during four years

The Table 2-4 gives the details of the quantity of SMW generated in each HCF accordance with the types of waste during a period of four years from 2011 to 2014 (MOH, 2014). It shows the total waste generated by each HCF for four years. In all HCFs, the high quantity of waste generated by types of waste is representing in the following position: 6,428,180 kg, 4,229 tons and 3,231tons for pathological waste, pharmaceutical waste and discarded medical plastics and absorbent cotton and placenta, respectively. Moreover, four public HCFs (1, 3, 6 and 8) present a high quantity of SMW with 15,741 tons (92.8%) compare to the private HCFs that represent 1,217tons (7.2%). It is explained by the hospitality capacity, low cost of cares, as well as the free care, offered to the pregnant women, patients having AIDS and children under five years (MOH, 2012; MOH, 2014). Private HCF10 presents a high quantity of waste with 467 tons (2.3%) among all private HCFs because of its specificity for treating the illness mental diseases (MOH, 2014).

Table 2- 4. SMW generated in each HCF during four years from 2011-2014

Health Care Facility	Hazardous Solid Medical Wastes (kg/4 years)						
	Medical Sharps	Infectious waste	Pathological waste and tissue	Pharmaceutical waste and discarded medical plastics	Chemical and radioactive waste	Absorbent cotton and placenta**	Total
HCF 1*	602,500	32,400	2,050,200	1,357,900	353,300	1,156,000 (9300)	5,234,300
HCF 2	2,800	1,500	26,000	17,430	2,000	13,000 (730)	62,730
HCF 3*	26,000	18,000	1,010,320	715,940	155,20	520,320 (6900)	2,306,100
HCF 4	4,400	4,200	64,000	39,000	10,320	24,500 (434)	146,420
HCF 5	7,200	2,260	65,920	51,600	2,820	18,600 (394.8)	148,400
HCF 6*	823,000	39,000	2,580,000	201,5000	801,450	126,0750 (19200)	7,519,200
HCF 7	9,625	5,600	60,900	49,005	9,000	19,250 (380)	153,380
HCF 8*	55,000	5,070	288,600	207,000	30,082	96,000 (1682)	681,752
HCF 9	6,350	300	22,030	15,243	1,250	10,006 (178.8)	55,179
HCF 10	26,000	14,901	200,000	129,200	12,000	85,000 (100.8)	467,101
HCF 11	12,000	8,200	40,000	35,237	12,103	18,000 (3260)	125,540
HCF 12	6,200	2,265	20,210	17,520	2,850	9,600 (644.8)	58,645
Total	1581075	133,696	6,428,180	4,650,075	934,695	3,231,026(43,207)	16,958,747

*: Public HCF, *: The value in parentheses is placenta only.

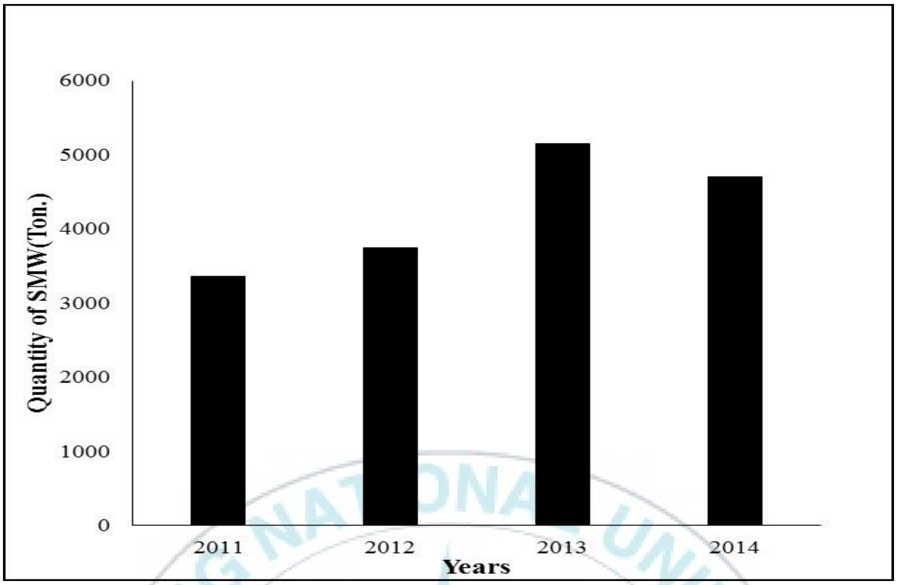

Figure 2- 2. Total quantity of SMW generated during four years

Figure 2-shows the total quantity of SMW yearly generated from 2011 to 2014. The results show that the quantity of SMW has increased from 2011 to 2013 and decreased in 2014. The highest quantity of wastes was observed in 2013 compared to other years. It is explained by a big number of inpatients presenting outbreak disease (cholera) that have been reported in public HCFs especially in 2013 (MOH, 2014). Because the public HCFs present a high quantity of wastes, the attention on SMW management should be oriented firstly for public HCFs compare to the private HCFs in Bujumbura.

The detailed classification and mass composition of SMW (yearly) generated from 12 HCFs is presented in Table 2-5. Such composition is based on the annual average values during the four period of 2011~2014. Pathological waste and tissue accounted for 37.9% of SMW, mostly from services such as maternity and surgery (MOH, 2014). Pharmaceutical waste and discarded medical plastics, and absorbent cotton and placenta composed 27.4% and 19.1% of total SMW, respectively. Other types of SMW constituted less than 10%. Typically 10-15 % of hospital wastes are infectious and some HCFs report 30% or more (Abdulla et al., 2008; Sartaj and Arabgol, 2015). Thus, the low amount of infected waste in Burundi is thought to be due to poor classification and collection systems.

Table 2- 5. SMW generated in 12 HCFs during 2011-2014

Health Care Facility	Hazardous Solid Medical Wastes (kg/yr)						
	Medical Sharps	Infectious waste	Pathological waste and tissue	Pharmaceutical waste and discarded medical plastics	Chemical and radioactive waste	Absorbent cotton and placenta*	Total
HCF 1	150,625	8,100	512,550	339,475	8,825	289,000 (2,325)	1,308,575
HCF 2	700	375	6,500	4,357	500	3,250 (182.5)	15,682
HCF 3	6,500	4,500	252,580	178,985	3,880	130,080 (1,725)	576,525
HCF 4	1,100	1,050	16,000	9,750	2,580	6,125 (108.7)	36,605
HCF 5	1,800	565	16,480	12,900	705	4,650 (98.7)	37,100
HCF 6	205,750	9,750	645,000	503,750	200,362	315,187 (4,800)	1,879,800
HCF 7	2,406	1,400	15,225	12,251	2,250	4,812 (95)	3,8345
HCF 8	13,750	1,267	72,150	51,750	7,520	24,000 (420.5)	170,438
HCF 9	1,587	75	5,507	3,810	312	2,501 (44.7)	13,794
HCF 10	6,500	3,725	50,000	32,300	3,000	21,250 (25.2)	116,775
HCF 11	3,000	2,050	10,000	8,809	3,025	4,500 (815)	31,385
HCF 12	1,550	566	5,052	4,380	712	2,400 (161.2)	14,661
Total	395,268	33,424	1,607,045	1,162,518	233,673	807,756(10801.7)	4,239,687

* The value in parentheses is placenta only

When considering the improper classification system, the amount of infectious waste can be much larger than that shown in Table 2-5, and it may be the second highest. Pathological wastes and infectious wastes were also the major SMW generated in HCFs in Limpopo province in South Africa (61.9% and 28.7%)

due to higher generation from maternity services (Nemathanga et al., 2008). 18.83% of infectious wastes and 8.11% of pathological wastes are the largest part of medical wastes in India except for general wastes (Patail and Shekdar, 2001). This indicates that even though the composition of SMW may vary depending on the types of services or country, pathological and infectious wastes are the most abundant SMW.

SMW generation, number of beds, and the number of inpatients of public HCFs were higher than those of private HCFs ($p<0.01$). Public HFCs produced 92.8% of SMW during 2011~2014. 78.0% and 93.9% of beds and patients were in public HCFs. This overall pattern did not vary by region ($p>0.05$) but differed depending on the type of operation ($P<0.01$). Three public HCFs (HCF1, HCF 3, and HCF6) generated 88.8% of SMW. They had more patients and beds than other HCFs. Free care is offered in public HCFs to pregnant women, AIDS patients, and children under five years, which is why there is a higher number of patients in public HCFs (Table2- 2). Private HCFs produced 7.2 % of SMW with HCF10 generating the largest amount of SMW among private HCFs, at 2.8%. Since the amount of SMW generated depends on diseases and type of their treatments, the amount of SMW generated may vary among hospitals even though they have similar numbers of patients. This trend can be observed in HCF10 and HCF5. While the number of patients in both HCFs is similar, HCF 10 that treats long-term psychiatric disorders, infectious diseases (HIV/AIDS) and wounds generated three times more SMW than HCF 5 that treats common diseases.

Table 2-5 also shows how the Burundi government can improve the efficiency and safety of SMW management. Management priorities should be given to pathological waste, Pharmaceutical waste and discarded medical plastics and Absorbent cotton and placenta wastes in terms of waste types and public HCFs in terms of the type of operation because of their contribution to the quantity of SMW. Although recycling of medical waste should be limited due to infectious characteristics, proper recycling or disposal of discarded medical waste plastics with no pollution or infection can significantly reduce the amount of hazardous SMW generated. Storage areas and containers should be prepared for proper management of infectious wastes and sharps that can cause AIDs, viral hepatitis, hemorrhagic fevers, septicemia, bacteremia, and candidaemia. Education and special guidance should be provided in public HCFs that have more patients and generate more SMW.

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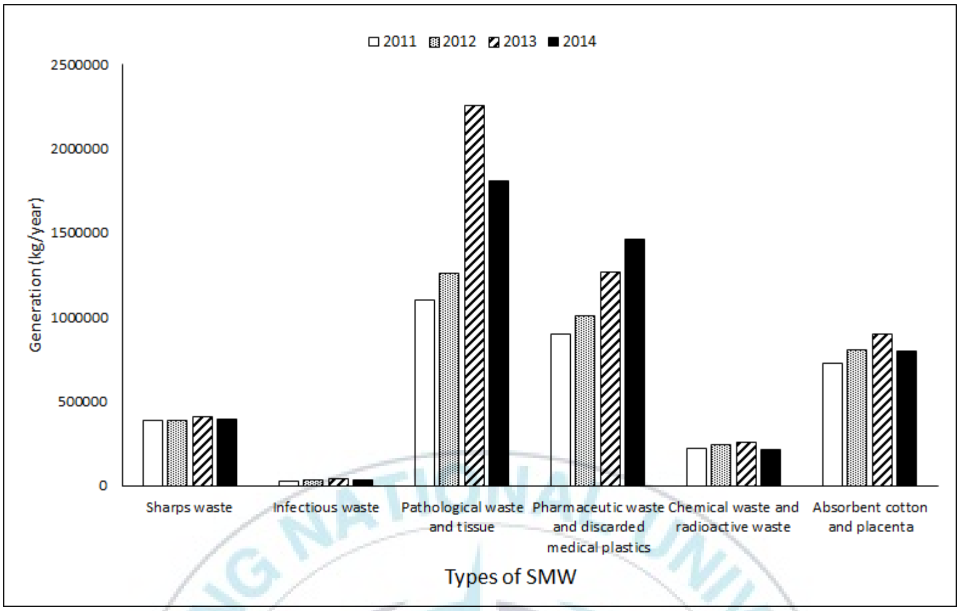


Figure 2- 3. Temporal change of solid medical waste generation during 2011-2014

Figure 2-3 shows the yearly change of the seven types of SMW generated between 2011-2014 in 12 HCFs. All of the hazardous SMW increased in 2012 and 2013 but decreased in 2014, except for pharmaceutical waste and discarded medical plastics. The Burundi government built three new HCFs in provinces near Bujumbura in 2014, so patients from neighboring provinces decreased. Pharmaceutical waste and discarded medical plastics increased in 2014, however. This is due to excessive consumption of pharmaceutical products due to the outbreak of cholera in Bujumbura, and as such related medical supplies were used more to treat patients in 2013 (MOH, 2014).

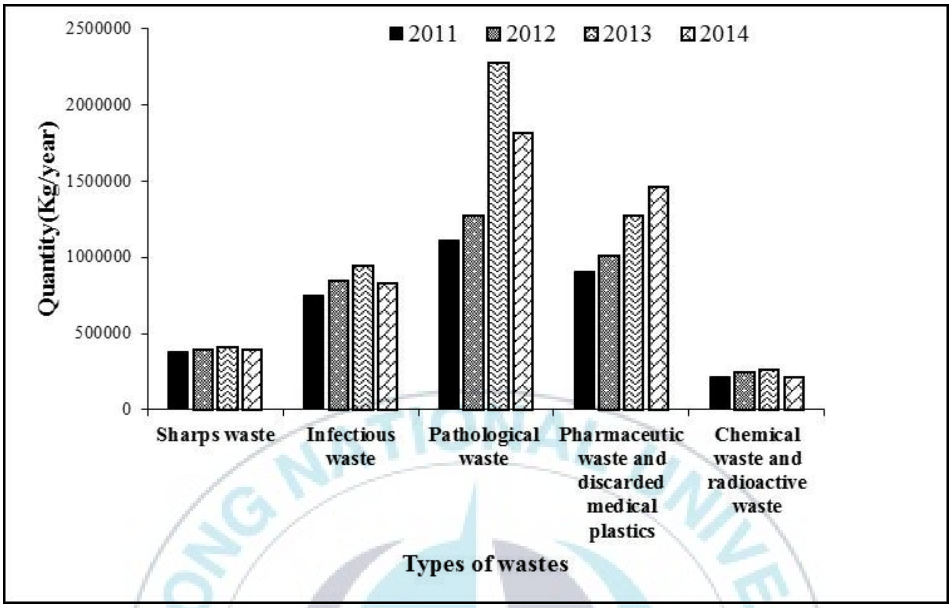
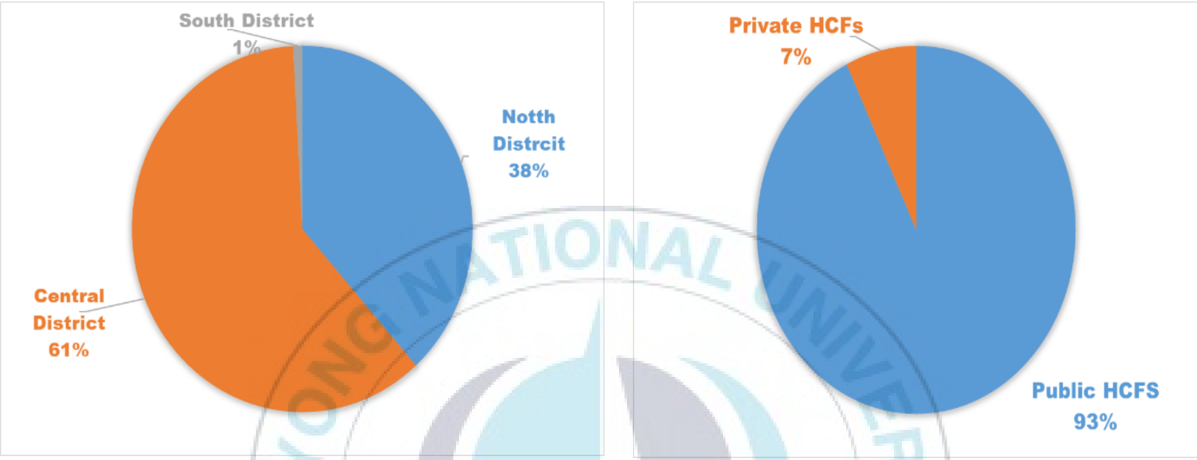


Figure 2- 4. Temporal change of solid medical waste generation during 2011-2014 referred to WHO classification

Figure 2-4 shows yearly change of SMW generated between 2011-2014 in 12 HCFs based on the evidence of WHO classification (WHO, 2014). Burundi classification does not separate the chemical waste and radioactive waste, pharmaceutical waste and discarded medical plastics; therefore, SMW generated according to these types were collected together and mixed in all HCFs. This figure shows how the quantity by type of waste should be presented yearly especially for sharps waste, infectious waste and pathological waste except for pharmaceutical waste and discarded medical plastics, and chemical waste and radioactive waste because their quantity was mixed during separation and collection practices in all HCFs. Moreover, the quantity of absorbent cotton and placenta was measured separately but collected together in all HCFs, therefore, this figure shows how the quantity of placenta and absorbent cotton could be collected in the group of pathological waste and infectious waste, respectively. Practically, if Burundi classification system could follow the WHO recommendation, the quantity of pathological waste and infectious waste could increase (Figure 2-4). In addition, the quantity of pharmaceutical waste, radioactive waste, and chemical waste could decrease in the case of Burundi classification could follow WHO recommendation by respecting the separation between pharmaceutical and discarded medical plastics, radioactive waste, and chemical waste.

This figure shows also how Burundi government could focus on priority for revising the classification of SMW by considering the absorbent cotton and placenta as items of infectious waste and pathological waste, respectively. It is important also to separate the chemical waste and radioactive waste, pharmaceutical waste and discarded medical plastics. This figure can orient the best management practices of SMW in all HCFs of Burundi, all the more infectious waste and sharps waste are considered as the most types of wastes that cause a high risk on the human health and environment (WHO, 2014).



(a) (b)

Figure 2- 5. Generation characteristics of SMW from 12 HCFs between 2011-2014 in Bujumbura, Burundi. Waste generation by districts (a) and type of HCFs (private vs public) (b)(ton)

Figure 2-5 (a) presents the quantity of SMW generated in each district for four years. Among 16,958 tons of SMW generated, 61% (10,303 tons) were generated by the central district. It due by the fact that seven HCFs among twelve are located in central district and among them a big quantity of waste was generated by two public HCFs (HCF3 and HCF6), respectively with 7,519 tons (44.33%) and 2,306 tons (13.6%) (Tables 2-1; 2-4). Moreover, the quantity of waste generated by these two HCFs constitute over the half of wastes generated by all twelve HCFs (9,825 tons or 57.94%). In the second position comes the north district with 38% (6,508 tons). This is explained by the high quantity of SMW (5,916 tons or 34.88%) generated by two public HCFs (HCF1 and HCF8) located in that district. Comparing the quantity of waste generated by the HCFs of these three districts, HCF1 and HCF8 of north district come in the second position after HCF6 and HCF3 of central district (Table 2-4). Due by the presence of one private HCF in south district among all HCFs selected in this study (Figures 1-2,1-3), south district comes in the last position with a small quantity of wastes (146 tons or 1%).

Considering a high quantity of wastes generated from Central district and North district; Burundi government should focus on the SMW management in these two districts firstly. Figure 2-5(b) shows the quantity of SMW generated by public and private HCFs. 93% (15,771 tons) were generated by public HCFs and 7% (1,187 tons) by private HCFs. It is explained by a big number of patients (Table 2-2) that are treated in these public HCFs following to the strategies implemented by Burundi government where the free cares are offered to the different layers of patient (children under five years, pregnant women, patients with HIV/AIDS). The second reason is the low price cost for cares in public HCFs compare to the private

HCFs. Even if, the private HCFs were numerous (8HCFs) compare to public HCFs, their quantity generated was low (7%). The results of this study show how much the government should focus on priority on the public HCFs because of their high quantity, as well as the north and central districts.

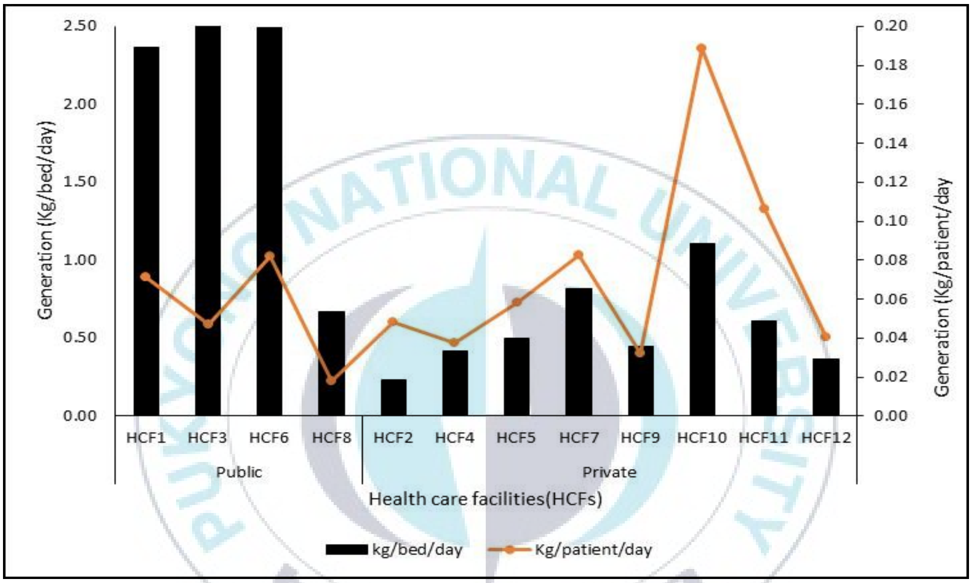


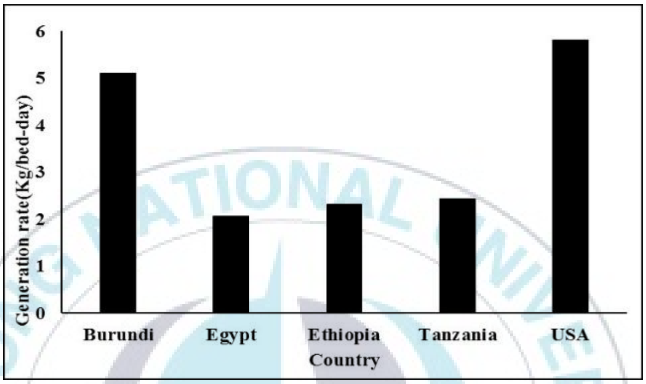
Figure 2- 6. Hazardous solid medical waste generation rates in public and private HCFs

Figure 2-6 shows SMW generation rates in 12 HCFs during the period of 2011~2014. The number of patients presented in this study is based on inpatients (Table 2-2). The average daily generation rate per patient was 0.27±0.17 kg. $patient^{-1}.day^{-1}$in all of the HCFs, but 0.29±0.21 $kg.patient^{-1}.day^{-1}$ in private HCFs, and

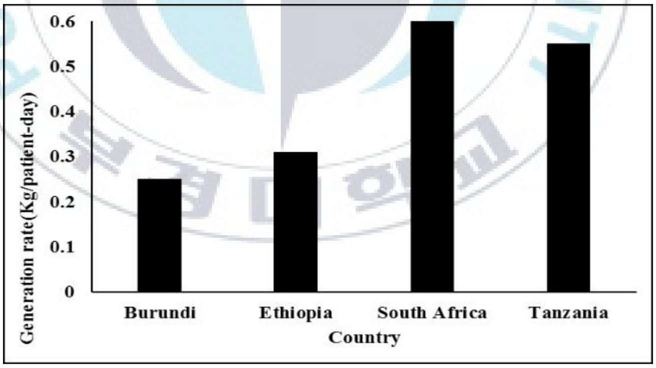
0.22±0.11 patient^{-1} .day^{-1}in public HCFs (Figure 2-7). Although the private HCFs 10 and 11 had the highest values at 0.74 and 0.42 kg patient^{-1}day^{-1}, the generation rates of public and private HCFs are similar, except for two HCFs. SMW generation rate per bed showed a different trend to the rate by patient base. Average daily generation rate per bed during 2011~2014 was 4.13±3.35 kg.bed^{-1}.day^{-1}, with that of public HCFs (7.97±3.57 kg. bed^{-1}.day^{-1}) greater than that of private HCFs (2.22±1.10 kg. bed^{-1} .day^{-1}). If HCF8, a military service, is excluded, the generation rate of public HCFs was 9.75±0.38 kg. bed^{-1}.day^{-1}, about 4.4 times larger than that of private HCFs.

Quantitative and qualitative differences in the services and treatment provided by HCFs affect the SMW generation rate. Among public HCFs, HCF1 is a university hospital and HCFs 3 and 6 are general hospitals. The daily generation rate based on the bed is known to be higher in university hospitals and general hospitals than primary health care centers (WHO, 1999) (Wallender et al., 2014). Furthermore, three public HCFs (HCF1, HCF3, and HCF6) had 66.9% of total beds and 79.9% of total patients treated for the study period, generating 88.8% of the total SMW as explained before. Even though HCF8 is a public service, its production of pathological waste and tissue, pharmaceutical waste and discarded medical plastics, and absorbent cotton and placenta was less than that of HCF3 because it is a military hospital.

Generation rates of SMW differ among countries and are usually higher in developed countries than in the developing countries (Asante et al., 2014; Askarian et al., 2004; Nemathanga, 2008; Phengxay, 2005; Ruoyan et al., 2010; WHO, 1999). The SMW generation rates of high-income countries are 1.1 to 12.0 $kg.patient^{-1}.day^{-1}$ while the middle income countries are 0.8-6.0 $kg.patient^{-1}.day^{-1}$. They are reported 0.34-1.24 $kg.bed^{-1}.day^{-1}$ in other African countries (Lee et al., 2002; Mato et Kassenga, 1997; WHO, 2014). They are 7-10 kg. $bed^{-1}.day^{-1}$ in North America region, but 1.8-2.2 kg. $bed^{-1}.day^{-1}$ in middle-income eastern Asia countries (WHO, 1999). This reflects that SMW generation rates are closely related to socioeconomic factors and tends to be higher in countries with high GDP (Mingoulou et al., 2017). Compared to other African countries, the generation rate of SMW in Bujumbura is very high. Therefore, if countermeasures are not taken from now on, the generation rate of SMW could significantly increase as Burundi's economy evolves. SMWs are not only generated in the treatment processes of inpatients but also in those of outpatients, and it is generally known that inpatient treatments generate more SMW (Shinee et al., 2008). In this study, the effects of medical waste generation during outpatient treatments were not considered because generation data for outpatient treatments were not available. Waste generation data from the treatments of both inpatients and outpatients are needed to better understand the waste generation characteristics and ensure safe SMW management during transport, storage and disposal of the wastes. The Burundi government needs to provide a guideline for HCFs to record waste generation for inpatients and outpatients separately.



(a)



(b)

Figure 2- 7 (a) (b).Comparison of generation rate of kg/bed/day, kg/patient/day in developing

Figures 2-8 (a) and (b) show the generation rates on kg.bed-^{1}.day-^{1} and kg.patient-^{1}day-^{1} in developed and developing countries. The generation rate by kg.bed-^{1}.day-^{1} of Burundi in this study is compared with these of three African countries and developed country (USA) (Abd El-Salam, 2010; Asante et al., 2014; Bassey et al., 2006; Wiafe et al., 2015). The results show that the generation rate (kg. bed-^{1} .day-^{1}) in Burundi is twice more compared to the generation rate observed in each African country (Egypt, Ethiopia, and Tanzania). In another hand, it is slightly lower than that of the USA (Figure.2-8(a)). It due by the fact that in Burundi, the HCFs especially public HCFs generated more waste following a high frequency of patients. The generation rate on kg.patient-^{1}.day-^{1} is the half compared to the generation rate of South Africa and Tanzania, but it is almost similar to that of Ethiopia (Figure 2-8 (b)). The results of this study show that Burundi presents a high generation rate of kg.bed-^{1} .day-1compare to other developing countries, even its GDP is low compared to them. Burundi government should plan the SMW management based on its economy.

2.5. Conclusions

Generation and properties of SMW, and their classification in 12 HCFs of Bujumbura, Burundi, were assessed to better understand the problems of SMW generation and provide insights for improving the management policy of SMW in the country. Large amounts of pathological waste, pharmaceutical waste and discarded medical plastics and absorbent cotton and placenta were generated from the HCFs. Public HCFs were responsible for 92.8% of SMW generated, while the rest is generated by private HCFs. 88.8% of SMW was generated by three public HCFs (HCF1, HCF 3, and HCF6). SMW classification does not respect WHO recommendation, because most of the types of wastes are combined except the sharps waste and infectious waste. A high quantity of SMW was observed in central district with 61% (10,304 ton) compare the north and south districts. A generation rate on kg. bed^{-1} .$day^{-1}$was high in public HCFs with 7.97±3.57 kg. bed^{-1}.day^{-1}.

Based on the results of this study, we recommend the following for the SMW management in Burundi to be improved. Revision of the SMW classification system is most important for ensuring the correct separation in HCFs of Bujumbura. The HCFs should focus on the management of three types of wastes such as pathological waste, Pharmaceutical waste, and discarded medical plastics and absorbent cotton and placenta because they present a high quantity of wastes. The government needs to introduce various incentive measures for HCFs to actively implement the guidelines and to focus on the management of wastes in public HCFs. In terms of districts, Burundi government should focus in priority on central district and north district, because 99% of SMW are generated from in these two districts.

III.MANAGEMENT PRACTICE OF SOLID MEDICAL WASTES FROM GENERATION TO FINAL TREATMENT DISPOSAL

3.1. Introduction

SMW generated in different wards of HCF after medical services, most of them contain potentially infectious or toxic materials. When it is not clearly identified by following the classification system and safely separated, collected at the source of generation, and proper treated at all stages of processes, it can lead the potential risks to human health and the environment (Jorge,2007; Longe and Williams, 2006; Muhwezi et al.,2014; WHO,2014). During the management practice of SMW, some groups such healthcare workers (particularly waste workers), patients, hospital housekeeping personnel, visitors to health care facilities (HCFs), add up the community are exposed to the high risks of potentially infectious and harmful microorganisms. Even after such waste is safely separated and collected, it can cause a high risk to waste handlers, workers in waste treatment and disposal facilities, and the general public, and result in other environmental pollution (drinking water pollution, rodent and pest growth, an unpleasant odor, and soil and groundwater contamination), if not properly managed from storage to final disposal stage (Babanyara et al., 2013; Jang et al., 2006; Lee et al., 2002; Mayele and Lyansega, 2011; Mohee,2005; Mmereki et al.,2017; Rao,2008). Proper separation, collection, safe transportation, and proper storage are the first current practices that orient the proper SMW management (ICRC, 2011; WHO, 2014). Numerous studies have been carried out by researchers and extent the serious problem related to each type of SMW wrong managed (Asante et al.,2014; Babanyara et al., 2013; Mohee, 2005; Muhwezi et al.,2014; Nemathanga et al.,2005; Rao, 2008). For preventing the risks, guidelines have been established by WHO for helping all nations in SMW management processes in HCFs from generation to final disposal (ICRC, 2011). These latter contain different treatment technologies related to the pretreatment (autoclaves, microwaves, chemical disinfection and mechanical destroyer, shredding) and final treatment methods (incineration, steam sterilization, microwave sanitation, chemical disinfection, dry heat disinfection, and disinfection with superheated steam) wastes (ICRC, 2011; Rao, 2008;WHO 2014; Sawalem et al.,2009; Mohee,2005). In addition, recycling method is adequate for treating certain waste materials (e.g., discarded medical plastics) by reducing the volume to be treated (Lee et al., 2002; WHO, 2005; WHO, 2004).

Developed countries (United States, Canada, and European Union), the guidelines are high regulated accordance to their local situation (Insa et al., 2010; Walkinshaw, 2011). For examples, United States, during the late 1980s, large amounts of medical waste were improperly disposed of; however, some improvements were done from 1988 by establishing the regulation for orient the management practices from generation to final disposal. Currently, medical waste treatment is high regulated using incinerators, autoclaves, microwave, and various chemical and mechanical systems, where the incinerator is the most common method used. Canada, thirteen Canadian provinces among fourteen do not have specific regulation relating to disposal of medical waste. HCFs passed laws on the method of incineration of medical on-site. European Union, however, all member nations have established their own guidelines referring to European commission and medical incineration facilities are highly regulated (Walkinshaw, 2011; Windfeld and Brooks, 2015). In developing countries, however, most of them do not have the proper guidelines and even others that have guidelines do not follow them appropriately during SMW management practice. The lack sufficient budget is the main challenge for ensuring the safe disposal (Abd El-Salam,2010; Awodele et al.,2016; Asante et al.,2014; Bassey et al.,2006; Diaz et al.,2005; Sawalem et al.,2009; WHO,2014). Moreover, HCFs are not able to support themselves the new technologies like advanced incineration technology (Walkinshaw, 2011; Mato and Kassenga, 1997; Jorge, 2007; Windfeld and Brooks, 2015). This could cause a high risk to the human health and environment especially since not the ashes and other residues generated by the incineration of waste frequently contain many toxic products (WHO, 2014; ICRC, 2011; Joshua et al., 2014; Abugri, 2014). WHO estimated that the injections with contaminated syringes caused 21 million hepatitis B, 2 million hepatitis C and 260,000 HIV infection (Banyara et al., 2013).

Based on WHO regulation of SMW management practices, Burundi has established national guidelines for SMW management practices in 2008 and all HCFs should follow them (MOH, 2008; WHO,2005). A recent study was conducted in 10 laboratories of HCFs in three provinces in Burundi, however, showed that 78.8% of laboratories did not follow the national guidelines (Godefroid and Jean, 2013). Furthermore, the report on the assessment of the health policy of SMW management revealed that most HCFs in the country failed to follow the national guidelines during SMW management and the national guidelines do not cover the final disposal steps (Joseph and Nina, 2010). SMW management practices in Burundi, therefore, must be regulated properly to reduce risks to public health and the ecosystem. To address this, the status of SMW management practices during all management steps in HCFs should first be analyzed. Previous studies were only conducted for a limited number of HCFs and examined whether the HCFs followed the guidelines. No comprehensive analyses for SMW management practices in

HCFs in Burundi from generation to final disposal have been performed.

In this chapter, the status of SMW management practices, from generation to final disposal in 12 HCFs in Bujumbura, Burundi, was assessed. Management steps from generation to transportation at final disposal was examined based on national guidelines. Current final treatment/disposal activities of SMW in Burundi are presented and discussed, based on the major components from a total of 12 HCFs and are compared to WHO recommendation. Rapid risk assessment (RRA) was also conducted to identify potential hazards and degree of risk, and to provide control measures for reducing risk from current SMW management system in Bujumbura, Burundi. It is important to compare the results of this chapter with the data of other studies carried out in different countries.

The main goals of this study were to assess the SMW management practices from generation to final disposal and final treatment methods. The RRA was also conducted to identify the potential hazards and degree of risk. The objectives of this study were to suggest the best management practices and adequate treatment and to provide control measures for reducing risk from current SMW management system in Bujumbura, Burundi. It could help the government to establish effective SMW management policies.

3.2. Literature review

3.2.1. Waste management practices

Separation is the key for the success of SMW management practice from generation to final disposal, and it is an initial step of management practice at the source into the wards of HCF after medical service (WHO, 2014). The waste workers in the SMW management process need to understand firstly the importance of separation step of wastes at source according to the types of waste after medical services. The national guidelines and policies of SMW orient the management practice of waste from generation to final disposal. For ensuring properly the management of SMW, the personal staffs (doctors and nurses) and waste workers should be trained firstly for all steps related to the process (WHO, 2014; ICRC,2011). In addition, the mechanisms related to the protection against infectious diseases or toxic from the waste should be set out especially for different groups of exposure (personal staff, waste workers, patients, visitors in HCFs, and environment). It is important to separate at source the general waste and infectious waste referring to the characteristic of each type of waste and routing plan (waste volume and number of waste bags or containers with specific color and code, waste types, capacity of waste storage, capacity of transportation and transport distances and journey times between the collection points). Moreover, the same proper separation should be maintained during transport at storage, and into the storage area. Practically, the containers should be arranged in their specific area according to their specific types of wastes. Most of the information required is the containers with a specific color, code accordance to the type of waste and label (originating ward), time generation and quantity of waste generated by the type of waste (ICRC, 2011; WHO, 2014; WHO, 2005). The same process should be applicable at final disposal. In Korea, some materials are used for the management practices inside of HCFs (separation and collection) after medical service, figure 3-1(a) and (b) (Oh, 2006; Joan, 2016; MOE of Korea, 2014). Some symbols related to the types of SMW and materials used for medical sharps were developed by WHO, figure 3-2 (a, b, c, d, and e, and f) (WHO, 2014).

(a) Separation of SMWs at the source of HCF in Korea

(b) Collection of SMWs inside of HCFs in Korea

Figure 3- 1.Materials used for SMW management inside of HCHs in Korea (Oh, 2006; Joan, 2016; MOE of Korea, 2014).

a. Biohazard symbol

b. Old radiation symbol

c. New radiation symbol

d. Toxic sign for chemical and hazardous pharmaceutical waste

e. Proper disposed of used syringes

f. Sharps box or Cardboard safety boxes for used plastic

Figure 3- 2. Symbols related to the types of wastes and materials used for medical sharps (WHO, 2014).

3.2.2. Solid medical wastes storage

Temporal storage is a place intended for storage of wastes before their transportation at final disposal. Depending to its location inside of HCF, it should respect the engineering condition (constructed, roofed and protected) and wastes should be separate and stored in the big containers or boxes that respecting different code and color specific to each type of SMW (Figures 3-3 (a) and (b)). However, some items of wastes like blood, chemical wastes, and radioactive wastes should be transported immediately at the specialized medical centers intended for their final treatment. The emplacement of storage area should follow the guidelines especially its design, distance between the households and its location as well as the symbols as recommended by WHO (Figure 3-4 (a, b, c, e, and d)). The size of the storage area should refer to the quantity of wastes generated in HCF. All conditions of hygiene should be respected inside of storage for preventing the risks (ICRC, 2011; WHO, 2014; WHO, 2005).

Symbols for indicating for storage for medical wastes (a)

Temporary storage box for infectious wastes only(b)

Figure 3- 3. Symbols for indicating for storage for medical wastes (a) Temporary storage box for infectious wastes only (Oh, 2006; MOE, 2014)

a. Label for a pathological waste storage room

b. No smoking

c. No entry for unauthorized persons for all storage areas

d. No eating or drinking

e. Interim waste storage ready

Figure 3- 4. Symbols at storage area and interim storage area (WHO, 2014)

3.2.3. On-site transport of solid medical waste

On-site transportation should take account of time and mechanisms for to prevent the different groups (doctors, nurses, waste cleaners, patients, visitors, and people) for being exposed to the high risk of diseases related to the improper SMW management. For ensuring safety transport at on-site, the schedule should be regulated by respecting the routes and collection times for preventing their decomposition and their leaking. Moreover, waste workers should be protected with adequate protective equipment (gloves, closed shoes, overalls, and masks) and wastes should be transported by using the adequate equipment (wheelbarrows, trolleys, or carts protected) that respecting all condition required (Figure 3-5). During transportation, hazardous waste and non-hazardous waste are separated for avoiding the contamination between them (ICRC, 2011; WHO, 2014; WHO, 2005).

Figure 3- 5. Medical waste transport trolleys outside a hospital in Thailand (WHO, 2014).

3.2.4. Off-site transport of solid medical waste

Off-site transport of SMW should refer to the regulations established by WHO. In the case of the lack of regulations, the offsite transportation should be conducted based on the recommendation related to the transport of dangerous goods established by the United Nations (UN) (WHO, 2014). In addition, a vehicle carrying the SMW should be labeled to indicate the contents and covered to prevent the risks to the waste workers, the people as well as the environment (Figure3-6). Waste workers involved in offsite transportation of SMW must be protected with adequate equipment that prevents risks to them (WHO, 2014; WHO, 2005). In addition, they should be trained in the offsite transportation system from temporal storage to final disposal. A consignment note containing the information relating to the collection of information (period, name of the consignor, name and address of the carrier, date of receipt, description of the waste and signatures of the consignor, the carrier and the consignee) should be completed for ensuring the assessment of SMW transport (ICRC, 2011;WHO,2014;WHO,2005).

Figure 3- 6. Off-site transportation trucks used in the Republic of Korea (Oh, 2006, MOE, 2014)

3.2.5. Treatment methods

The purpose of treatment is to reduce the potential risk caused by SMW towards human and environmental. The adequate treatment methods used for treating different types of SMW are selected based on their characteristics, technology capabilities, diverse requirements, environmental and safety factors, and costs (WHO, 2014). Moreover, different factors and proper treatment methods should take account on several items, such as quantity of wastes, operation, and maintenance requirements, and skills needed for operating the technology, location and surroundings of the sites of treatment, public acceptability, and regulatory requirements (WHO,2014; WHO,2005). In addition, it is required the monitoring and assessment conducted by the committee in charge of the SMW management practices in each HCF should be applied for ensuring the proper final disposal of

SMW. Each treatment method can be applied for numerous types of wastes depending on its capacity for ensuring completely treatment of SMW (WHO, 2014). The following Table (3-1) details the different treatment methods with their corresponding types of wastes (WHO, 2005).

a. Incinerator used in Korea

b. Collection of ashes after incineration

Figure 3- 7.Incineration and collection of ashes after incineration in Korea (Jang, 201

Table 3- 1. Treatment methods with their corresponding types of wastes

Treatment methods	Infectious waste	Pathological waste	Sharps waste	Pharmaceutical waste and discarded plastics	Chemical waste	Radioactive waste	Absorbent cotton and placenta
				On-site			
Sharps pit	No	No	Yes	No	No	No	No
Needle destroyer	No	No	Yes	No	No	No	No
Alkaline hydrolysis	No	Yes	No	No	No	No	Placenta
Encapsulation	No	No	Yes	Pharmaceutical waste	No	No	No
Shredding	No	No	No	Discarded plastics	No	No	No
Inertization	No	No	No	Pharmaceutical waste	No	No	No
Disinfection with	No	No	No	No	Yes	No	No

chlorine							
Low T° burning (400- 800℃)	Yes	No	No	No	No	No	No
Medium T° burning (800 – 1000℃)	Yes	Yes	No	Pharmaceutical waste	No	No	Placenta
High T° burning (>1000℃)	Yes	Yes	Yes	Pharmaceutical waste	Yes	No	Placenta
Organic pit	No	Yes	No	No	No	No	Placenta
Autoclaving	Yes	No	Yes	Pharmaceutical waste	No	No	No
Destroyer	No	No	No	No	No	Yes	No
Dry heat treatment	Yes	No	No	No	No	No	No
Microwaving	Yes	Yes	Yes	No	No	No	Absorbent cotton only

Chemical disinfection	Yes	No	Yes	No	No	No	No
Recycle and reuse	No	No	Yes	Discarded plastics		No	No
				Off-site			
Sanitary landfill	Yes	No	No	Pharmaceutical waste	No	Yes	Absorbent cotton only

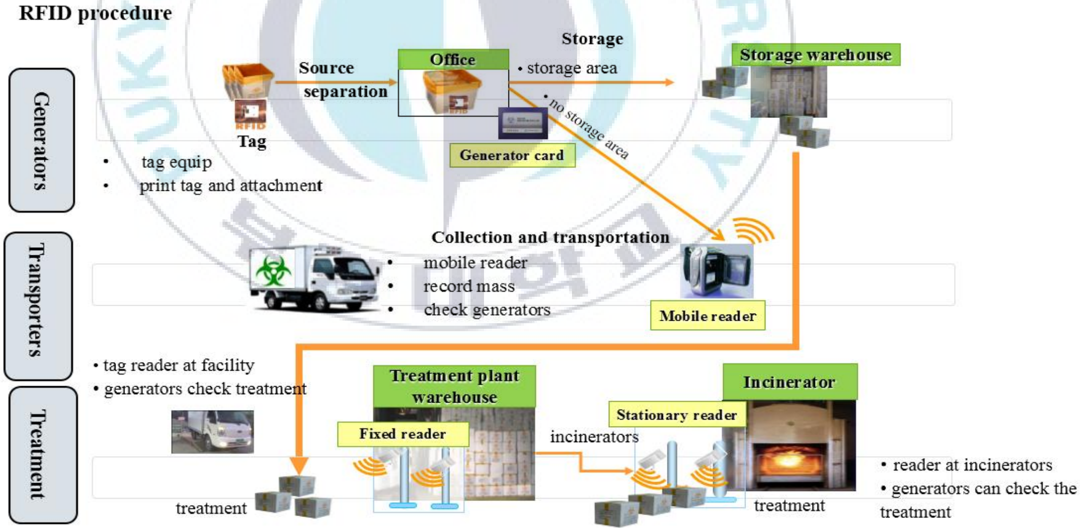
Table 3- 2. Advantages and disadvantages of final treatment methods (ICRC, 2011; WHO, 2014; WHO, 2005)

Treatment methods types	Advantages	Disadvantages
Sharp pit	a. It presents a low cost and its design is simple. b. t is adequate for large quantities of needles and no atmospheric pollution.	a. Some advantages are the lack of sufficient space and waste not disinfected. b. It can lead to potential contamination of soil and water.
Organic pit	It contributes to treating pathological waste	It presents the potential contamination of soil and groundwater.
Low-temperature incinerator (<400^{0}C)	a. It can reduce the volume and weight of waste and it doesn't need a highly trained operator. b. It presents a relative high disinfection efficiency.	It presents several advantages such as a big quantity of fuel or dry waste to start burning, some wastes are not completely sterilize destroyed, and the presence of toxic emissions.
Medium temperature	a. It reduces the volume and weight of waste and it can	The advantages are a big quantity of fuel, maintenance problems, possible toxic emissions, potential heavy smoke, ash containing leachable

incinerator ($800-1000^0C$)	be applied for treating infectious materials waste. b. It achieves complete sterilization of contaminated waste.	metals, the requirement of trained personnel, and needles not destroyed.
High-temperature incinerator ($>1000^0C$)	a. The waste is completely destroyed (volume is reduced). b. It presents complete combustion, sterilization of used injection and can reduce the toxic emissions.	The disadvantages are expensive building and its maintenance, requirement of electricity, fuel and trained personnel to operate, the presence of toxic emissions, ash containing leachable metals, dioxins, and furans.
Rotary Kiln incinerator($1200-1600^0C$)	a. It is adequate for infectious waste, chemical waste, and pharmaceutical waste. b. It is very effective at high temperatures and reduces significantly volume and	a. It presents a high technology of construction with a high cost. b. The operating and maintenance costs are relatively high. C. The incinerator needs a high quantity of fuel and electricity and personnel with high skills. d. The ash contains metals leachate, dioxins, and furans.

	weight of waste.	
Sanitary landfill	a. It has a capacity to control the adverse environmental impact and it is a final disposal waste away from the HCF.	The advantage is a high cost related to the transport organization, operation, and maintenance.
Recycling	a. It contributes to creating income, generates the opportunities and it is environmentally friendly. b. he used syringes and medical plastics waste are turned into useful products.	a. It is used for plastics only after their disinfection.

RFID equipment (a)



Medical waste RFID and management system in Korea (b)

Figure 3- 8.Radio frequency identification (RFID) equipment (a) and RFID-based medical waste treatment tracking system in Korea (b) (Oh, 2006, MOE, 2014).

3.3. Materials and Methods

3.3.1. Description of management practice steps

Table 3-3 gives the details of national guidelines based on the three main part of SMW management practices in Burundi. Each part has specific items corresponding to the management steps of SMW. However, the final treatment part doesn’t have national guidelines (MOH, 2008).

Table 3- 3. Description of management practice steps

Location	Different steps	National guidelines
1.Inside the facility	Separation and Collection	A1: Coding system exist on small containers A2: Color identification exist on small containers A3: Small containers are arranged according to SMW classification. B1: Small containers covered and arranged B2: HCWWs are protected during the handling. C: Measurement is effected before transportation.
2.Outside the facility	Transportation	D1: The wheelbarrows are covered during transportation to the storage area. D2: The schedule is respected during transportation.
	Storage	E1: Separation of sharps and other types E2: The containers of big size exist in the storage area E3: The temperature (3- 80c) is respected on storage. E4: Storage duration under 5 days is respected during storage. E5: Storage area is protected and roofed. E6: Storage area is constructed.
	On-site and off-site transport	F1: Truck protected F2: Wheelbarrow covered F3: Waste workers protected. F4: Regular transport.
Final treatment	On-site and off-site treatment	No guidelines used

3.3.2. Data collection and analysis

Current practice data from generation to transport and final disposal of SMW was collected from the official government report prepared by the Ministry of Health (MOH) of Burundi (MOH, 2014). Each HCF measured daily SMW production, completed a government-distributed questionnaire, and produced a monthly report under the supervision of the district offices that are involved in the management of SMW. The MOH of Burundi investigated the monthly report and produced an annual report. Burundi has national guidelines from generation to the transportation of SMW at different sites only, but not for final disposal (MOH, 2008). Therefore, the adequacy of separation, collection, storage, and transport phases was assessed by whether the HCFs followed the national guidelines or not. The guidelines for SMW management practices related to these different current practices are subdivided into different steps according to each current practice (MOH, 2008).

The appropriateness of the final treatment stage was also assessed by comparing current treatment methods with the WHO recommendations (WHO, 2014; WHO, 2004). The generation characteristics of SMW in 12 HCFs during 2011-2014 were analyzed using descriptive statistics. The current practice of SMW management practices from generation to transport phase at on-site and off-site in HCFs was analyzed using the questionnaire report. After evaluating the compliance with the national guideline in each management stage and whether appropriate treatment methods were applied for each SMW type, the throughputs at each stage and for SMW types were calculated and then the amount of SMWs incorrectly treated for each type of waste in 12 HCFs has been estimated. In this study, the current management practices in Bujumbura was compared with other countries.

3.3.3. Rapid risk assessment

RRA was developed to manage acute public health events by reducing or preventing diseases in affected peoples (WHO, 2012). It is similar to preliminary hazard analysis that evaluates the safety of the system using hazard risk matrix and thus can be applied to assess the overall safety of SMW management system from generation to storage in 12 HCFs (Vincoli, 2014). RRA has three steps to characterize risks such as hazard, exposure, and context assessments (WHO, 2012). Hazard assessment identifies hazards from each type of SMW, exposure assessment is the evaluation of the exposure of people and environment to identified hazardous SMW, and context assessment evaluates the environment that the risk events occurred such as weather, the health status of the population, and infrastructure related to SMW management in this study. Finally, risk matrix that contains estimates of the likelihood and consequences can be used for characterizing four levels of risks: low risk, moderate risk, high risk and very high risk that require different levels of management responses. According to RRA guidelines of WHO, likelihoods are defined as 5 levels based on their levels such as almost certain (5) (is expected to occur in most circumstances), highly likely (4) (will probably occur in most circumstances, likely (3) (will occur some of the time), unlikely (2) (could occur some of the time) and very unlikely (1) (could occur under exceptional circumstances). The consequences are also defined as 5 levels based on their degree of severity such as minimal (1), minor (2), moderate (3), major (4) and severe (5) (Figure 3-8) (WHO, 2012). The known hazards of SMW of 12 HCFs as well as current management practices obtained from this study from generation to final disposal were used to estimate likelihood and consequences in the risk matrix (Figure 3-9). In this study, it was applied for SMW management from generation to transportation at storage. In addition, it was applied for the final disposal in Bujumbura based on the comparison between the guidelines related to the final treatment methods as recommended by WHO and current final treatment methods used in Bujumbura.

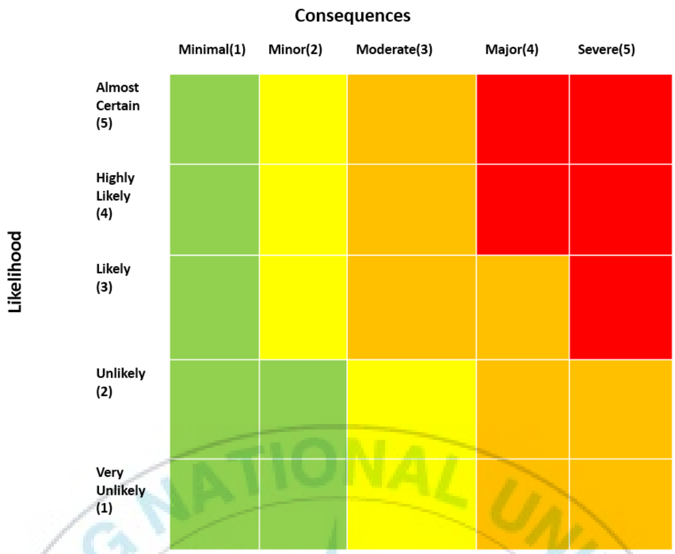


Figure 3- 9. Risk matrix of treatment methods, and peoples involved during final disposal of SMW in 12 HCFs. Red, orange, yellow and green colors indicate very high risk, high risk, moderate risk, and low risk, respectively(WHO,2012)

3.4. Results and Discussion

3.4.1. Comparison of WHO guidelines and Burundi national guidelines

Table 3-4 shows the comparison between WHO guidelines and Burundi national guidelines. In the first part (inside the facilities), the separation step was completely followed in Burundi guidelines. For collection phase inside of the facility, Burundi guidelines consider one item on three items suggested by WHO recommendation. For the second part related to the outside of the facility, the items for each phase developed in WHO guidelines are followed by Burundi guidelines in the following situation: transport of wastes at interim storage: 0 on 1 item, interim storage in the department: no item followed, on-site transport: 2 on 7 items, central storage: 6 on 15 items, off-site transport: 1 on 6 items (Table 3-4). This shows that Burundi national guidelines were not established completely, as WHO have suggested. It could impact negatively the management practices of SMW in Burundi all the more the classification system is not well established and the waste workers are not trained for ensuring the proper SMW management. For improving the management practices, it is important to Burundi government to revise the guidelines accordance to WHO by including all items of different phases from separation inside of facility to off-transport.

The comparison between WHO guidelines and Burundi national guidelines for final disposal are presented in Table 3-5. The results show that Burundi does not have the guidelines for final disposal as recommended by WHO (incineration method with high temperature and air control pollution and controlled landfill). The exception is observed for organic pit recommended by WHO as alternative method after incineration method (WHO, 2014). This demonstrates that the wastes could be improperly treated in all HCFs. Therefore, the risks could be high to the people and environment involved during the final disposal. Burundi government should revise the guidelines from generation to transportation at final disposal and establish the guidelines related to the final disposal as recommended by WHO.

Table 3- 4. Comparison of WHO guidelines and Burundi national guidelines from generation to transportation at final disposal (MOH,2008; WHO,2014)

Location	Different steps	WHO guidelines	Burundi guidelines
1.Inside the facilities			
	Separation	1. Containers or bags colored	A1: Coding system exist on small containers
		2. Containers or bags coded	A2: Color identification exist on small containers
		3.Containers or bags with the symbol	A3: Small containers are arranged according to SMW classification.
	Collection	1. Waste bags and containers labeled (date, type of waste and point of generation)	B1: Small containers covered and arranged
		2.Replacement bags or containers available at each waste-collection location	No guideline
		3. Respect the time of collection (infectious wastes: mid-morning after cares, general wastes: after visitors have departed).	No guideline
	Measurement	1. Weight routinely recorded	C: Measurement is effected before transportation.

2.Outside the facility	Transportation at interim storage in the department	1. Using of trolley protected	No guideline
	Interim storage in the medical departments	1.Utility rooms not available (protected)	No guideline
		2.Container closed and clearly labeled and preferably lockable	No guideline
	On-site transport of waste	1. To respect the set routes in HCF	No guideline
		2.Regular transport routes and collection times	D2: The schedule is respected during transportation
		3. Transport staff with adequate personal protective equipment (gloves, strong and closed shoes, overalls and masks).	F3: Waste workers protected.
		4.Waste transportation trolleys for general waste painted (black and labeled "general waste")	No guideline

	5.Separation of infectious waste and sharps with appropriate code and color (yellow), and labeled "infectious wastes"	No guideline
	6. Hazardous waste (Chemical and pharmaceutical wastes) transported separately in boxes to central storage sites.	No guideline
	7. Wheeled trolleys or carts labeled, dedicated to a particular waste type, secured with a lock, and easy to push and pull.	D1: The wheelbarrows are covered during transportation to the storage area or F2: Wheelbarrow covered
Central storage	1. Area cleaned and disinfected	No guideline
	2.Separation of infectious wastes and general wastes	E1: Separation of sharps and other types
	3.Easy access for staff in charge of handling the waste	No guideline
	4.Unauthorized persons	E6: Storage area is constructed.
	5.Easy access for waste-collection vehicles	No guideline
	6.Protected against the sun	E5: Storage area is protected and roofed.
	7.Inaccessible to animals, birds, and insects	No guideline

	8. Not being situated in the proximity of fresh food stores and food preparation areas	No guideline
	9.Have a supply of cleaning equipment, protective clothing and waste bags or containers located conveniently close to the storage area	No guideline
	10. Be cleaned regularly (at least once per week)	No guideline
	11.Soap used by waste workers for washing	No guideline
	12. Be appropriate to the volumes of waste generated from each health-care facility	E2: The containers of big size exist in the storage area
	13.The existing of symbol	No guideline
	14. The temperature preferably no higher than 3 ℃ to 8 ℃	E3: The temperature (3-8^0c) is respected on storage.
	15.Storage times for infectious waste (temperate climate: 72 hours in winter, 48 hours in summer; warm climate: 48 hours during the cool season, 24 hours during the hot season)	E4: Storage duration under 5 days is respected during storage.
	1.Drivers of trucks trained about SMWs regulation, classification, risks, and labeling	No guideline

	2.The vehicle transporting hazardous waste roadworthy (secure, wastes protected)	F1: Truck protected
Off-site transport	3.The vehicle transporting hazardous waste labeled (symbol)	No guideline
	4. Drivers protected	No guideline
	5.SMWs proper separated inside the truck	No guideline
	6. Consignment note for a vehicle (waste classification, waste sources, pick-up date or regular transport, destination, driver name, number of containers or volume, receipt of load, received from the responsible person at pick-up areas).	F4: Regular transport Not totally followed

Table 3- 5. Comparison of WHO guidelines and Burundi national guidelines of final treatment (MOH, 2008; WHO, 2014)

Type of treatment methods	WHO guidelines	Burundi guidelines
1.Incineration method		
	1.Separation of wastes	No guideline used
	2.Capacity (destruction rate of wastes)	No guideline used
	Temperatures: a. Primary chamber (540 to 980^{0}C) b. Secondary chamber (980 to 1100^{0}C)	No guideline used
	3.Gas entering air pollution control devices (230^{0}C)	No guideline used
	4.Air flows (total combustion air: 140-200% excess)	No guideline used
	5.Control and monitoring (T and many other parameters)	No guideline used
	6.Waste destruction efficiency	No guideline used
	7.Enclosure (roof)	No guideline used
	8.Chimney (height: 4-5 m)	No guideline used
	9.Pollution control equipment	No guideline used
	10.Location (500 to 750 m) and far to the households	No guideline used
2. Controlled landfill		
	1.The distance separating the area and households	No guideline used
	2.Barriers against pollution of the environment (Geological barrier, bottom liner system, landfill body, surface liner system, landfill operation, leachate collection system, gas collection system, collection of surface water, enclosure, monitoring)	No guideline used
	3.Landfill operation (definition of	No guideline used

	waste admitted to disposal, entrance control, pre-treatment, rotting-procedure)	
	4.Monitoring of landfill (objectives and responsibilities, monitoring practice)	No guideline used
	5.Used for treating the general wastes	No guideline used
3.Organic pit		
	1.Location of organic pit:	
	a. As far away as possible from publicly accessible areas and from hygienically critical areas	Followed
	b. Far enough from other buildings and public areas to avoid problems from odors	Not followed
	c. A secure location that non authorized people and animals	Not followed
	2. Organic pit constructed based on the local soil and groundwater)	Followed
	3. It used only for pathological waste and biodegradable organic waste	Followed
	4. Ash, charcoal or lime may also be added to reduce odors.	Followed
	5. Make a drainage channel around the pit to prevent runoff water from entering and to protect the walls of the pit	Not followed
	6. The pipe should be at least 2 m high	Not followed
	7. The area should be protected and roofed	Not followed
	8. Maintenance and monitoring are required	Not followed

3.4.2. Solid medical waste management

The operations related to the SMW in HCF are organized according to the steps of practice from generation to final disposal. Moreover, the improvement of management practice should take account of the tasks, responsibilities and resources such financial and people involved in SMW management practice process at different levels. Head of HCF composed by the administrative staffs and the committee in charge of monitoring and assessment of medical wastes management is in charge of all materials required for medical waste management inside and outside of HCFs, as well as their monitoring. Current staffs (doctors and nurses) are in charge of the assessment of medical wastes at source based on their separation and collection, and to raise awareness the waste workers on the importance related to the proper medical wastes management (WHO, 2014). The companies (public or private) are in charge of transportation of medical wastes at the final disposal. Table 3-6 gives the details related to the different group of people involved in SMW management according to the steps of the management plan of SMW in Bujumbura-Burundi.

Table 3- 6. Current practice steps and their stakeholders in HCF (MOH, 2011)

Current practice steps	People in charge of manage
Separation, collection, and measurement	Head of HCF, doctors, nurses and waste workers
Transportation to storage	Head of HCF and waste workers
Storage	Head of HCF, and waste workers
On-site transportation	Head of HCF and waste workers
Off-site transportation	Head of HCF and waste workers
On-site treatment	Head of HCF and waste workers
Off-site treatment	Head of HCF, private company and waste cleaners

3.4.3. Management practices from generation to the transportation at final treatment

3.4.3.1. Separation, collection, inside transport of SMW and storage

Figure 3-10 gives the details related to the current management practices from inside of facility (services) to the storage area in 12 HCFs. Based on the current situation, no HCFs followed the national guideline steps completely. For the proper separation steps (A1, A2, and A3), 58% of HCFs used the coded containers and 50% of HCFs used specific colored containers, while only 25% HCF separated SMW following the national guidelines. For the safe collection step (B1 and B2), 7 of 12

HCFs (58%) did not follow the guideline. These results show that no public HCFs followed the separation steps properly (A1, A2, A3) and only one public HCF followed the guidelines in the collection safety step (B1, B2). Because 93.9% of patients used public HCFs during the period of 2011~2014, patients and current staffs (doctors and nurses), as well as workers in public HCFs, might have been exposed to SMW during SMW management in the services. The studies developed in Pakistan and Mongolia showed that HCFs do not have a uniform protocol for waste separation and collection system (Ali et al., 2009). The measurement of SMW (C) was conducted without considering the national guidelines in all 12 HCFs. Even though separation is the most important step to control all subsequent SMW management, no HCFs properly separated SMW generated in their services. For example, radioactive wastes were mixed and treated together with chemical wastes. Lack of budget for SMW management in services and indifference of hospital officials were the main reasons why safe and proper collection and separation failed (Joseph and Nina, 2010).

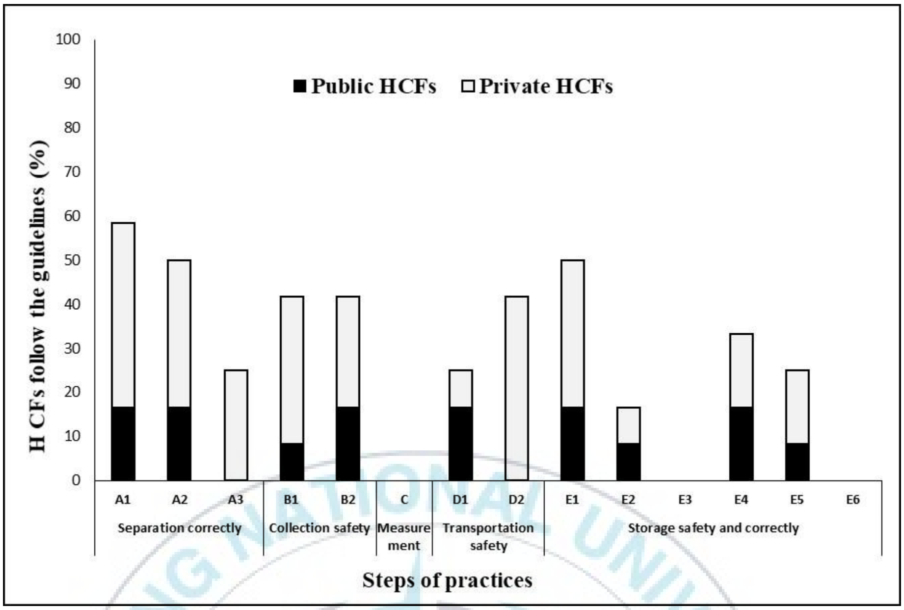


Figure 3- 10. Compliance status of national guidelines during HSMW management steps

The daily checklist can help to improve these waste management steps. Most SMW workers were illiterate and not trained how to treat SMW safely, so poor HSMW management practices, as well as exposure to hazardous materials during practice, could increase. During transportation safety steps (D1 and D2), only three HCFs (25%) used covered wheelbarrows and five HCFs (42%) transported SMW according to the national guidelines. Two public HFCs used wheelbarrows but no public HCFs transported to a storage area as scheduled. The results are similar to an earlier study where wheelbarrows without covers were used by most HCFs

(Joshua et al., 2014). Many HCFs did not follow the guidelines after SMW were transported outside of the services to a storage area in HCFs, therefore, the waste workers could be exposed to contaminated wastes during transport. Half of the HCFs separated sharps and other types of hazardous SMW in the storage area, but only two HCFs have containers large enough for all types of hazardous SMW. Therefore, SMW could be mixed, overflow from the container or cross-contaminate other SMW in the storage area. Storage conditions were worse than the other management steps. The national guideline suggests a storage temperature of 3 to 8 ℃ and a duration of fewer than 5 days. No HCFs, however, maintained the recommended temperature in the storage areas, and only four HCFs followed the guidelines for storage duration. This led to the decomposition of SMW in the storage area, causing odor problems and creating an environment for the potential spreading of disease-causing germs. Only 25% of HCFs had protected and roofed storage areas, but no HCFs constructed storage areas following the national guidelines. If the storage area is not protected, SMW can have negative effects on neighboring people and environment. Hazardous constituents are likely to enter the surrounding area including groundwater, especially during the rainy season, and animals, as well as people, can easily access infectious or toxic wastes. Infectious diseases can be carried by vectors such as rats, flies, and cockroaches (Meerburg and Kijlstra, 2007; WHO, 2014). The results of the study carried out in Botswana showed that public HCFs did not have any adequate temporary storage areas and infectious waste and non-infectious waste were often mixed together at temporary storage area, and the central storage in HCFs was not protected and fenced (Mmereki et al., 2017).

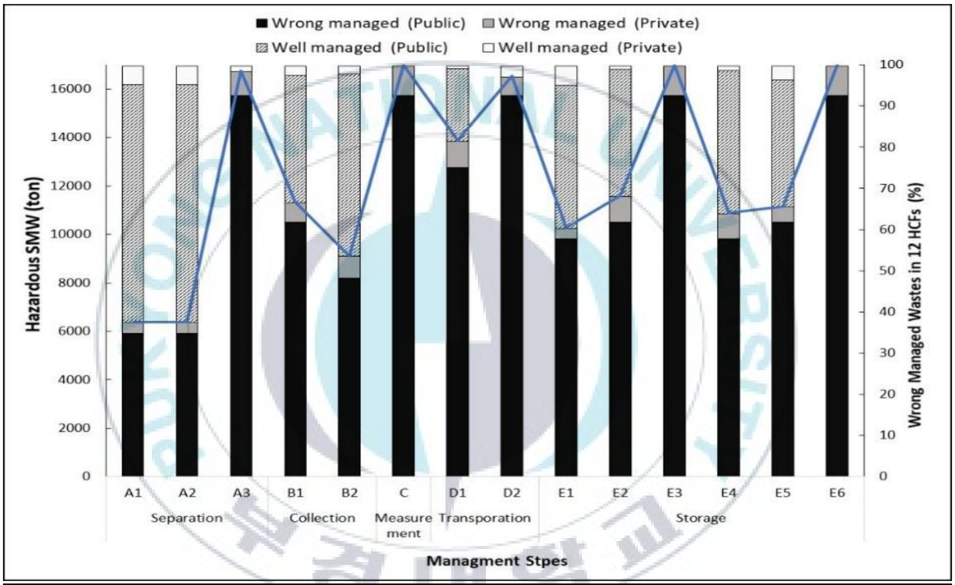


Figure 3- 11. Quantity of hazardous SMW in 12 health care facilities according to national guidelines

Figure 3-11 shows the amount of properly or incorrectly managed SMW by the 12 HCFs, according to the national guidelines from generation to storage. The data were calculated using generation data of 12 HCFs and compliance status of the national guidelines. 98.6 % of SMW were not separated in accordance with the SMW classification (A3) and only 1.47% of SMW that were from one private HCF followed the guideline during A3. Lack of funds to purchase the containers intended for the collection of wastes inside of HCFs was the limiting the effectiveness of the waste segregation and collection system (Mmereki et al., 2017). Of 16958.8 tons of SMW, 11310.8 tons were not collected safely (B1) and workers were exposed to 9080.2 tons during the separation and collection steps (B2). This indicates that among the steps taken inside the services of the HCFs, separation and collection steps need to be improved more than safety steps. During on-site transportation to the storage area, 13845.4 and 16508.3 tons of SMW were treated without following the guidelines for safety and the schedule, respectively. Storage of SMW is the least well managed in Bujumbura. No HCFs has constructed a storage area as directed by the national guidelines (E6), and all SMW were stored without controlled temperature (E3). This may lead to multiplication and spreading of pathogens in infectious wastes. A total of 11131.8 tons of SMW were stored in the storage areas without a fence or roofing, increasing the health risk from SMW on people and biota in and nearby HCFs.

In conclusion, there was no HCF that followed the national guidelines completely and all SMW were mismanaged at least one of the suggested management steps. This means that patients and medical workers, as well as SMW workers and surrounding neighbors, could be exposed to SMW directly or indirectly. People in the public HCFs are more susceptible to the mismanaged SMW. Polluted groundwater can also contaminate rivers or lakes, causing health problems for people or animals using them as water sources (Wallender et al., 2014).

3.4.3.2. Current practices of SMW from Storage to Final Disposal in 12 HCFs

Figure 3-12 presents the current management practices for transportation and final treatment of SMW in 12 HCFs in Bujumbura, Burundi. During practices, SMW can be disposed at the designated place at on-site facilities or should be transported to off-site treatment facilities. The regular collection of wastes using closed or covered transport equipment and waste handlers should be safely protected are important for avoiding the risk related to improper SMW management (WHO, 2014). The waste materials were transported from storage areas to either on-site disposal facilities by wheelbarrows or off-site disposal sites by trucks in 12 HCFs. Table 3-7 shows treatment methods and transportation equipment for each type of SMW currently used in 12 HCFs in Bujumbura, Burundi.

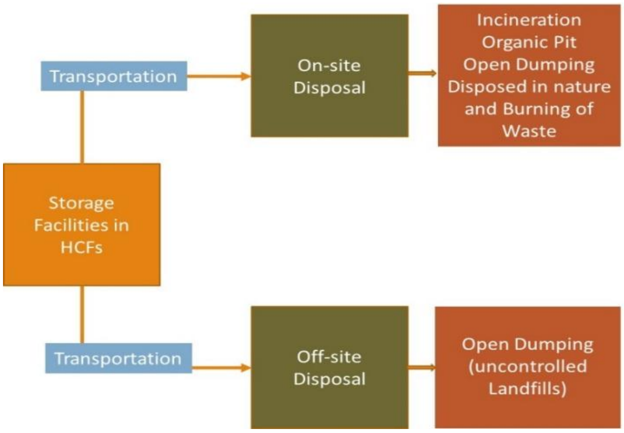


Figure 3- 12. Current practices of SMW management in 12 HCFs from storage to Final treatment in Bujumbura, Burundi

Table 3- 7. Transportation and final disposal methods used in 12 HCFs in Bujumbura, Burundi

SMW type in Burundi	Transportation equipment and location	Treatment method
Medical Sharps	On-site by wheelbarrow	Incineration
Infectious waste	On-site by wheelbarrow	Incineration
Pathological wastes	On-site by wheelbarrow	Organic pit
Pharmaceutical waste and discarded medical plastics	On-site by wheelbarrow or off-site by truck	Open dumping, disposed of in nature, uncontrolled landfill
Chemical waste and radioactive waste	On-site by wheelbarrow	Incineration
Absorbent cotton	On-site by wheelbarrow	Incineration
Placenta	On-site by wheelbarrow	Organic pit

Figure 3- 13. Compliance status of national guidelines during SMW transport steps in Bujumbura, Burundi

Figure3-13 presents the current practices and the amount of wastes not properly handled during the transportation process. Pharmaceutical wastes and disposable medical plastics have been reported to dispose at on-site dumping sites or off-site uncontrolled landfills. However, since it is not known for some HCFs how much SMW are disposed of inside HCFs, this study assumed that all pharmaceutical wastes and disused medical plastics are disposed of at off-site landfills and transported using trucks. The results showed that most of the trucks used for transportation of 70.8 % (3,292.2 ton) of pharmaceutical wastes and discarded medical plastics from storage areas to off-site uncontrolled landfills were not properly protected (Figure3-12). People could be potentially exposed to those wastes if they contain any cytotoxic or infectious wastes by inappropriate separation.

Other SMWs treated by on-site incinerators or organic pits were transported using wheelbarrows. However, 75% of HCFs used uncovered wheelbarrows and 7,850.1 tons of SMW were not transported appropriately. During on-site SMW transportation, waste workers in 67% of HCFs that are 92 out of 130 workers were not safely protected during 2011-2014. Because SMW can be infectious, radioactive or toxic, not only workers but also the staff members in HCFs are potentially exposed to them during normal work or by accidental hazards. Waste handlers are more exposed to potential risks associated with other diseases through direct contact (Jang, 2011). The safety status of the SMW transport stage in other developing countries is similar to that in Burundi. Transportation of stored SMW to final disposal sites is irregular and transportation vehicles pass through residential areas without a cover in Libya (Sawalem et al., 2009). Guidelines of off-site transportation, during which SMW is most likely to be exposed to the environment and humans, are not being followed properly in Uganda and Cameroon (Dzekasha et al., 2016; Muhwezi et al., 2014). There are no relevant national policies and guidelines, and even transportation equipment is in very poor conditions, leading to a high possibility of exposure to the people during transportation (Awodele et al., 2016). Another problem during the transportation process is that SMW can be transported together with general wastes. Developing countries in Asia, such as Cambodia and Myanmar, also share the problem because the same transportation vehicles and equipment are used for both general wastes and SMW (Ananth et al., 2010).

Another problem with SMW transportation is that the SMW in the storage area is not transported on a regular basis. If the SMW is not removed regularly and stored beyond a period recommended by the guideline, the waste may decompose and produce an unwanted odor or cross-contaminate through the mixing of wastes due to lack of space especially during the hot season (WHO, 2014). Current vehicles used in Bujumbura, Burundi, to transport SMW can increase the health and environmental risks because they lack necessary safety measures. In this study, however, only HCF1 transported SMW from the storage area to the final disposal site regularly. Approximately 69.1% (11,724 ton) of SMW was placed in the storage area for longer than the recommended period in the guideline (Figure3-10). Since Burundi's waste storage facilities are constructed without enough safety measures implemented, secondary contamination by the waste is also an issue of concern.

Improvement of the transportation system of SMW in HCFs is important. Safe transport of SMW inside HCFs is the responsibility of the facilities. Proper equipment needs to be supplemented. Because unsafe transportation of SMW results from lack of understanding of the current guideline, the current guideline should be revised in such a way that all the personnel involved in the transportation process can easily understand the proper procedure and a better training program for workers needs to be implemented. Although it is essential to strengthen the internal waste management for regular SMW transfer, consideration should also be given to the outsourcing of SMW transport for off-site treatment. In some countries such as Iran and South Africa, off-site transportation is carried out by municipalities (Askarian et al., 2004; Abu-Awwad, 2008).

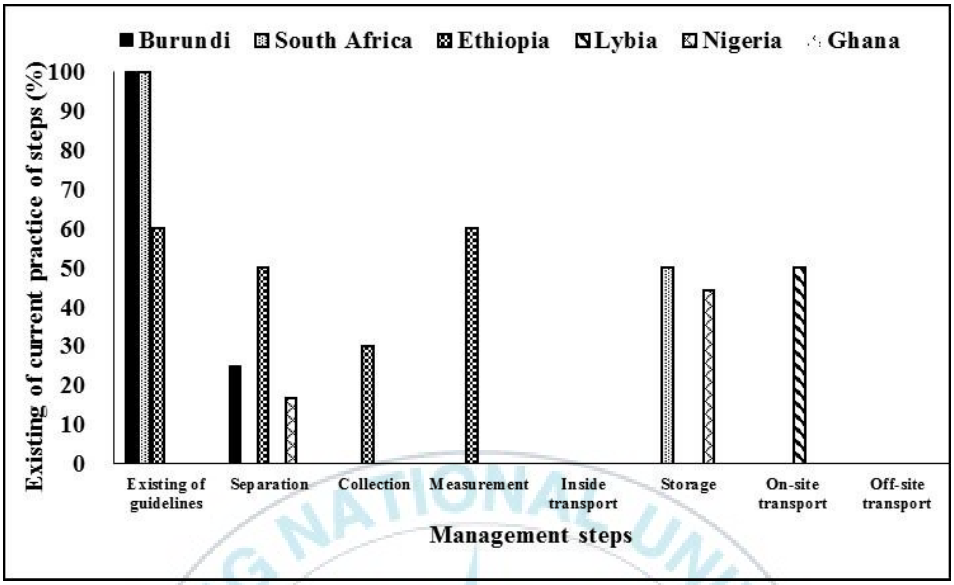


Figure 3- 14.Comparison of management practices from separation to final disposal between Burundi and other African countries

The comparison of management practices from separation to final disposal between Burundi and other African countries is presented in Figure 3-14. SMW management practices in other African countries are almost similar to Burundi. The Figure shows the Exception for Burundi, South Africa, and Ethiopia where the existing guidelines from generation to transportation at final disposal that have been respected during practices for 100%, 100 %, and 60%, respectively in HCFs selected in the studies. However, Lybia, Nigeria, and Ghana do not have guidelines in all HCFs selected in the studies (Abugri, 2014; Asante et al., 2014; Longe and Williams, 2006; Nemathanga et al., 2008; Sawalem et al., 2009; Tadesse and Kumie, 2014). Among 12 HCFs assessed in Burundi, three (25%) have followed the proper separation at source of separation. The similar situation was developed in Ethiopia for 50% of HCFs and Nigeria for 17% (8) HCFs. It was explained in these studies that the main issue was the fact that most of the waste workers were not trained and the lack of a proper management system and budget (Longe and Williams, 2006, MOH, 2014). The same explanation could be shared by Burundi (Joseph and Nina, 2010). In another hand, the separation was not conducted in all HCFs selected in South Africa, Lybia and Ghana (Abugri, 2014; Asante et al., 2014; Sawalem et al., 2009; Tadesse and Kumie, 2014).

Except, 30% among 10HCFs of Ethiopia that have followed the collection system, Burundi and other four countries did not follow the proper collection at source based on their types. The measurement was conducted only by 60% of HCFs of Ethiopia among the six countries including Burundi. Even if the storage of waste was beyond of the period required for four HCFs, Ethiopia, 50% (5) HCFs and 44% (23) HCFs of Nigeria have stored safely the wastes in a temporal storage area that respected the engineering condition among six countries (Tadesse and Kumie, 2014). Except, 50% HCFs of Lybia, the rest of countries share the same situation related to the improper of SMW during their transportation at temporal storage area, and on-site and off-site. This shows that the current management practice steps from separation at final disposal (on-site and off-site) in all five countries were almost similar with Burundi, except for some steps such as separation, collection, measurement that were followed partially in Ethiopia. In general, based on the results developed (Figure 3-12), the storage and on-site transport were followed in South Africa and Nigeria compare to Burundi. For achieving the goal of proper management of SMW, Burundi government should set up the guidelines and help all HCFs in the process of SMW management practices steps, from generation to final disposal as recommended by WHO (WHO,2014).

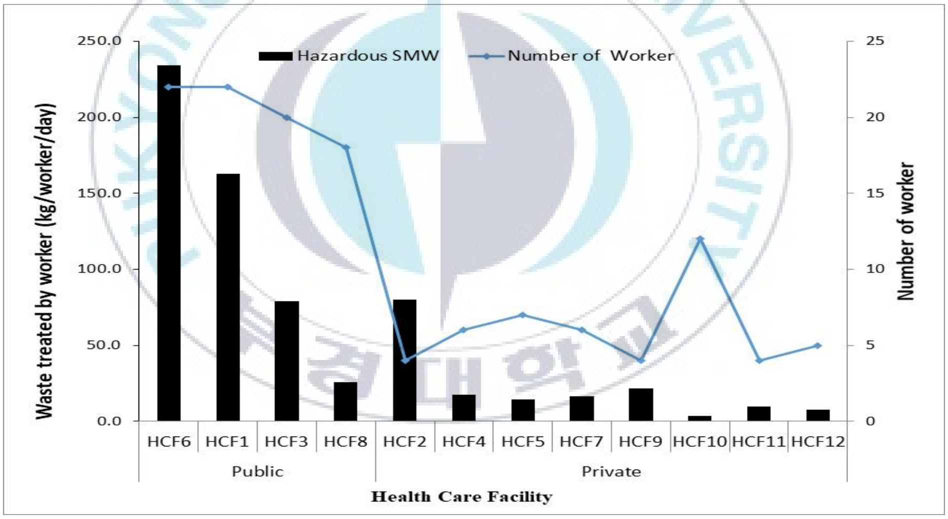


Figure 3- 15. Number of waste workers and the amount of hazardous SMW by each worker per day

Figure 3-15 shows the number of waste workers and the quantity of SMW managed per worker per year. On average more people were involved in the SMW management in the public HCFs than private ones, with 20.5±1.9 workers for the public and 6.0±2.7 workers for the private. The amount of SMW handled by each worker was also higher in public HCFs. Waste workers in HCF6 handled the most SMW at 234.1 kg.worker-^{1}.day-^{1}. The number of workers in public HCFs were 3.4 times more, but the amounts of SMW that were treated by a worker are, on average, 5.9 times larger. Two exceptions were found in HCF 8 and HCF 10, however. Although HCF 8 is public, the military clinic has the smallest amount of SMW per worker (25.9 kg. worker-^{1}.day-^{1}), similar to other private HCFs (21.4 kg. worker-^{1}.day-^{1}). Among the private HCFs, HCF 10 had the highest number of workers and the lowest amount of SMW to handle (3.6 kg. worker-^{1}.day-^{1}).

The above results suggest that the number of waste workers in the public HCFs should be increased first. When most of the SMW is mismanaged, workers' exposure to SMW will increase and safety problems could become worse if the amount of SMW treated by a worker is greater. A study conducted by Abu-Awwad (2008) on medical waste management in public health care centers and private clinics in Palestine showed that the number of waste workers was not proportional to wastes generated by the HCFs. This is due to a lack of budget for the payment of waste workers, and there is no policy specifying the number of waste workers required in HCFs. Therefore, the Burundi government should establish a guideline that can help HCFs determine appropriate numbers of waste workers required based on types and quantities of SMW, specific management steps, and financial and personnel capacity of each HCF with minimum workers clearly specified in any circumstance.

3.4.3.3. Current management steps in Twelve HCFs of Bujumbura

The current management practice steps related to the national guidelines for each HCF is presented in Figure 3-16. Among all HCFs, three private HCFs (2, 9 and 11) presenting 651,286kg (3.81%) have followed completely the separation steps (three steps) inside of the facility. Two steps on three were followed in 2 public HCFs (3 and 6), and 2 private HCFs (10 and 12). However, 2 public HCFs (1and 8) and 3 private HCFs (4, 5 and 7) have failed to follow these three steps. Because 9 HCFs with 16,307,461kg (96.15%) failed the proper separation, this could impact negatively the rest of management practices. This current situation orients how Burundi government should focus first on the separation of wastes at the point of generation. Collection steps (2) were totally followed by one public HCF (1) among 12 HCFs and one step among two was respected by 6 private HCFs (4, 5, 7,9,11 and 12). Three public HCFs (3, 6 and 8) and two private HCFs (2 and 10) have failed completely the collection system.

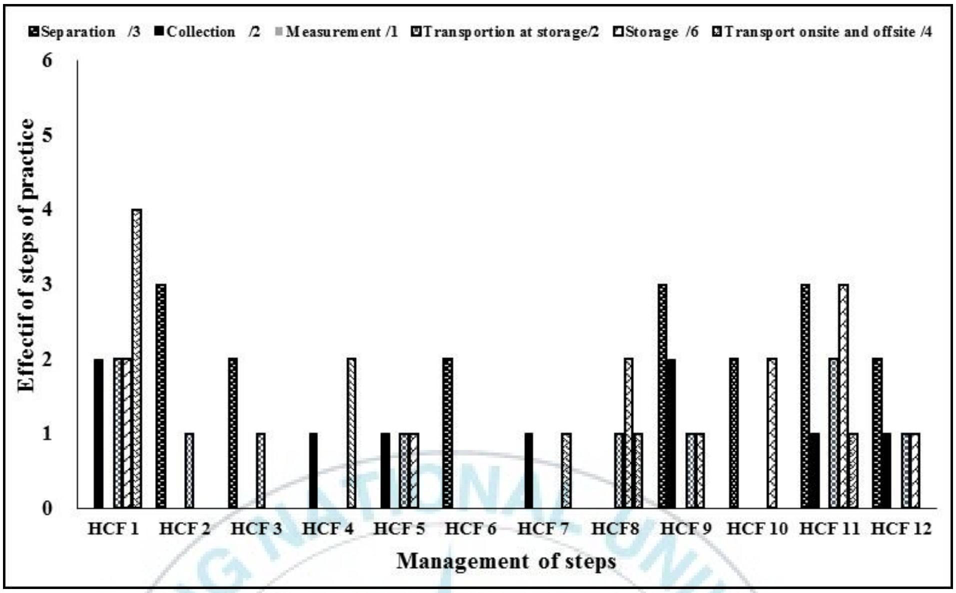


Figure 3- 16.Current management practice steps in twelve HCFs according to guidelines

Therefore, a large quantity of wastes was wrong collected during this study with 10,628,427kg (62.67%). The germs of different diseases could affect easily the medical staffs (doctors and nurses), waste workers, and patients in 11 HCFs. The measurement was not followed in all 12 HCFs of Bujumbura. Transportation at storage area steps (2) was followed completely by one public and one private HCF (1 and 11). All HCFs were assessed for storage management practice steps (6 steps) in the following situation: private HCF (11) with 3steps, public HCFs (1 and 8) and private HCF (10) with two steps, and private HCFs (9 and 12) for one step. However, the half of HCFs have failed to follow all six steps. Four steps related to the transportation from storage at on-site and off-site were completely followed by one public HCF (1). Two public HCFs (3 and 6) and 5 private HCFs (2, 5,9,10 and 12) failed completely to follow all steps related to the off-site transportation. In conclusion, no HCF have followed completely all steps from generation to transportation at different sites of final disposal. It is important for the Burundi government to improve the management practice, especially in the public HCFs, in reason of their high generation quantity, by emphasizing firstly on the separation and storage steps.

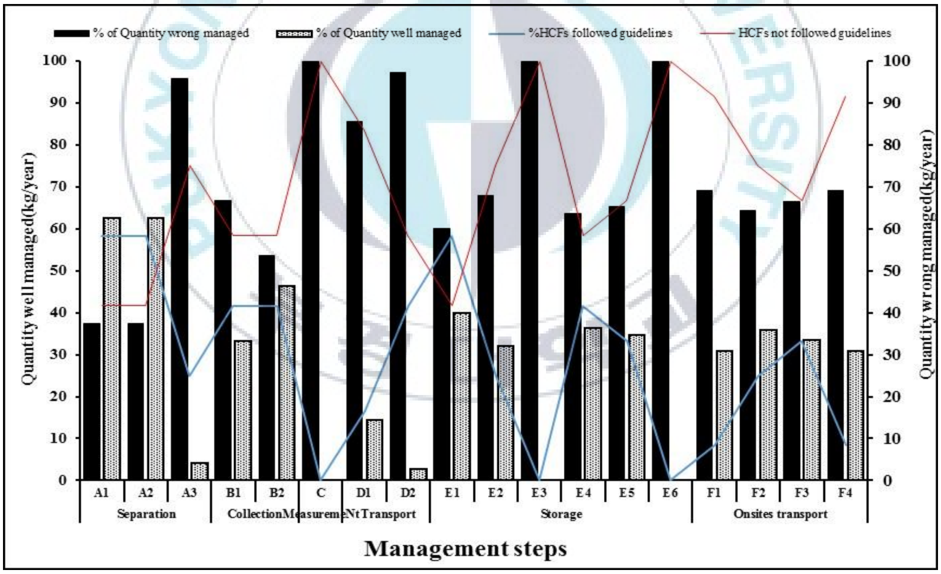


Figure 3- 17. Yearly quantity wrong and well managed by 12 HCFs for each step of practice from generation to transportation at onsite and offsite

The yearly quantity wrong and well managed by 12 HCFs for each step of practice from generation to transportation at on-site and off-site is presented in Figure 3-17. 1,591 tons (37.5%) and 1,591tons (37.5%) were wrong managed for separation A1 and A2 steps, respectively. 4,062 tons (95.8%) were wrong managed for separation A3 step. 2,827 tons (66.7%) and 2,272 tons (53.6%) were wrong managed for collection B1 and B2 steps. The worst, all quantity of wastes generated in all HCFs 4,239,687 kg (100%) was wrong measured. 3,631 tons (85.6%) and 4,127 tons (97.3%) were wrong managed for transportation steps D1 and D2. 2,545 tons (60.02%), 2,877 tons (67.8%), 2,699 tons (63.6%), and 2,767 tons (65.2%) were wrong managed for storage steps E1, E2, E4, and E5, respectively. All quantity 4,239 tons (100%) were wrong managed for E3 and E6 steps. 2,931 tons (69.1%), 2,724 tons (64.2%), 2,824 tons (66.6%) and 2,931 tons (69.1%) were wrong managed for the transport of wastes at different sites in the following steps: F1, F2, F3 and F4, respectively. Moreover, all quantity of wastes were improperly managed for A3, C, E3, E6, D1, and D2 steps. This figure gives the details of the amount of wastes improper managed inside and outside of facilities. The results can orient Burundi government in collaborating with HCFs how the SMW management practices should be improved based on the steps that presenting a large amount of wastes compare others, especially the separation at source (inside of facilities).

3.4.4. Rapid risk assessment of solid medical wastes from generation to transportation at final disposal

The types of exposure and their levels referring to the practical steps of SMW management practices from generation to final disposal, and final treatment are illustrated in Table 3-8.

Table 3- 8. Types of exposure and levels referring to the management practice steps of SMW

Location	Practice steps	Exposure	Levels
Inside of the facility	1.Separation and collection	(a): Current staffs, waste workers and patients (b): Current visitors and neighbors	(a): Almost certain (5) (b): Likely (3)
Outside of the facility	1.Transportation of wastes from generation to storage	(a): Waste workers ;(b): Patients and current visitors	(a): Almost certain (5) (b): Likely (3)
	Storage of wastes	(a): Waste workers ;(b): Nearby resident	(a): Almost certain (5) (b): Likely (3)
	2.Transportation of wastes from storage to final disposal	-At on-site: (a): Waste workers; (b): Patients, visitors, current staffs -At off-site: (a): Waste workers and drivers of trucks (b): Environment, people on the road.	At on-site: (a): Almost certain (5) (b): Unlikely (2) -At off-site: (a): Almost certain (5) (b): Unlikely (2)
	Final treatment		
	1.Incineration	(a): Waste workers ; (b): Environment (air); (c): Nearby resident; (d): Groundwater, animals, insects, birds, soil, nearby water source, chain food, visitors, current staffs, patients	(a): Almost certain (5) (b): High likely (4) (c): Likely (3) (d): Unlikely(2)

2.Organic pit	(a): Groundwater, soil, surrounding environment (b): Waste workers, nearby resident, patients, current staffs, and visitors	(c): Likely (3) (d): Unlikely(2)
3.Open dumping (On-site)	(a): Waste workers, animals, scavengers, insects, birds, and the environment (air, soil, underground water, water source) (b): Current staffs and patients; (c): Current visitors, nearby resident	(a): High likely (4) (b): Likely (3) (c): Unlikely(2)
4.Uncontrolled landfill (Off-site)	(a): Workers, animals, scavengers, insects, and birds, people entering inside. (b): Surrounding environment (air, soil, underground water, water source),	(a): Almost certain (5) (b): High likely (4)

(a) Rapid risk assessment of SMWs management practices from generation to storage

Presence of infectious agents, toxic chemicals, radioactivity, used sharps, or biologically aggressive pharmaceuticals in SMW can have serious health effects when people are exposed to them (WHO, 2014). Some studies classified the consequences of infectious wastes, sharps, and radioactive as severe and those of pharmaceuticals, chemicals, and human anatomical as major. Both levels of consequences indicate serious, fatal injury or death (Alwabr et al., 2017; Sefouhi et al., 2013). It is observed from Figures 3-10, 3-11, 3-16 and 3-17 that all HCFs failed to follow guidelines and most of SMWs were wrongly classified, mixed and cross-contaminated during management steps of A1, A2, A3, and E1. SMWs were unprotected during storage and transport both inside and outside of HCFs during management steps of B1, D1, E2, and E5. Workers were not properly protected and the amount of SMW handled per capita was high during management steps of B2 (Figure 3-15). Storage infrastructure and overall management of SMW were poor during the management steps of D2, E3, E4, and E6. Therefore, there is a high probability of exposure to SMW for staffs, patients, workers, visitors, and even nearby residents considering current management practices in 12 HCFs. It is hard to clearly tell the boundaries of likelihoods between people and SMWs involved, they can be at least likely, highly likely or almost certain as in other studies (Alwabr et al., 2017; Sefouhi et al., 2013).

Table 3- 9.Current management practices, problems, risks, exposure, current situation, and improvement based on RRA for SMWs management practices from generation to storage

Practice steps	Problems	Risks	Current situation	Improvement
Generation to storage	SMWs were mixed	The risks were related to the infectious agent, toxic chemicals, radioactivity, used sharps, cytotoxic or genotoxic chemicals composition, biologically aggressive pharmaceuticals, or radioactive substances, and chemical substances	1. Waste workers were not protected 2. Small containers were not covered 3. Wheelbarrows were not protected and covered 4. Wastes were not protected during the transportation 5. The schedule during transportation was not respected. 6. The temperature and storage duration were not respected, as well as the storage area was not constructed and covered.	1. Burundi government should revise first the classification system. 2. Proper materials are needed 3. The wastes should be separated from generation to storage. 4. Waste workers should be protected with appropriate equipment (mask, gloves, apron, and shoes). 5. The wastes should be transported using the wheelbarrow covered. 6. The temperature and storage duration should be respected 7. Storage should be constructed and protected, and respect the temperature. 8. The storage should be constructed taking into account of households and surrounding environment for avoiding the risk.

Figure 3-18 shows the risk matrix of both SMWs and people involved in the SMW management process from generation to storage. Currently, all SMWs and HCFs are at very high risks, and improving the overall management practices is essential to reducing risk. Reducing exposure through segregation and safe storage may reduce the risk to some extent, but they are still at high risk of the yellow region in Figure 3-18 (a). To control and reduce risk to a safe low level (green), it is necessary to use additional measures such as disinfection of infectious wastes and medical sharps and to implement safe and detailed guidelines for toxic chemicals and radioactive wastes.

As shown in Figure 3-18 (b), most people including staffs and neighbors are at very high or high-risk levels. Current staffs and workers who stay in the HCFs for a long time and directly handle SMW, as well as patients with poor health, can be classified as very high risk (red color or 5). Considering current poor SMW management practices, visitors and residents around HCFs were at least at high-risk level (orange or red or 4). Safe classification and segregation can reduce the risk to a certain extent but reduce it to low-risk level, there is a need for safe protection of staffs and workers, proper use of equipment, and investment of infrastructure for the safe storage system.

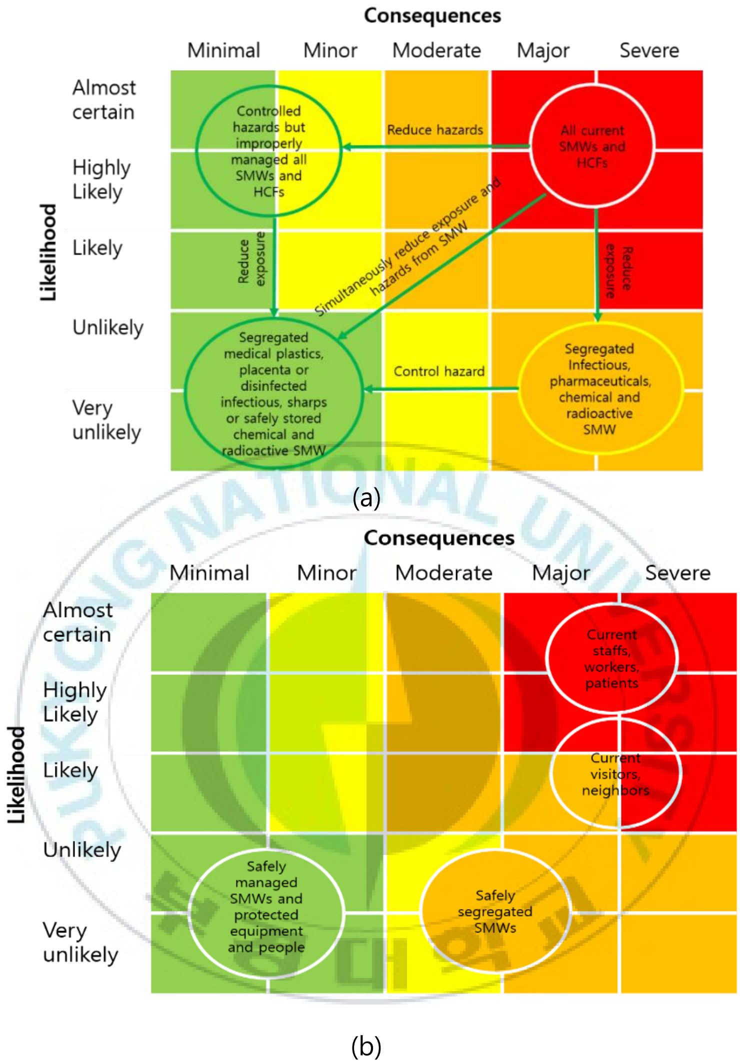


Figure 3- 18. Risk matrix of (a) SMW and HCFs, (b) peoples involved during SMW management in 12 HCFs. Red, orange, yellow and green colors indicate very high risk, high risk, moderate risk, and low risk, respectively

(b) Rapid risk assessment on SMWs transportation from storage to final disposal

When the SMW is not safely transported using adequate materials from storage to on-site and off-site, they can cause a high risk to all people and environment involved in all transport process (WHO, 2014). The results in this study have shown that the wheelbarrows and trucks were the main equipment used during the transport of wastes at on-site and off-site. Most of the trucks used for off-site transport of 70.8 % (3,292.2 ton) of pharmaceutical wastes and discarded medical plastics were not properly protected and 77.5% of HCFs used uncovered wheelbarrows for to transport 7,850.1 tons of SMW at on-site (Figure 3-13). The wastes were mixed from at source in the majority of HCFs (Figure 3-10). Except for one public HCF (1) followed completely the transportation phases, the rest of HCFs failed (Figure 3-16). The potential degree of exposure was high all the more the SMWs were transported after a long period of storage (Figures 3-10; 3-11).

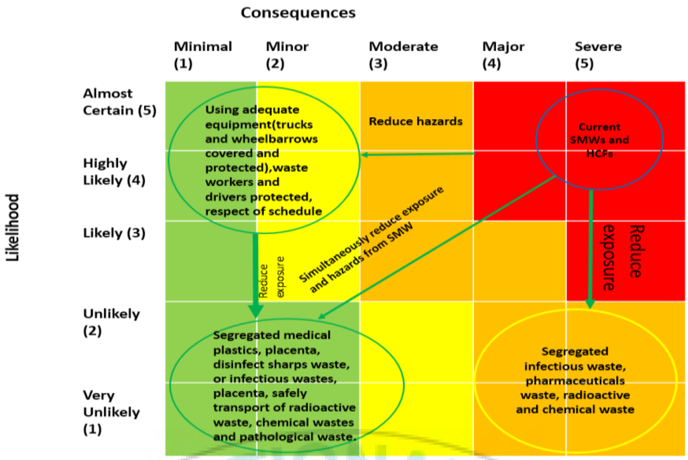
Table 3- 10.Current management practices, problems, risks, exposure, current situation, and improvement based on RRA for SMWs transportation from storage to final disposal

Practice steps	Problems	Risks	Current situation	Improvement
Transportation of SMWs from storage to final disposal	SMWs were mixed	The risks were related to the infectious agent, toxic chemicals, radioactivity, used sharps, cytotoxic or genotoxic chemicals composition, biologically aggressive pharmaceuticals, or radioactive substances, and chemical	1. Waste workers and drivers were not protected 2. Wheelbarrows and trucks were not protected and covered 3. The unsafe transportation of wastes at on-site and off-site (wastes not covered) could cause the deterioration of HCF environment and road by bad odor, fugitive	1. Burundi government should revise first the classification system. 2. The wastes should be separated from generation, storage, during transportation even at final disposal. 3. Waste workers and drivers of trucks should be protected with appropriate equipment (mask, gloves, apron, shoes) 4. The wastes should be transported using the wheelbarrows and trucks

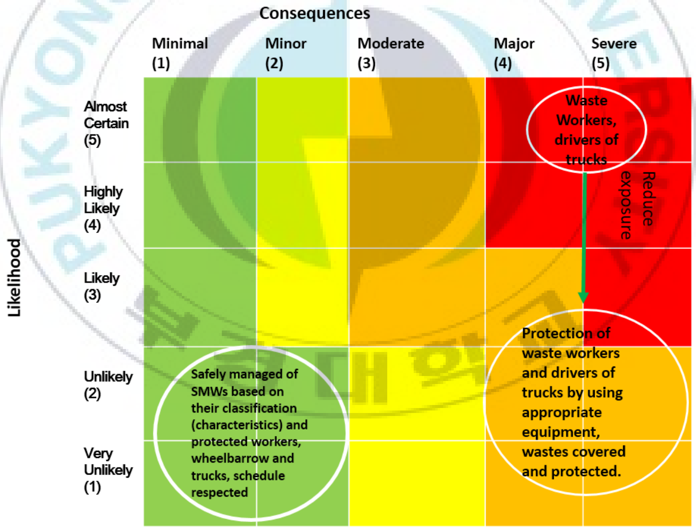
	substances	dust, and pest.	covered and protected regularly for avoiding the spreading of microorganisms through the air or the leaking outside into the road or surrounding environment.

The RRA showed that all SMWs and HCFs were at very high risks, and improving the overall management practices is essential to reducing risk in Figure 3-19(a). Proper separation is the key for reducing exposure during transportation of SMW from storage to on-site and off-site. In addition, it is important to use additional measures such as disinfection of infectious wastes and medical sharps and to implement safe transportation and detailed guidelines for toxic chemicals and radioactive wastes. At on-site, waste workers who are in the contact directly with SMW during all process of transportation at on-site were assessed to be highly exposed to the hazards with the likelihood of almost certain (5 or red color).

(Figure 3-19 (b)) shows that the nearby resident was assessed to be exposed to the hazards with the likelihood of likely (3 or red color, orange color), patients, visitors, and current staffs were assessed for the unlikely (2 or orange color). At off-site, waste workers and drivers of trucks were assessed to be highly exposed to the hazards with the likelihood of almost certain (5 or red color). The surrounding environment and people on the road were assessed with less risk of unlikely (2 or orange color). To reduce the risks, the government should focus on the revising of the classification system, budget, and guidelines. The HCFs should focus on the proper separation of types of wastes based on their characteristics, especially at the source first and use adequate containers as recommended by WHO (WHO, 2014). It is important to protect the waste workers and drivers of trucks with the equipment recommended, to cover the wastes during transportation at sites, and to protect the wheelbarrows and trucks for avoiding the leaking of wastes outside. Moreover, the respect of schedule is important during the wastes transport. The current guideline should be revised in such a way that all the personnel involved in the transportation process can easily understand the proper procedure and a better training program for workers needs to be implemented. In the case of the government is not able to transport safely the wastes by respecting the schedule, consideration should also be given to the outsourcing of SMW transport for off-site treatment.



(a)



(b)

Figure 3- 19. Risk matrix of peoples involved during transportation of SMW in 12 HCFs from storage to final disposal. Red, orange, yellow and green colors indicate very high risk, high risk, moderate risk, and low risk, respectively

3.4.5. Final treatment methods

3.4.5.1. Adequate treatment methods and Burundi treatment method for each type of waste

The adequate treatment methods according to WHO were compared with Burundi current treatment methods in this table 3-10. WHO has set up the pretreatment methods and final treatment methods for each type of SMW referring to their characteristics (WHO, 2014). Burundi, however, the treatment doesn't respect the recommendation of WHO all the more the pretreatment was not conducted for all types of wastes. Except only the organic pit used to treat pathological waste and placenta, the rest of the final treatment methods used were not recommended by WHO (WHO, 2014). This shows that 5 groups of SMW among six were treated by using the inadequate treatment methods. The worst, the incinerator with low temperature (< 300-400℃) was used by 8 private HCFs and 3 public HCFs. Therefore, the wastes were not completely destroyed, people and environment could be exposed to the high risk. In addition, the open dumping or disposed of in nature and uncontrolled landfill used at onsite and offsite could contribute for arising a high risk for different types of exposure. These results could help to Burundi government in collaborating with HCFs to improve the treatment methods, especially the pretreatment and final treatment methods specific for each type of waste. The similar situation was developed in most of developing countries where the pretreatment methods were not considered and final treatment methods were not based on WHO recommendation (Asante et al., 2014; Muhwezi et al., 2014; Nemathanga et al., 2008). However, in developed countries, pretreatment and final treatment methods used are highly regulated based on WHO recommendation (Windfeld and Brooks, 2015).

Table 3- 11. Comparison of current treatment methods of Burundi and WHO recommendations (ICRC, 2011; Joshua et al., 2014; WHO, 2014; WHO, 2017; WHO, 2005)

Types of wastes	**WHO treatment methods**		**Burundi treatment methods**	
	Pretreatment methods	**Final treatment methods**	**Pretreatment methods**	**Final treatment methods**
1.Sharps waste	Encapsulation, needle destroyer, autoclaving and microwaving	Sharps pit, recycling, and reuse	NA	8HCFs[2],[3],[7] and 3 HCF[1,7],1HCF[1,3,8]
2.Infectious waste	Chemical disinfection, autoclaving, microwaving, and dry heat treatment.	Incineration	NA	8HCFs[2],[3],[7] and 3 HCF[1,7]1 HCF[1,3,8]
3.Pathological waste and tissue	Alkaline hydrolysis and microwaving.	Incineration and organic pit.	NA	Organic pit[3]
4.Pharmaceutical waste and discarded medical plastics	a*: Autoclaving and encapsulation. b*: Shredding	a*. Incineration and sanitary landfill. b*. Recycling and reuse	NA	Open dumping or disposed of in nature[3], Uncontrolled landfill[4]
5. Chemical waste	Disinfection with chlorine	Incineration	NA	8HCFs[2],[3],[7] and 3 HCF[1,7]1 HCF[1,3,8]
6.Radioactive waste	Destroyer	Sanitary landfill	NA	8HCFs[2],[3],[7] and 3 HCF[1,7]1 HCF[1,3,8]
7. Absorbent cotton	Microwaving	Incineration and sanitary landfill.	NA	8HCFs[2],[3],[7] and 3 HCF[1,7] 1 HCF[1,3,8]
8.Placenta	Alkaline hydrolysis	Incineration and organic pit	NA	Organic pit[3]

NA: Not Applicable, [1]Public HCF, [2]Private HCF [3] On-site, [4] Off-site, [5]: Pharmaceutical waste, [6]: Discarded medical plastics, [7]: Low-temperature incinerator (<300-400 ℃), [8]: Medium incinerator (800 ℃),

3.4.5.2. Amount of SMW treated by different treatment methods

The infectious wastes, medical sharps, chemical wastes, radioactive wastes, and absorbent cotton were treated by incinerators at low (< 300-400℃) or medium temperature (< 800 ℃) in the HCFs (Table 3-12). On-site incineration was performed in all 12 HCFs. Low-temperature incinerators constructed with burnt bricks and cement are poorly designed and have the insufficient capacity (Figure 3-20(a)). About 23.8% (4,020.6 ton) of SMW produced during four years (2011-2014) was treated by the low-temperature incinerators (300-400 ℃) in 11 HCFs. However, the incineration capacity and the treatment temperature are insufficient to complete the incineration of SMW and may produce harmful gases such as dioxins and furans during the incineration process (Lee et al., 2002; Mato and Kassenga, 1997).

A total of 1,817.9 tons of SMW (10.7%) were incinerated from HCF1 using a medium temperature incinerator (Table 3-12). Medical sharps, chemical wastes, and radioactive wastes should be treated securely with different methods. Most incinerators are located only 15 to 30 meters from the residential area and do not have facilities to handle the exhaust gas (Joseph and Nina, 2010). The incineration of these substances may release harmful substances during incineration and may affect the health of not only waste workers but also nearby residents. Improper incineration is not a problem in Burundi alone. HCFs in other African countries such as the Limpopo province in South Africa, Uganda, and Egypt used low-temperature incinerators made from cement and bricks (Abd El-Salam, 2010; Joshua et al.,2014; Muhwezi et al.,2014; WHO,2005).

Table 3- 12. Amount of SMW (ton) treated by treatment and disposal methods of 12 HCFs in Bujumbura, Burundi

<table>
<tr><th colspan="2">Treatment</th><th>H1[1]</th><th>H2</th><th>H3[1]</th><th>H4</th><th>H5</th><th>H6[1]</th><th>H7</th><th>H8[1]</th><th>H9</th><th>H10</th><th>H11</th><th>H12</th></tr>
<tr><td rowspan="3">Incinerator2</td><td><300-400°C</td><td></td><td>18.6</td><td>573</td><td>43</td><td>30.5</td><td>2,905</td><td>43.1</td><td>184.5</td><td>17.8</td><td>137.8</td><td>47</td><td>20.3</td></tr>
<tr><td><800°C</td><td>1,817.9</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>1200°C</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Open dumping or disposed in nature[2]</td><td rowspan="2">1,358</td><td rowspan="2">17.4</td><td rowspan="2">716</td><td></td><td></td><td rowspan="2">2,015</td><td></td><td rowspan="2">207</td><td></td><td rowspan="2">129.2</td><td></td><td></td></tr>
<tr><td colspan="2">Uncontrolled landfill[3]</td><td>39</td><td>51.6</td><td>49</td><td>15.2</td><td>35.2</td><td>17.52</td></tr>
<tr><td colspan="2">Sanitary landfill[3]</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Organic pit[2]</td><td>2,059.5</td><td>26.7</td><td>1,017.2</td><td>64.4</td><td>66.3</td><td>2,599.2</td><td>61.3</td><td>209.3</td><td>22.2</td><td>200.1</td><td>43.2</td><td>20.8</td></tr>
<tr><td colspan="2">Total Waste (ton)</td><td>5,234.3</td><td>62.7</td><td>2,306.1</td><td>146.4</td><td>148.4</td><td>7,519.2</td><td>153.4</td><td>681.8</td><td>55.2</td><td>467.1</td><td>125.4</td><td>58.6</td></tr>
</table>

H: HCF [1]Public HCF, [2] On-site, [3] Off-site.A shaded cell indicates that the method is used by each HCF.

Pharmaceutical wastes and discarded medical plastics were disposed of in nature or at open dumping sites in HCFs (Figure 3-21(a)) and burned irregularly or treated at off-site uncontrolled landfills (Figure 3-21(b)). However, half the HCFs including all the public HCFs did not record how much waste was disposed of at the uncontrolled landfills (Table 3-12). Public HCFs were responsible for 95.5 % of pharmaceutical wastes and discarded medical plastics buried at open dumping sites and landfills (Table 3-12). In the hospitals of Lybia, Ghana and Limpopo Province of South Africa, SMWs are still dumped at uncontrolled landfills as in Burundi (Awodele et al., 2016; Sawalem, 2009; WHO, 2005).

As a result, 27.48% of SMW were disposed of at open dumping sites or uncontrolled landfills. A total of 34.4% of SMW were incinerated without proper admission control. If SMW continues to be improperly treated at landfills and by incinerators, soil, surface water, groundwater and air in adjacent areas may be contaminated by toxic substances or infectious pathogenic microorganisms. Humans and animals can be exposed to pollutants through a variety of routes such as skin contact and penetration, inhalation and ingestion through the food chain (WHO, 2014; Muhwezi et al., 2014). Animals, insects, and birds could be affected by hazardous wastes, while they could become vectors that transmit pollutants or germs.

In developing countries, most SMW were not separated properly and were treated by incinerators with insufficient capacity and temperature or dumped at uncontrolled landfills (Awodele et al., 2016; Coker et al., 2009; Godefroid and Jean, 2013; Muhwezi et al., 2014). In Cameroon, only 4 out of 30 hospitals used low-temperature incinerators and the rest disposed of SMW using dumping pits.

The commonly used disposal methods in Aba, Nigeria, is landfilling at open dumpsites (Ezechi et al., 2017). The problem is that these dumpsites are not protected and thus waste pickers and animals can enter them freely (Dzekasha et al., 2016; Muhwezi et al., 2014). Organic pits were used to dispose of pathological wastes and placenta (Figure 3-21(c)), accounting for the disposal of 38.16% (6,390.2 ton) of SMW generated during 2011-2014 in 12 HCFs. Organic pits in four public HCFs treated 5,885.2 tons of SMW. Although organic pits are one of the recommended methods by WHO for placenta, pathological wastes should be treated by other safe methods such as incineration (WHO, 2014). SMW treatment in Ethiopia is similar to that in Burundi in that placenta is treated separately in placenta dumping pits (Da Silva et al., 2005). However, organic pits currently in use in Burundi must be supplemented with safety devices such as roofs and fences (MOH, 2017).

(a) (b)

Figure 3- 20. Incinerators used to treat solid medical wastes in 12 HCFs in Bujumbura, Burundi. (a) Low-temperature incinerator and (b) Medium temperature incinerator

(a) (b) (c)

Figure 3- 21. Types of burial of SMW used by 12 HCFs in Bujumbura, Burundi (a) open dumping (on-site), (b) uncontrolled landfills (off-site), and (c) organic pit (on-site)

Table 3- 13. Amount of SMW improperly treated in 12 HCFs Bujumbura, Burundi, during the period of 2011-2014

Classification	**Improperly treated SMW**		**Total amount**
	Ton	**%**	**(Ton)**
Medical sharps	1,581.1	100	1,581.1
Infectious waste	101.2	7.6	133.7
Pathological waste and tissue	6,428.2	100	6,428.2
Pharmaceutical waste and discarded medical plastics	4,650.1	100	4,650.1
Chemical waste and radioactive waste	934.7	100	934.7
Absorbent cotton	2,041.1	64.0	3,187.9
Placenta	0	0	43.2
Total	15,736.4	92.8	16,958.7

The quantity of SMW improperly treated in 12 HCFs during four years (2011-2014) is presented in Table 3-13. The results show that a total of 15,736.4 tons (92.8%) were inappropriately treated in the HCFs of Bujumbura, Burundi. The present treatment methods for medical sharps, pathological wastes, infectious wastes, and absorbent cotton should be improved. Medical sharps may be processed in low-temperature incinerators in other developing countries (Coker et al., 2009), but it is not a safe method. Sharp wastes should be disinfected or destroyed and separately disposed of using sharps pits or encapsulation. This can reduce 10% of

SMW that is improperly treated. Incinerating medical sharps can affect the incineration of other SMW because the capacity of the incinerator is not sufficient at present. It can also have a negative impact on the complete combustion of wastes such as infectious or absorbent cotton that is mostly treated at low-temperature incinerators. Therefore, it is not appropriate to use incinerators to treat sharps even though incineration can act as a pretreatment for final disposal of medical sharps.

Pathological wastes should be completely incinerated, not disposed of using organic pits as currently practiced in Bujumbura, Burundi. Because they are the most produced SMW in 12 HCFs, storage space problems could occur within a short period of time. The capacity of organic pits in all the HCFs was relatively small (30 ~ 54 m^3) (MOH,2016), and they were built without much safety consideration (Ananth et al., 2010). It can overflow due to rain and floods or leachate can contaminate soil and groundwater. In both cases, it can pose a serious risk to people and the environment. Because of such shortcomings, WHO recommends that HCFs first use a high-temperature incinerator and an engineered organic pit, if it is unavoidable (WHO,2014; WHO,2004).

Pharmaceutical wastes and discarded medical plastics should be separated. The former should be returned to the manufacturer, encapsulated, buried at a sanitary landfill or incinerated at high temperature, while the latter can be recycled. If pharmaceutical wastes and disused medical plastics (4650.1 tons) that account for 29.5% of the total SMW were properly disposed of, the treatment costs could be reduced and resources saved depending on the degree of recycling. Chemical wastes and radioactive wastes should be carefully managed. They are currently being incinerated, but they should be sent back to the supplier or safely disposed of. Radioactive wastes should not be incinerated as it is currently practiced (WHO,2014). The only placenta was disposed of safely, but it is necessary to supplement safety facilities as mentioned above. Since the placenta is of great value for medical uses, it is not desirable to simply discard it. If enough capacity of incinerators is available to treat SMW at medium or high temperature, a total of 8,570.5 tons of infectious wastes, absorbent cotton, and pathological wastes can be treated safely. They comprise 54.4 % of inappropriately disposed of SMW in 12 HCFs in Bujumbura, Burundi. However, incineration has also some disadvantages, including the potential emission of toxic substances into the surrounding area, high operation and maintenance costs, and the requirement of ash disposal. There is a great potential for emission of toxic air pollutants from medical waste incinerators, if improperly operated and managed, partly because it typically contains a variety of plastic materials (e.g., polyvinyl chloride) as well as toxic materials. Emissions from medical waste incinerators may include carbon monoxide (as a result of incomplete combustion), particulate matter, hydrogen chloride, metals_(e.g., mercury, lead, arsenic, and cadmium), polycyclic aromatic hydrocarbons (PAHs), and dioxins (polychloro-dibenzo-p-dioxin (PCDD)) and furans (polychloro-dibenzo-furan (PCDF)) that are carcinogens (WHO,2014).

Many air pollutants in emissions from medical waste incinerators can be significantly reduced by modern air pollution control devices if properly designed and operated. Typical air pollution control devices used for medical waste incinerators in developed countries may include cyclones, semi-dry scrubbers, and baghouse filters (or fabric dust removers). Many devices can be modified to effectively control dioxins and furans. Therefore, when installing an incinerator, it is necessary to provide a safe distance from residential areas, equipped with a hazardous gas treatment facility, and prepare measures to safely treat the ash.

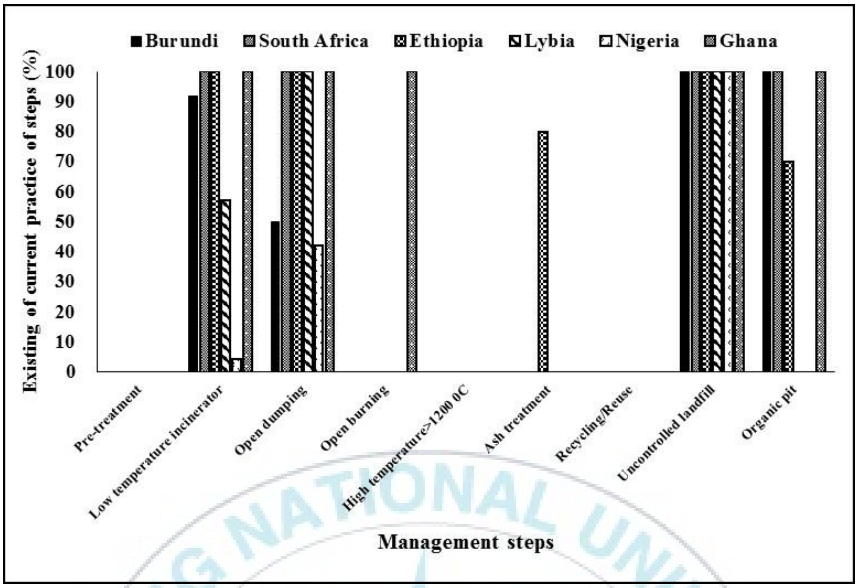


Figure 3- 22.Comparison of management practices at final disposal between Burundi and other African countries

The management practices at final disposal between Burundi and other African countries are compared in Figure 3-22. The results show that the pretreatment and high-temperature incinerator (>12000C) were not used in all countries, including Burundi. At on-site treatment, low-temperature incinerator, open dumping, and organic pit were the common treatment methods used by all four countries including Burundi (Figure 3-22). Except for the organic pit which was not used in Libya and Nigeria. In addition, low temperature incinerator and open dumping methods were used by a small number of HCFs of these two countries (Abugri, 2014; Asante et al., 2014; Longe and Williams, 2006; Nemathanga et al., 2008; Sawalem et al., 2009; Tadesse and Kumie, 2014). The open burning was used only in Ghana by 80 HCFs assessed (Asante et al., 2014). At off-site, the uncontrolled landfill was the main treatment method used by all six countries. No country has followed completely the management practices from generation to final disposal. This shows how the current treatment observed in Burundi was similar to other African countries. In all countries, similar explanation related to the improper management practices were developed such as the lacking budget, lack of policies and guidelines or uniform guidelines, untrained workers for the management practices, and the committee in charge of assessment of SMW management practices from generation to final disposal. These results can orient the Burundi government to improve the SMW management by considering the current situation of developed countries and WHO recommendation.

3.4.6. Potential threats, impacts on ecosystem upon improper SMW

Table 3-14 describes potential threats to the ecosystem that could occur if the management practices from generation to final disposal method were to be continued. Regardless of inside or outside the hospital, ecosystems exposed to the SMW management in all steps of practices are at greater risk of exposure to hazardous waste and can be directly or indirectly a potential victim. Therefore, it is imperative that integrated management and an improvement in the final disposal system of SMW in Burundi are needed. More specifically, improvement of the entire SMW treatment system is required in accordance with WHO recommendations, as in the developed countries such as the United States, the EU, the United Kingdom, Australia, Canada, and Korea that use high temperature incinerators, sanitary landfills, and recycling (Bassey et al.,2006; Jang et al.,2006; Lee et al.,2002;Udofia et al.,2015). In order to improve the waste management in developing countries, it is necessary to improve education and awareness, guidelines, system classification, policies, to develop suitable technologies and to increase investment (Ezechi et al., 2017). However, considering Burundi's low economic status and poor medical sector investment, it seems difficult to improve SMW management immediately. The lack of budget and absence of guideline for final treatment were the main reasons that the majority of HCFs used the low - temperature incinerators in Burundi (Joseph and Nina,2010).

Table 3- 14. Types of potential threats and impacts on human and ecosystem upon improper SMW

Management Step	**Location**	**Ecosystem**
Separation and collection	Inside of HCF	Because the practices are conducted inside the wards of HCFs, no adverse ecosystem effects can be caused by the wrong separation and collection of wastes.
Transportation at storage area	Inside of HCF	-The scattered waste can contaminate soil and ground by infectious and toxic waste.
		-Animals are direct or indirect exposed following scattered waste that contains the diseases and imminent contamination of the food chain.
Storage area	Inside of HCF	Contamination of ecosystem and animals following decomposed and unprotected waste.
Transportation	Inside of HCF	-Soil and groundwater contamination by infectious, cytotoxic, and radioactive wastes.
		-Direct or indirect exposure of animals to SMW and transfer of diseases and contaminants through the food chain.
	Outside of HCF	-Contamination of ecosystem by fugitive dust and spilled SMW during unprotected transportation
Final Disposal	Incineration of medical sharps, infectious, chemical, radioactive wastes	-Contamination of surrounding ecosystems by various incineration by-products.
	Uncontrolled landfills of pharmaceuticals and discarded	-Contamination of groundwater, soil and nearby water source
		-Animals, insects, and birds act as vectors of diseases or pollutants

plastics	
Organic pits for pathological wastes and placenta	-Contamination of soil and groundwater if organic pits overflew due to heavy rain and floods or leachate occurs; easily accessed by animals

Therefore, if financial investment is difficult, improvement of regulations and guidelines as well as education and training of medical personnel should be preceded. Establishment of proper management policies for SMW is not possible without objective and reliable data for every stage of SMW management. A quality control system for data collection on SMW needs to be a top priority for the Burundian government to improve SMW management. In the future, Burundi government can refer to radio frequency identification (RFID)-based medical waste treatment tracking system used in Korea, in which a whole process of medical waste management practices from generation to final disposal is detailed (Figure 3-7).

3.4.6.1. Rapid risk assessment for final SMW disposal

Solid medical wastes (SMW) that are not properly managed from generation to final disposal, can cause a high risk of infectious diseases to the people and environment that are involved directly or indirectly during the management practices (Brichard, 2002; ICRC, 2011; Mohee, 2005; WHO, 2014).

Most the risks are the infectious agent, toxic chemicals, radioactivity, used sharps, cytotoxic or genotoxic chemicals composition, biologically aggressive pharmaceuticals, or radioactive substances, and chemical substances, presence of carbon monoxide, particulate matter, hydrogen chloride, polycyclic aromatic hydrocarbons, toxic materials, metals (mercury lead, arsenic cadmium), dioxins (plastic, polyvinyl chloride : PADS, and PCDD: polychloro-dibenzo-p-dioxin or toxic air polluants), furans (PCDF: polychloro-dibenzofuran), and polycyclic hydrocarbons (PAHS) (WHO,2014). If those SMWs are not safely disposed of, they can pose a high risk to waste workers, current staffs, patients, current visitors, a nearby resident, people and environment involved in the SMW management (Babanyara et al., 2013; Niyongabo et al., 2018). Adequate treatment methods have been recommended by WHO for reducing the risks (WHO, 2014). Bujumbura, in 12 HCFs assessed, SMWs were wrong managed from generation to transportation at final disposal (Figure 3-4, Figure 3-7). Even if the final treatment methods used were not recommended for safe treatment of SMWs (Table 3-14). It is important to use RRA for assessing the risk caused by hazards to the exposure at the four treatment methods currently used in all HCFs at on-site and off-site

Table 3- 15. Problems, risks, exposure, current situation, and improvement for (a) low-temperature incinerator, (b) organic pit, (c) open disposal, and (d) uncontrolled landfill

(a)Problems, and risks for (a) low-temperature incinerator, (b) organic pit, (c) open disposal, and (d) uncontrolled landfill

Practice steps	Problems	Risks
1.Low-temperature incinerator (On-site)	The problems were related to the wastes mixed; incinerator constructed with bricks and cement wastes not completely destroyed; lack of treatment system of ashes after incineration in 10 HCFs	The risks were: the presence of carbon monoxide, particulate matter, hydrogen chloride, polycyclic aromatic hydrocarbons, toxic materials, metals (mercury lead, arsenic cadmium), Dioxins (plastic, polyvinyl chloride: PADS, and PCDD: polychloro-dibenzo-p-dioxin or toxic air polluants), furans (PCDF: polychloro-dibenzofuran), polycyclic hydrocarbons (PAHS).
2.Organic pit (On-site)	The problems were related to: 1. The wastes mixed 2.The inadequate maintenance condition (fence, roof, regular monitoring) 3.The lack of collection system of water surrounding the area during the rain season	The risks were the infectious agent; organic pits overflew due to rain or floods; deterioration of the surrounding living environment by bad odor
3.Open dumping	The wastes were mixed and dumped on the ground.	The risks were related to the infectious agent, toxic chemicals, radioactivity, used

(On-site)		sharps, cytotoxic or genotoxic chemicals composition, biologically aggressive pharmaceuticals, or radioactive substances, and chemical substances.
4.Uncontrolled landfill (Off-site)	The wastes were mixed and dumped on the ground.	The risks were related to the infectious agent, toxic chemicals, radioactivity, used sharps, cytotoxic or genotoxic chemicals composition, biologically aggressive pharmaceuticals, or radioactive substances, and chemical substances.

(b) Current situation and improvement for (a) low-temperature incinerator, (b) organic pit, (c) open disposal, and (d) uncontrolled landfill

Practice steps	Current situation	Improvement
1.Low-temperature incinerator (On-site)	1. Waste workers were not protected. 2. Incinerator doesn't have modern air pollution control. 3. Households were located near the residential area of the incinerator. 4. The area was not protected and animals could enter inside easily. 5. The lack of a treatment system of ashes was observed in 10 HCFs. 6. The wastes were incomplete destroyed and could be moved in nature during the rainy season. Therefore, they could cause a high risk in the environment.	1. The guidelines, budget, high-temperature incinerator with modern air pollution control, and trained workers are required in all HCFs assessed. 2. The wastes should be separated from a source to the incineration area. 3. The area should be protected by the fence for avoiding the entrance of people and animals inside of its location area. 4. The distance between the residential area of incinerator and households should be respected. 5. The ashes should be treated after incineration, and the residues metals should be recycled and reused 6. The waste workers should be protected with appropriated equipment.
	1. During the rain season, the flooding	1. The guidelines, budget and trained workers are

2.Organic pit (On-site)	could take away the wastes containing the infectious agents outside into the environment. 2. Waste workers were not protected during operation. 3. The residential area of organic was located near the households.	necessary. 2. The wastes should be separated from a source to the organic site area. 3. Temporary all organic pits should be maintained properly using a fence, roof, drainage channel and regular monitoring for avoiding the contamination of groundwater, soil, workers, patients, current staffs and nearby resident, and fields. 4. In the perspectives, Burundi government should change this treatment method by using the high-temperature incinerator with air pollution
3.Open dumping (On-site)	1. The wastes were openly treated 2. Because the wastes were dumped on the ground inside of HCFs, they could give out the	No improvement required for this treatment method type, because it is not recommended by WHO in reason of its high risk to the people and the environment. Therefore, It should be stopped immediately in all six HCFs, and the wastes should be treated at off-site by using the sanitary landfill recommended by WHO, especially only the general wastes (WHO, 2014).

4.Uncontrolled landfill (Off-site)	1. Waste workers were not protected during the management. 2. The area was an open access area (people and animals could entering inside). 3. The area was located near the surrounding environment (groundwater, rivers, fields, air, and rain) without leachate	1. The guidelines, policies, budget, and trained workers are needed. 2. The wastes should be separated from a source to the landfill location. 3. The area should be protected by a fence and isolated with the surrounding environment. 4. The safe operation by daily covering should be an obligation for avoiding the odors and spreading of germs through the air. 5. The leachate treatment system should be implemented 6. The distance separating the households and landfill should be respected for preventing the transmission of diseases. 7. It is important to treat the general wastes after their pretreatment using the sanitary landfill, otherwise, other types of waste should be incinerated.

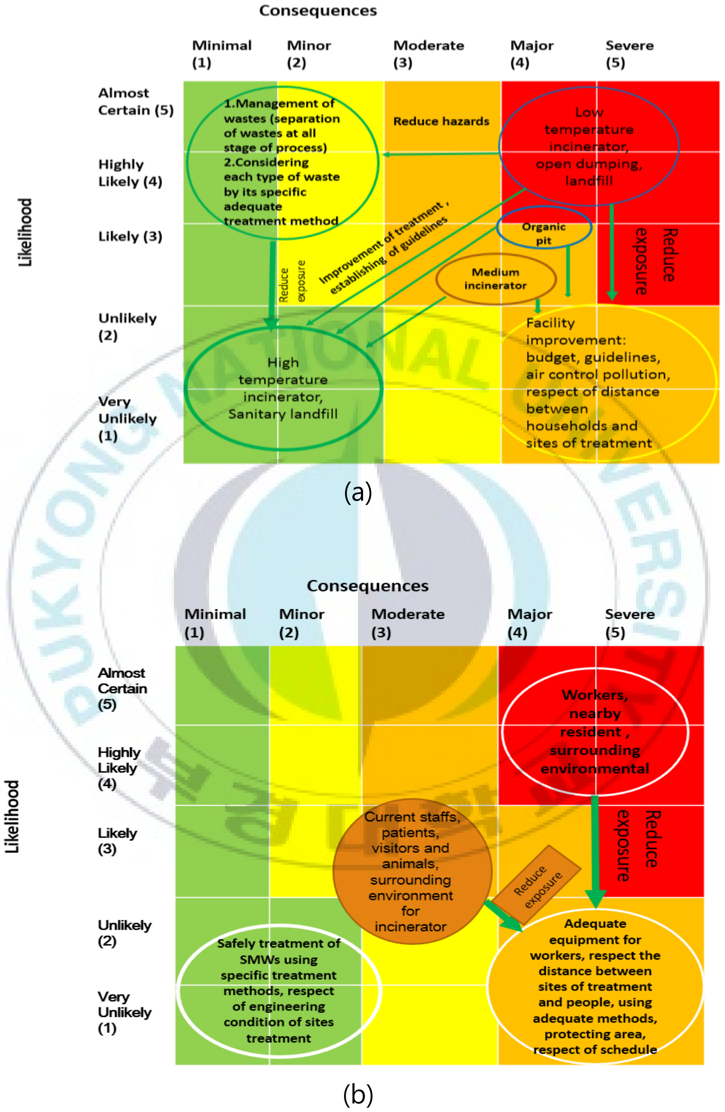


Figure 3- 23. Risk matrix of treatment methods (a), and peoples (b) during final disposal of SMW in 12 HCFs. Red, orange, yellow and green colors indicate very high risk, high risk, moderate risk, and low risk, respectively

Figure 3-23 (a) and (b) shows the risk matrix of treatment methods (a), (b) peoples and environmental involved during SMW treatment in 12 HCFs. Red, orange, yellow and green colors indicate very high risk, high risk, moderate risk, and low risk, respectively. The risk could increase in Bujumbura because in most of HCFs the wastes were improper disposed. A large quantity of wastes (92.8% or 15,736.4 ton) was inappropriately treated in all HCFs due to the wastes mixed during separation and inadequate treatment methods types used. Currently, low-temperature incinerator, open dumping, and uncontrolled landfill were assessed at a very high degree of severity (severe (5) or red color). The organic pit and medium temperature incinerator were assessed with the severity of major (4 or red color), and moderate (3 or orange color), respectively (Figure 3-23 (a). For reducing the risks, some facility improvement are required such as: budget, national guidelines, high temperature incinerator with air control pollution, sanitary landfill, the respect of distance between each resident area of method and households, and the respect of engineering condition (fence, roof, and maintenance) for all treatment methods.

Figure 3-23 (b), waste workers who stay in the areas for a long time and handle directly SMW, as well as nearby resident and surrounding environment of on-site and off-site were classified as very high risk with the likelihood of almost certain (5=red color). Current staffs (all health workers), current visitors, patients, a nearby resident and surrounding environment located near the area were assessed to the likelihood of likely (3) (orange color). To reduce the risks, it is important to protect the waste workers with adequate equipment or materials (gloves, mask, apron, boot, etc.), to respect the distance between the households and the sites of treatment methods and people, to protect the resident areas of treatment methods with fence, and to respect the schedule during the operation at sites. For the landfill, the area should be protected for avoiding the contamination of the surrounding environment (soil, groundwater, fields). The distance recommended by WHO between households and landfill should be respected. The study conducted in Algeria showed the likelihoods between people and SMWs based on the RRA by assessing the poor management of healthcare waste (Sefouhi et al., 2013).

3.4.7. Practical Suggestions

Inappropriate management of SMW could result in serious health and ecological hazards during transit from generation to final disposal in Burundi. The followings are recommendations to the Burundi government to improve SMW management of the country.

1. Proper separation and collection inside of wards of HCFs by using

appropriate equipment that respecting code, color and signs.

2. Waste workers should be protected with appropriate materials.
3. The storage area should respect the engineering condition (constructed, roofed and fenced) in all HCFs.
4. Safe transportation equipment needs to be supplemented and the current guideline should be revised.
5. Proper pretreatment should be introduced to reduce the volume and potential risks of SMW.
6. Safe treatment should be considered first, but source separation system that can segregate unpolluted or infection-free recyclable SMW should be improved together.
7. Pharmaceutical wastes and discarded medical plastics should be separated. The former should be returned to the manufacturer, encapsulated, buried at a sanitary landfill or incinerated at high temperature, while the latter can be recycled.
8. Medium or high-temperature incineration should be employed to handle SMW that contains potentially infectious and toxic materials, but should be located at a safe distance from residential areas, and equipped with air pollution prevention system.

9. Uncontrolled land disposal of SMW should be prohibited by legislation and regulations.
10. Sharp wastes should be disinfected or destroyed and separately disposed of using sharps pits or encapsulation.
11. Pathological wastes should be completely incinerated, not disposed of using organic pits.
12. Chemical wastes and radioactive wastes should be carefully managed and should be sent back to the supplier or safely disposed of.
13. Organic pits currently in use in Burundi must be supplemented with safety devices such as roofs and fences.

3.5. Conclusions

Improper management practices of SMW could potentially result in serious health risks and environmental problems (e.g., the spread of infectious diseases, direct/indirect human exposure to toxic materials), it is extremely important to properly treat and dispose of the waste. In this Chapter, Burundi national guidelines and WHO guidelines were compared. Currently, WHO guidelines are not followed totally in Burundi national guidelines, because most of the items from generation to transport at on-site and off-site are not considered in Burundi guidelines process. In addition, the final disposal doesn't have national guidelines. The risks could be high to the people and environment involved during the management process of SMW. Burundi guidelines should be improved for ensuring proper management of SMWs at all stages of practice. The management practices from a generation inwards of HCF to transportation at final disposal and final treatment methods were assessed. In all HCFs, 98.6% (16721.4 tons) and 65.6% (11131.8 tons) were improperly managed during separation and at storage, respectively. 9/12(75%) do not separate the wastes at the source of generation inside of the wards of HCFs. All quantity of SMW generated in all HCFs was improperly stored (area not constructed and doesn't respect the temperature condition). No HCF followed completely all steps of practice from generation to the transportation at final disposal. The results showed that most transportation equipment, as well as workers, were not safely protected. Approximately 75% (7,850 ton) and 92% (3,292 ton) of HCFs used uncovered wheelbarrows and trucks for on-site and off-site SMW transportation, respectively, exposing healthcare workers or the public to potential risks. To make matters worse, 67% of HCFs that are 92 out of 130 workers were not safely protected during 2011-2014. Only HCF1 transported SMW from storage area to the final disposal site regularly. 75% of HCFs used uncovered wheelbarrows and 7,850.1 tons of SMW were not transported appropriately at on-site. 70.8 % (3,292.2 ton) of pharmaceutical wastes and discarded medical plastics were transported from storage areas to off-site uncontrolled landfills by using the trucks not properly protected. The transportation system of SMW with proper equipment in Burundi should be improved. The results showed that 92.8% (15,736.4 ton) of SMW were inappropriately treated in all the HCFs of Bujumbura, Burundi.

The present treatment method for medical sharps, pathological wastes, infectious wastes, and absorbent cotton should be improved. If sufficient capacity of medium or high-temperature incinerators were available to treat SMW, 54.4% (8,570.5 ton) of infectious wastes, absorbent cotton, and pathological wastes could be treated safely. In Burundi, recycling may be dangerous and inadequate because there is no pre-treatment of SMW and the separation of SMW is poor. Only metal medical sharps were collected after incineration and dumped in a hole excavated, built with bricks and cement, and hermetically closed in only in two public HCFs, but no other residues of SMW have been treated. Among SMW produced in Bujumbura, Burundi, discarded medical plastics are recyclable wastes. However, in order to recycle the plastics, the separation must be ensured, and if contaminated, pretreatment is also necessary. Appropriate recycling has a positive impact on the environment and may also generate economic benefits by reducing the amount of waste generated and the waste of reusable resources. If pharmaceutical wastes and discarded medical plastics (29.5% of SMW) can be separated and recycled, the treatment costs can be reduced and resource savings can be achieved. Through the RRA, all SMW and HCFs were assessed at high risk for the degree of severity of almost certain (5 or red color). SMW management from generation to storage, current staffs, waste workers, and drivers of trucks who stay in the HCFs for a long time and directly handle SMW as well as patients were classified as very high risk (red). Visitors, environment, and residents around HCFs were at least at high-risk likely level (orange or red). It is important to the government in collaborating with the HCFs to reduce the risks by using all strategies required.

Based on the results of this Chapter, we recommend the following for the SMW management in Burundi to be improved. Strict implementation of the national guidelines, proper separation of wastes from generation to final disposal by respecting the waste classification system, regular training, current national guidelines should be translated into local languages, waste workers and drivers protected, wheelbarrow and trucks covered, construction and operation of safe storage areas, and sufficient budget, adequate treatment methods (high temperature incinerator with air pollution control, sanitary landfill, and organic pit protected with fence, roof, and drainage channel), pre-treatment, recycling and reuse, treatment system of ashes, and respect of distance between the resident area of treatment and households are priority requirements to be addressed for the safe management of medical wastes. The Burundi government needs to enforce the national guidelines more strictly. If no HCFs do not follow the guidelines, SMW management in the country cannot be improved. The government needs to introduce various incentive measures for HCFs to actively implement the guidelines. Revision of the SMW classification system is most important because safe management of SMW cannot start without an adequate system. Training and education of health-care personnel who are involved in generation and management of SMW in HCFs can be a very cost-effective way to greatly reduce health risks for patients, medical staffs, and workers and to improve the overall efficiency of SMW management.

It is important to respect the separation of wastes in all stages of management practice and the distance between the site of treatment and households, to protect waste workers and drivers, to cover the wastes during transportation and to introduce Proper treatment like advanced incineration technology with air pollution control and sanitary landfill. The active participation of hospital staff in the source separation step that affects all subsequent SMW management can be improved without a large budget. Proper and safe storage facilities are crucial for reducing the health risks posed by SMW and their disposal in later steps. Because the construction of the storage facility can be expensive during the management of SMW for HCFs, the Burundi government needs to partially support or provide financial incentives for HCFs to build safe storage areas for SMW. Because the materials equipment like wheelbarrow and truck used for to transport the wastes at on-site and off-site were not adequate, Burundi government in collaborating with HCFs should improve the transportation system by protecting wastes and waste workers. Alternative treatment methods to open dumping are the major future challenges for waste management professionals and HCFs in Burundi. The organic pits should be maintained with fence, roof, drainage channel, and regular monitoring. The government should recommend all HCFs to treat the general wastes at off-site by using the sanitary landfil

IV. EMERGY EVALUATION OF TREATMENT METHODS FOR SOLID MEDICAL WASTE

4.1. Introduction

Treatment of SMWs is a complex task that requires specific treatment methods corresponding to types of SMWs (ICRC, 2011). WHO has identified major final treatment methods of SMWs, like high-temperature incinerators with air control pollution, sanitary landfill, and recycling as the best methods that should be implemented in all countries (WHO, 2014). A variety of treatment methods that can treat SMWs efficiently were implemented in most developed countries (Insa et al., 2010; Walkinshaw, 2011). Developed countries have abandoned the inappropriate treatment methods such as low-temperature incinerators, open dumping, and open burning, due to their high risks to human health and environment, resulting from their low capacity for ensuring the complete treatment of wastes (WHO, 2014; Windfeld and Brooks, 2015).

Developing countries, however, have serious problems in SMW treatment because in most of the countries low-temperature incinerators (<300-4000 C), open dumping, disposal in nature, and uncontrolled landfills are the main final treatment methods currently used. Moreover, these treatment methods do not have the capacity to completely destroy the wastes (Asante et al., 2014; Awodele et al., 2016;Babanyara et al., 2013;Bassey et al., 2006; Coker et al., 2009; Dzekasha et al., 2016; Muhwezi et al., 2014; Windfeld and Brooks, 2015). Insufficient financial capacity and inadequate technologies are the main reasons that contribute to inappropriate treatment of SMWs in developing countries (Joseph and Nina, 2010).

In Burundi, SMWs generated by HCFs are treated using low-temperature incinerators, medium temperature incinerators, organic pits, open dumping or disposal in nature and uncontrolled landfills (MOH, 2014). Most of the methods are not recommended by WHO because of their limitations and risks to the people and environment. The assessment of current treatment methods and their improvement are an urgent matter in order to prevent or reduce the risks to people and environment, and improve their efficiency and effectiveness before the Burundi government and HCFs implement advanced technologies for safer treatment of SMWs.

Among many parameters of SMW treatment processes that can be used to better understand their performance, this study focused on the cost-efficiency of these processes. This study adopted the emergy methodology, a biophysical approach in systems evaluation, to calculate costs of treatment methods for SMWs generated by HCFs in Bujumbura, Burundi. The emergy methodology was applied to assess performance and environmental impacts of general solid waste treatment processes (Lui et al., 2017; Marchettini et al., 2007; Niccolucci et al., 2003; Pan et al., 2018). However, there are no previous studies that used the emergy methodology to analyze medical solid waste treatment methods.

This study aimed to evaluate the current practices by calculating costs in emergy terms that are required to treat one ton of SMWs through treatment methods selected for this study and to derive policy implications for the final treatment of SMWs in Burundi.

4.2. Materials and Methods

4.2.1. Study target

This study selected three main SMW treatment methods used by HCFs in Bujumbura, Burundi due to lack of reliable data for the emergy evaluation: low-temperature incineration, organic pits, and uncontrolled landfill. They treat 95 % of SMWs generated by HCFs in Bujumbura. Low-temperature incinerators and organic pits are located inside the boundary of the HCFs, while open dumping occurs at an uncontrolled landfill outside the HCFs. Low-temperature incinerators (< 300-400℃) that are constructed with bricks and cement are used by 11 among

12 HCFs assessed in this study. They treat several types of SMWs such as sharps wastes, infectious wastes, chemicals, radioactive wastes, and absorbent cotton wastes. They are not protected by fences, allowing open access to everyone in the HCFs. Organic pits are used in all HCFs of Bujumbura to treat pathological wastes and placenta (Table 3-9). They do not have fences and roofs to avoid the entrance of people and animals inside the area (Figure3-20 (c)). All HCFs use uncontrolled landfill to dispose of pharmaceutical wastes and discarded medical plastics at an uncontrolled landfill that also receives municipal solid wastes (Figure3-20 (b)). The landfill is located in the north district of Bujumbura without barriers to limit access by people and animals. It also lacks leachate and gas collection systems, and surface liners to protect contamination of groundwater, surface water, air, and human health.

4.2.2. Emergy evaluation

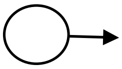
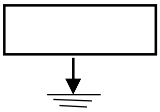
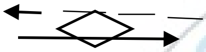
The emergy methodology is a system evaluation tool that uses available energy as the common currency to compare different things (Odum, 1996). Odum (1996) defined emergy as "the available energy of one kind of previously used up directly and indirectly to make a service or product." It is an abbreviation of "energy memory", indicating that the emergy concept uses the sum of all the energies required to produce the service or product for the systems evaluation, not the current energy left in the service or product. The emergy methodology has been applied to a variety of systems to better understand the status and performance of those systems and to provide policy suggestions (e.g. Brown et al., 2011, 2013, 2015, 2017).

The emergy methodology requires conversion factors to compare different types of energy storages and flows because they do not have the same ability to do work (Odum, 1996). All energies should be converted to equivalents of solar energy that is used as the reference energy in the current emergy practices. The conversion factors are called unit emergy value (UEV), with specific names of transformity for energy unit (sej/J), specific emergy for the mass unit (sej/J), and emergy-money ratio for the monetary unit (e.g., sej/$). Even though the definition of emergy only includes energy, in practice any biophysical data are converted to emergy quantity using appropriate unit emergy values for the systems evaluation. All UEVs that were used in this study were obtained from literature. They were adjusted to the global annual renewable emergy baseline of 15.83E+24 sej/yr if they are in different emergy baselines.

The emergy evaluation was conducted in two main steps as presented in Odum (1996). The first step was the construction of an energy systems diagram (Fig. 4-1) using the emergy systems language (Table 4-1) that was developed by Howard T. Odum (Odum, 1983, 1996). The evaluation boundaries chosen for the three treatment methods followed the areal perimeters of the sites for each method. In the second step, the emergy evaluation tables were constructed. Raw data were calculated for each item in these three treatment methods for construction and operation phases (Appendix B: footnotes for the incinerator, the organic pit, and uncontrolled landfill).

Data for the emergy evaluation for the construction phase were collected from companies that participated in the construction of three treatment methods (EBATRACO: Company for Buildings and Construction Work; ETRACO: Company works and construction; AGCOL: Agency for Housing Construction and Office Automation of Luanda). For the operation phase, the detailed information was collected from the Ministry of Health of Burundi (MOH, 2010).

Table 4- 1 Energy systems symbols that are used in this study (Odum, 1983)

Symbols	Description
	System boundary: a rectangular box that represents the boundaries of systems under evaluation.
	Pathway: flow of energy, material, or information.
	Source: outside sources of energy that deliver forces according to a program controlled from outside.
	Box: miscellaneous symbol to use for whatever unit or function is labeled.
	Transaction: a unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed line).

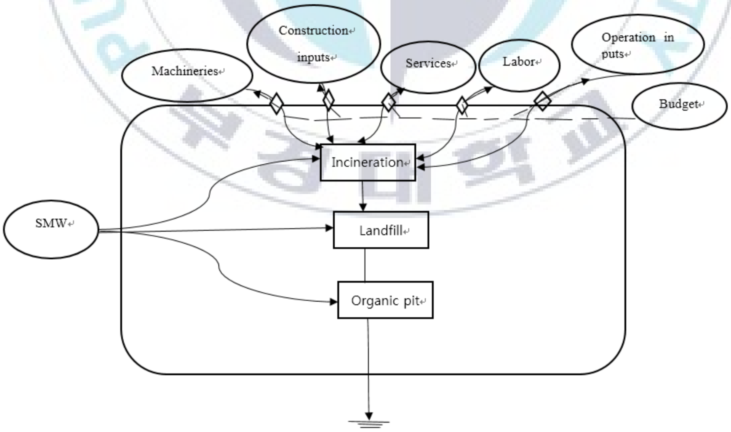


Figure 4- 1. Energy systems diagram for the three main treatment methods that are used for SMW treatment in health care facilities in Bujumbura, Burundi.

4.3. Results

4.3.1. Emergy evaluation of low-temperature incineration

Table 4-2 shows the emergy evaluation of low-temperature incinerators that are used by 12 HCFs in Bujumbura to treat SMWs. The total annual emergy input to treat 1,284 tons of SMW per year by 12 HCFs was calculated as 3.36E+17 sej/yr. The construction phase accounted for 33% (1.11E+17 sej/yr) of the total annual emergy input and the operation phase required 67% (2.25E+17 sej/yr) of the total input. Services provided the highest emergy input (2.20E+16 sej/yr) during the construction phase, followed by fuel, sand, gravel, and fire bricks. Services also accounted for the highest emergy input with 1.29E+17 sej/yr (38%) of the total emergy input for the operation phase. The annual emergy cost required to treat one ton of SMW was calculated as 2.62E+14 sej/ton SMW/yr. The annual monetary cost to treat 1,284 tons of SMW 15,834 $/yr (sum of cost for labor and services during construction and operation phases in Table 4-2), yielding a unit cost of 12.4 $/ton SMW/yr.

Table 4- 2. Emergy evaluation of low-temperature incineration of solid medical wastes in HCFs of Bujumbura, Burundi.

NO.	Item	Raw Data		Unit Emergy Value (sej/unit)		UEV source	Emergy (sej/yr)
Construction							
Machinery for preparation							
1	Bulldozer	7,778	g/yr	2.20E+10	sej/g	a	1.71E+14
2	Compactor	6,222	g/yr	2.20E+10	sej/g	a	1.37E+14
3	Truck	7,200	g/yr	2.20E+10	sej/g	a	1.58E+14
Materials used for the construction of furnace and building							
4	Sand	6.67E+06	g/yr	2.13E+09	sej/g	b	1.42E+16
5	Fire bricks	3.33E+06	g/yr	3.70E+09	sej/g	b	1.23E+16
6	Gravel	7.00E+06	g/yr	2.13E+09	sej/g	b	1.49E+16
7	Galvanised metal	4.00E+05	g/yr	1.39E+10	sej/g	c	5.56E+15
8	Sheet metal	4.08E+04	g/yr	1.39E+10	sej/g	c	5.67E+14
9	Nails	3.33E+02	g/yr	1.39E+10	sej/g	c	4.63E+12
10	Wood	6.00E+04	g/yr	1.84E+04	sej/J	d	1.10E+09
11	Concrete	3.33E+05	g/yr	2.41E+09	sej/g	e	8.03E+14
12	Water	1.33E+06	g/yr	8.14E+04	sej/g	f	1.09E+11
13	Fuel	8.80E+10	J/yr	1.89E+05	sej/J	g	1.66E+16
14	Lubricants	4.44E+10	J/yr	1.80E+05	sej/J	g	7.99E+15
15	Electricity	1.80E+10	J/yr	2.86E+05	sej/J	h	5.15E+15
Materials for construction of septic tank for metal residues							
16	Sand	1.00E+06	g/yr	2.13E+09	sej/g	b	2.13E+15
17	Fire bricks	2.67E+05	g/yr	3.70E+09	sej/g	b	9.87E+14
18	Gravel	4.67E+05	g/yr	2.13E+09	sej/g	b	9.94E+14
19	Galvanised metal	6.00E+04	g/yr	1.39E+10	sej/g	c	8.34E+14
20	Concrete	5.00E+04	g/yr	2.41E+09	sej/g	d	1.21E+14
Labor and services							
21	Labor	1,277	$/yr	1.45E+13	sej/$	i	1.85E+16

22	Services	1,515	\$/yr	1.45E+13	sej/\$	i	2.20E+16
Operation							
Materials							
23	Fuels(diesel)	1.69E+11	J/yr	1.89E+05	sej/J	g	3.19E+16
24	Chemical: Chlorhexidine	3.82E+05	g/yr	5.70E+09	sej/g	j	2.18E+15
Labor and services							
25	Labor	4,262	\$/yr	1.45E+13	sej/\$	i	6.18E+16
26	Services	8,880	\$/yr	1.45E+13	sej/\$	i	1.29E+17
Total emergy input							3.36E+17
Total quantity of SMW treated per year					1,284 ton/yr		
Annual emergy cost per one ton of SMW treated					2.62E+14 sej/ton/yr		

>UEV source: a) Odum et al. (1987), b) Odum (2000), Buranakarn (1998), c) Odum and Odum (1983), d)) Odum (1996), e) Buranakarn (1998), f) Odum (2000), g) Brown et al. (2011), h) Odum (1996), i) NEAD 2.0, and j) Brandt-Williams (2002).

>All UEVs were adjusted to the global renewable emergy baseline of 15.83E24 sej/yr.

4.3. 2. Emergy evaluation of organic pits

Table 4-3 shows the emergy evaluation of organic pits that are used in 12 HCFs of Bujumbura to treat pathological waste and placenta. The total annual emergy input to treat 1,618 tons of SMW per year by 12 HCFs was calculated as 7.27E+16sej/yr. The construction phase accounted for 63% (4.57E+16sej/yr) of the total annual emergy input and the operation phase required 37% (2.70E+16sej/yr) of the total input. Fire bricks provided the highest emergy input (2.31E+16 sej/yr) during the construction phase, followed by services (1.20E+16 sej/yr). For the operation phase, services accounted for the highest emergy input with 1.81E+16 sej/yr (25%), followed by labor with 8.63E+15 sej/yr (12%). The annual emergy cost required to treat one ton of SMW was 4.49E+13 sej/ton SMW/yr (sum of cost for labor and services in Table 4-3). The annual monetary cost to treat 1,618 tons of SMW was 2,886 $/yr (sum of cost for labor and services in Table 4-3), yielding a unit cost of 1.8 $/ton SMW/yr.

Table 4- 3. Emergy evaluation of organic pits that are used to treat solid medical wastes in HCFs of Bujumbura, Burundi.

NO.	Item	Raw Data		Unit Emergy Value (sej/unit)		UEV source	Emergy (sej/yr)
Construction							
Machinery							
1	Truck	5,000	g/yr	2.20E+10	sej/g	a	1.10E+14
Materials for the construction							
2	Gravel	1.E+06	g/yr	2.13E+09	sej/g	b	2.84E+15
3	Sand	1.E+06	g/yr	2.13E+09	sej/g	b	2.66E+15
4	Concrete	6.E+05	g/yr	2.41E+09	sejg	b	1.51E+15
5	Galvanised metal	3.E+04	g/yr	1.39E+10	sej/g	b	3.48E+14
6	Fire bricks	6.E+06	g/yr	3.70E+09	sej/g	b	2.31E+16
7	Cover (steel griller)	8.E+01	g/yr	1.39E+10	sej/g	b	1.16E+12
8	Ventilation pipe(PVC)	1.E+03	g/yr	9.90E+09	sej/g	c	1.25E+13

9	Water	8.33E+05	g/yr	8.14E+04	sej/J	d	6.78E+10
Labor and services							
10	Labor	215	$/yr	1.45E+13	sej/$	e	3.12E+15
11	Services	825	$/yr	1.45E+13	sej/$	e	1.20E+16
	Operation						
12	Wheelbarrow	15,000	g/yr	1.77E+10	Sej/g	b	2.66E+14
13	Charcoal	6.00E+04	g/yr	1.78E+05	Sej/J	f	1.07E+10
Labor and services							
14	Labor	595.3	$/yr	1.45E+13	sej/$	e	8.63E+15
15	Services	1,250	$/yr	1.45E+13	sej/$	e	1.81E+16
Total emergy input							7.27E+16
Total of SMW treated				1,618 ton/yr			
Emergy use per ton of SMW treated				4.49E+13 sej/ton SMW/yr			

>UEV source: a) Odum et al. (1987), b) Odum (2000); Odum and Odum (1983), c) Buranakarn (1998), d) Odum (2000), e) NEAD 2.0, and f) Odum (1996)

>All UEVs were adjusted to the global renewable emergy baseline of 15.83E24 sej/yr.

4.3.3. Emergy evaluation of uncontrolled landfill

Table 4-4 shows the emergy evaluation for an uncontrolled landfill that is used to dispose of solid medical wastes produced in HCFs of Bujumbura, Burundi. The total annual emergy input to treat 5,223 tons of solid wastes (77.7% municipal wastes and 22.3% solid medical wastes) was calculated as 1.75E+18 sej/yr. The construction phase accounted for 4% (3.40E+17 sej/yr) of the total annual emergy input and the operation phase 18% of the total input (1.41E+18 sej/yr). Galvanised metal provided the highest emergy input (1.76E+17 sej/yr) during the construction phase, followed by labor and services. For the operation phase, services accounted for the highest emergy input of 9.38E+17 sej/yr (12% of the total emergy input), followed by labor and fuel. The total annual emergy input to treat 1,163 tons of SMWs was calculated as 3.90E+17 sej/yr that is 22.3% of the total annual emergy input for the entire solid wastes disposal at uncontrolled landfill.. The annual emergy cost required to treat one ton of SMW was calculated as 3.35E+14 sej/ton SMW/yr. The annual monetary cost to treat 1,163 tons of SMW was 19,452 $/yr (22.3% of the total monetary cost for the entire uncontrolled landfill in Table 4-4), yielding a unit cost of 16.7 $/ton SMW/yr

Table 4- 4. Emergy evaluation of uncontrolled landfill that is used to dispose of solid medical wastes produced by HCFs of Bujumbura, Burundi.

NO.	Item	Raw Data		Unit Emergy Value(sej/unit)		UEV source	Emergy (sej/yr)
Construction							
Machinery for preparation							
1	Bulldozer	16,667	g/yr	2.20E+10	sej/g	a	3.67E+14
2	Compactor	13,333	g/yr	2.20E+10	sej/g	a	2.93E+14
3	Truck	8,000	g/yr	2.20E+10	sej/g	a	1.76E+14
Materials used for the landfill preparation							
4	Dry mud	2.67E+06	g/yr	3.35E+09	sej/g	b	8.93E+15
5	Clay	8.00E+06	g/yr	3.35E+09	sej/g	b	2.68E+16
6	Sand	4.00E+06	g/yr	2.13E+09	sej/g	b	8.52E+15
Materials used for the office building construction							
7	Sand	5.83E+06	g/yr	2.13E+09	sej/g	b	1.24E+16
8	Fire bricks	3.00E+06	g/yr	3.70E+09	sej/g	b	1.11E+16
9	Gravel	7.00E+06	g/yr	2.13E+09	sej/g	b	1.49E+16

10	Galvanised metal	1.27E+07	g/yr	1.39E+10	sej/g	c	1.76E+17
11	Sheet metal	6.68E+04	g/yr	1.39E+10	sej/g	c	9.29E+14
12	Concrete	8.33E+05	g/yr	2.41E+09	sej/g	d	2.01E+15
13	Water	1.00E+06	g/yr	8.14E+04	sej/g	e	8.14E+10
14	Wood	8.50E+04	g/yr	1.84E+04	sej/J	f	1.56E+09
Labor and services							
15	Labor	3,098	$/yr	1.45E+13	sej/$	g	4.49E+16
16	Services	2,257	$/yr	1.45E+13	sej/$	g	3.27E+16
Operation							
17	Excavator	176,800	g/yr	2.20E+10	sej/g	a	3.89E+15
18	Truck	104,000	g/yr	2.20E+10	sej/g	a	2.29E+15
19	Chemical: Chlorhexidine	3.05E+06	g/yr	5.70E+09	sej/g	h	1.74E+16
20	Fuels(diesel)	1.06E+12	J/yr	1.89E+05	sej/J	i	2.00E+17
21	Electricity	1.74E+09	J/yr	2.86E+05	sej/J	j	4.96E+14
Labor and services							
22	Labor	17,165	$/yr	1.45E+13	sej/$	g	2.49E+17
23	Services	64,710	$/yr	1.45E+13	sej/$	g	9.38E+17
Total emergy input							1.75E+18
Total quantity of SMW treated per year					1,163 Ton/yr		
% of SMW treated in landfill					22.3%		
Total emergy used for SMW					3.90E+17 sej/yr		
Emergy use per ton of SMW					3.35E+14 sej/ton		

>UEV source: a) Odum et al. (1987), b) Odum (1996); Odum (2000), Buranakarn (1998), c) Odum and Odum (1983), d) Buranakarn (1998), e) Odum (2000), f) Odum (1996), g) NEAD 2.0, h) Brandt-Williams (2002), i) Brown et al. (2011), and j) Odum (1996).

>All UEVs were adjusted to the global renewable emergy baseline of 15.83E24 sej/yr.

4.4. Discussion

Table 4-5 compares the emergy cost (sej/ton/yr) between three methods that are used to treat SMW in health care facilities in Bujumbura, Burundi. The emergy cost and monetary cost were highest for the uncontrolled landfill, followed by low-temperature incinerators and organic pits. Organic pits showed the lowest emergy and monetary costs among the three methods selected for this study. The emergy cost of organic pits was 17% and 13% of those of low-temperature incinerators and uncontrolled landfills, respectively. The monetary cost of organic pits was only 15% and 11% of those of low-temperature incinerators and uncontrolled landfills, respectively. Therefore, if the three methods can treat the same types of SMW, the organic pits that has the lowest emergy and monetary costs, is the most appropriate for final disposal methods in Burundi.

Table 4- 5.Comparison of emergy cost for three methods that are used to treat solid medical wastes in health care facilities in Bujumbura, Burundi.

Treatment methods	Emergy cost (sej/ton/yr)	Monetary cost ($/ton/yr)
Incineration	2.62E+14	12.4
Organic pit	4.49E+13	1.8
uncontrolled landfill	3.35E+14	16.7

However, organic pits used to dispose of pathological wastes and placenta only, so it cannot be applied to all SMW generated in Bujumbura. Considering the types of SMWs treated by HCFs of Bujumbura, three methods for analyzed in this study cannot be compared directly because the types of SMW treated by each method are different. Incinerators are used for treating sharps wastes, infectious wastes, chemicals, radioactive wastes, and absorbent cotton and uncontrolled landfills are used for disposing of pharmaceutical wastes and discarded medical plastics (Table 3-11).

The emergy and monetary costs of uncontrolled landfills were 1.27 times and 1.4 times higher than those of low-temperature incinerators, respectively. These results indicate the low-temperature incinerators can be more favorable method than uncontrolled landfills in terms of emery cost if SMW in Burundi should be treated in the current way due to financial difficulties. Considering that general wastes are landfilled with SMW and SMW were not properly separated in HCFs, uncontrolled landfills should be replaced by low-temperature incinerators that were relatively cheaper and safe.

The safety of SMW disposal methods is another important factor to consider. In term of safety, WHO (2014, 2017) considers uncontrolled landfills and low temperature incinerates as improper treatment methods with high risks to people and the environment. Organic pit, however, can be used temporarily for pathological waste and placenta as recommended by WHO (WHO, 2014). They should all be replaced by safer and more permanent treatment methods such as high-temperature incinerators or sanitary landfills.

Table 4- 6.Emergy cost of treating general solid wastes by incineration and sanitary landfills.

Treatment methods	Emergy cost (sej/ton/yr)	Source
Incineration	1.46E+14	Liu et al.(2017)
	2.83E+14	Marchettini et al.,(2007)
Sanitary landfill	1.20E+14	Liu et al.(2017)
	8.75E+14	Marchettini et al.,(2007)

*Emergy costs were adjusted to the global annual renewable emergy baseline of 15.83E+24 sej/yr

*All cases cover the entire process of collection, treatment, and final disposal, and equipped with electricity production systems.

The emergy and monetary costs of uncontrolled landfill and low-temperature incinerators in this study can be compared with those developed in the literature of two studies conducted in China (Beijing) and Italy on sanitary landfills and high-temperature incineration (Table 4-6). The emergy cost of high-temperature incineration in Beijing and Italy was 0.55 times, and 0.45 times lower than low-temperature incinerators operated in Bujumbura. The emergy cost of sanitary landfills in Beijing and Italy was 0.84 times, and 2.6 times lower than uncontrolled landfill in Bujumbura (Tables 4-5, 4-6). This means that SMW has been treated in an unsafe manner at a higher emergy cost in Bujumbura. In other words, with small investments, SMWs in Bujumbura could be treated more safely.

Based on the results of the emergy analysis, low-temperature incinerators should be replaced with high-temperature incinerators, and organic pits and uncontrolled landfills could be replaced with sanitary landfills. However, considering the current SMW management practices and landfill conditions, high-temperature incinerators are safer than sanitary landfills. Consequently, it is desirable that all SMWs are treated with high-temperature incinerators, except for safe and recyclable wastes. Although the recycling did not consider in emergy analysis of this study, recycling should be considered for waste reduction and economics. Discarded plastics can be recycled if they are infection-free. Placenta is also of great value for medical use and it should not be simply discarded.

Since the construction and operation of SMW treatment facilities are financially costly, it is also important to consider the economic situation of the country. This study suggests following step-by-step recommendations for safe disposal of SMW.

First, prohibit the use of uncontrolled landfill and replace them with low-temperature incinerators. The organic pits should be safely maintained by fence, roof, and monitoring until it can be replaced by high-temperature incinerators.

Next, improve SMW collection system so that safe and recyclable wastes can be recycled. Then, replace low-temperature incinerators with high-temperature incinerators. In all cases, a safe distance must be secured between households of the residential area and treatment methods. As discussed in Chapter 3, high-temperature incinerators are not the perfect methods. All high-temperature incineration system should have air pollution control facilities, if financially feasible.

Finally, construction of sanitary or controlled landfills is also needed to safely dispose of incineration ash or poorly separated general waste and SMW.

4.5. Conclusions

Emergy cost (sej/ton/yr), and monetary cost ($/ton/yr) for three treatment methods used in health care facilities in Bujumbura, Burundi, were assessed through emergy evaluation method to better understand the problems related to each method and provide the improvement based on the cost-effectiveness and safely. Organic pit was assessed with the lowest in terms of emergy cost, and monetary cost compared to the low-temperature incinerator and open dumping. Among all three methods, the organic pit is only one method recommended by WHO (WHO, 2014). Because most types are wrongly treated by using the inappropriate treatment methods (low-temperature incinerator, and open dumping), the improvement is required for ensuring the safe treatment of wastes.

Rapid improvement of the organic pit by ensuring its maintenance, the gradual replacement of low-temperature incinerator by high-temperature incinerator with air control pollution and landfill by sanitary landfill are highly recommended. Organic pit presents the lowest emergy, and cost requirement. Therefore, it is desirable to be maintained in all HCFs by respecting its maintenance (fence, roof and monitoring evaluation) for reducing the risks. The low-temperature incinerator has the advantages to treat several types of SMW compare to the rest of treatment methods. The uncontrolled landfill is commonly used for all HCFs and it was used also to treat municipal solid wastes. These two improper treatment methods should be replaced by respecting the effectiveness and efficiency related to human health and environment, as recommended by WHO (WHO, 2014). A national program of SMW management is suggested to be developed by the government. For example, WHO has reported that the high-temperature incinerator contributes to treating completely most of infectious medical wastes types. Sanitary landfill is indicated to treat general wastes after their pretreatment (WHO, 2014).

V.CONCLUSIONS

This study examined SMW management practices in 12 HCFs from generation to final disposal, by assessing its classification system, generation properties, management practices, final disposal, risk assessment based on management practices and final treatment methods, and relative efficiencies of three treatment methods selected among these used in HCFs. Generation properties of SMW are totally different in HCFs assessed in this study according to their status (public and private HCFs) during four years. The amount of waste was presented according to the types of waste (classification system). The findings of this study show that the classification of SMW in Burundi was not established based on their characteristics and mode of final disposal, because most of them were classified together, except sharps waste and infectious waste. Discarded medical plastics was classified together with pharmaceutical waste, however, WHO consider the discarded medical plastics as an item of general waste, it may be classified in the group of non-hazardous SMW. Even if the chemical waste and radioactive have different characteristics and disposal methods, in this study, they were classified together. Moreover, the placenta was classified together with absorbent cotton. The poor classification in Burundi could impact negatively on the separation and collection systems. In the case of the classification system will stay in the same situation without improvement, the risks to the people and environment could be high.

Therefore, for ensuring safe management practices of SMW from generation to final disposal, it is important to revise the classification system, by considering the absorbent cotton and placenta as the items of infectious waste and pathological waste, respectively. The system classification should consider the discarded medical plastics in the group of general waste. Moreover, chemical waste and radioactive waste should be classified separately. It is important for Burundi government to revise the guidelines according to WHO guidelines. A large amount of pathological waste, pharmaceutical waste and discarded medical plastics, and absorbent cotton and placenta were generated for 14,308 tons (84.38%). Among all total amount generated, 92% were generated by the public HCFs, where 88.8% came from three public HCFs (HCF1, HCF 3, and HCF6) only. Among the three districts, a large quantity of wastes was coming from the central district with 61% in reason its big number of HCFs (7HCFs). The results of this study show that a large quantity of wastes was mixed from generation to storage. In terms of wastes generated by types and HCFs, Burundi government should focus on the three types of wastes and three public HCFs presenting a large quantity of wastes.

The separation step at the source, with three items as recommended by WHO guidelines, was followed completely in Burundi national guidelines. The collection step inside of HCF, and outside steps (transport of wastes at storage, storage, transport of wastes at on-site and off-site) were followed in Burundi guidelines partially. Transportation of wastes at interim storage into the department of HCFs and interim storage into the department were not taken account in Burundi guidelines. At the final disposal, except organic pit recommended as alternative method after incineration method and medium temperature incinerator used by one HCF, however, other treatment methods used such as a low-temperature incinerator, uncontrolled landfill and open dumping are not recommended by WHO (WHO,2014). The results show that the guidelines used in Burundi are not adapted totally to WHO guidelines. This could impact negatively all process of management practices (from generation to final disposal). The revision of guidelines based on WHO guidelines is an emergency situation in Burundi for ensuring in all HCFs the proper management of wastes.

The current management practices were assessed based on Burundi national guidelines (from generation to transportation at final disposal), and treatment methods used were compared with WHO recommendation. Even the separation is the most important step to control all subsequent SMW management, no HCF has properly separated SMW generated in their services. At the source of generation, 98.6% (16721.4 tons) were improperly separated and 65.6% (11,131.8 tons) were improperly separated at storage. Waste workers, current staffs (doctors and nurses), and patients could be exposed to the high risk inside of HCFs. This indicates that among the steps taken inside the services of the HCFs, separation and collection steps need to be improved more than safety steps. Daily checklist can help to improve these waste management steps. During on-site transportation to the storage area, 13,845.4 and 16,508.3 tons of SMW were treated without following the guidelines for safety and the schedule, respectively. Two HCFs (public and private) used wheelbarrows covered and protected, but no public HCFs transported to a storage area as scheduled. Storage conditions were worse than the other management steps. The national guideline suggests a storage temperature of 3 to 8 ℃ and a duration of fewer than 5 days. No HCFs, however, maintained the recommended temperature in the storage areas, and only four HCFs followed the guidelines for storage duration. This led to the decomposition of SMW in the storage area, causing odor problems and creating an environment for the potential spreading of disease-causing germs. Only 25% of HCFs had protected and roofed storage areas, but no HCFs constructed storage areas following the national guidelines.

A total of 11,131.8 tons of SMW were stored in the storage areas without a fence or roofing, increasing the health risk from SMW on people and biota in and nearby HCFs. Because waste workers were not protected with adequate equipment and waste not covered, the high risk could be high for them. A nearby resident, temporal visitors, patients, and environment could be exposed to the high risks, all the more the wastes were not covered and were stored beyond the period recommended. Considering the current situation of storage area, the SMW can have negative effects on neighboring people and environment. Hazardous constituents are likely to enter the surrounding area including groundwater, especially during the rainy season, and animals, as well as people, can easily access infectious or toxic wastes. For ensuring the safe storage of SMW in all HCFs, the government should build the storage respecting all requirement, mobilize the funds for all materials necessary (containers, other equipment), and train all wastes workers. Through the RRA, all SMW and HCFs were assessed at high risk for the degree of severity of almost certain (red color). Waste workers and drivers of trucks who stay in the HCFs for a long time and directly handle SMW, as well as current staffs and patients with poor health, can be classified as very high risk (red). Visitors, nearby residents and surrounding environment around HCFs especially storage area were at least at high-risk likely level (orange or red). The improvement of management practices from generation to transportation at on-site and off-site is important for preventing the risks. To reduce the risks, the government should focus on the revising of the classification system, budget, and guidelines. The HCFs should focus on the separation the types of SMW properly based on their characteristics at source first and use adequate containers recommended for SMW, to protect the waste workers and drivers of trucks with the equipment recommended, to cover the wastes during transportation at sites, and to protect the wheelbarrows and trucks for avoiding the leaking of waste outside.

Moreover, the respect of schedule is important during the transportation of wastes. The current guideline should be revised in such a way that all the personnel involved in the transportation process can easily understand the proper procedure and a better training program for workers needs to be implemented. In the case of the government is not able to transport safely the wastes by respecting the schedule, consideration should also be given to the outsourcing of SMW transport for off-site treatment. For ensuring the safe storage of SMW in all HCFs, the government should build the storage respecting all requirement, mobilize the funds for all materials necessary (containers, other equipment), and train all wastes workers. Even if the final disposal stage in Burundi doesn't have national guidelines, but the current treatment methods used in 12 HCFs were compared to WHO recommendation for understanding the problems related to the treatment methods used and to improve the existing methods by those recommended by WHO. No pretreatment methods conducted in all 12 HCFs assessed in this study. Except organic pit recommended by WHO in the second position to treat pathological waste and tissue and placenta 38.16% (6,390.2 tons). In all HCFs, the organic pits were not protected by fence, roof and drainage channel. The wastes could spread out during the rainy season or flooding and could cause a high risk to the soil, groundwater, nearby resident, and workers. Over sixty percentages of wastes were improper treated in all HCFs. However, 23.8% (4,020.6 ton), and 27.48% of SMWs were improperly treated by using low-temperature incinerator, and uncontrolled landfill and open dumping. These latter are not recommended by WHO (WHO, 2014). The lack of budget and guidelines were the main reason for the improper treatment of SMW in all HCFs.

Moreover, in 11 HCFs, the incineration capacity and the treatment temperature were insufficient to complete the incineration of SMW and may of hazards cause the risks such as the carbon monoxide, particulate matter, hydrogen chloride, polycyclic aromatic hydrocarbons, toxic materials, metals (mercury lead, arsenic cadmium), Dioxins(plastic, polyvinyl chloride : PADS, and PCDD: polychloro-dibenzo-p-dioxin or toxic air polluants), furans (PCDF: polychloro-dibenzofuran), polycyclic hydrocarbons (PAHS). Pharmaceutical wastes and discarded medical plastics) were disposed of in nature or at open dumping sites in HCFs and burned irregularly or treated at off-site uncontrolled landfills. In addition, half the HCFs including all the public HCFs did not record how much waste was disposed of at the uncontrolled landfills. The uncontrolled landfill or open dumping could cause a high risk to the soil, surface water, groundwater and air by toxic substances or infectious pathogenic microorganisms. Humans and animals can be exposed to pollutants through a variety of routes such as skin contact and penetration, inhalation and ingestion through the food chain (WHO, 2014; Muhwezi et al., 2014). Animals, insects, and birds could be affected by hazardous wastes, while they could become vectors that transmit pollutants or germs.

The assessment based on RRA show that the low-temperature incinerator, open dumping, and landfill were assessed at a very high degree of severity (red color). The organic pit and medium temperature incinerator were assessed with the severity of major (red color), and moderate (orange), respectively. For the exposure, waste workers who stay in the areas for a long time and handle directly SMW, as well as nearby resident and surrounding environment of on-site and off-site were classified as very high risk with the likelihood of almost certain (red color). Current staffs (all health workers), visitors, patients and animals located near the area were assessed to the likelihood of likely (orange color). The improvement of final treatment methods is important to reduce the risks to the exposure group. The wastes should be separated from generation to final disposal, the organic pits should be maintained by fence, roof, drainage channel, and regular monitoring. For the perspectives, Burundi government should replace the organic pit by high-temperature incinerator with an air control system (WHO, 2014).

Burundi government should improve the incineration method by using the high-temperature incinerator with air pollution. Burundi government should replace the open dumping method and uncontrolled landfill by sanitary landfill. In addition, the distance between the residential area of sites of treatment and nearby resident should be respected. For the landfill, the area should be protected for avoiding the contamination of the surrounding environment (soil, groundwater, fields). Moreover, it is important to protect the waste workers with adequate equipment or materials (gloves, mask, apron, boot, etc.), and to protect the residential areas of treatment methods with a fence.

In the last part, the emergy evaluation was applied for three types of treatment methods (low-temperature incinerator, uncontrolled landfill, and organic pit), where the emergy and monetary costs for three methods used to treat solid medical wastes in health care facilities in Bujumbura, Burundi were compared. The emergy cost and monetary cost were highest for the uncontrolled landfill, followed by low-temperature incinerators and organic pits. However, organic pits showed the lowest emergy and monetary costs among these three methods selected for this study. In term of safety, WHO (2014, 2017) considers these two methods as improper treatment methods with high risks to people and the environment. Organic pit, however, can be used temporarily for pathological waste and placenta as recommended by WHO (WHO, 2014). Based on the findings of this part, some improvements were suggested to the government such as the rapid improvement of the organic pit by ensuring its maintenance (fence, roof and monitoring evaluation). Burundi government in collaborating with the HCFs should replace the low-temperature incinerator by high-temperature incinerator with air control pollution, and open dumping by sanitary landfill considering the country economic.

VI. LIMITATIONS AND FUTURE WORKS

6.1. Limitations

In spite of the assessment on SMW management conducted in the sample of 12 HCFs of Bujumbura during a period of four years for all process of management practices from generation to final disposal, some limitations can be developed, such as:

1. The data used in this study were collected based on the report provided by the health public ministry and could be contained some biases following to the improper management practices observed in the HCFs and the data collection system (from HCF to central department of MOH).

2. The data used for RRA were assumed based on the current management practices of SMW.

3. For emergy evaluation, some data used were assumed and others were collected using communication mode.

6.2. Future works

Based on the limitations above developed, the future works should focus on the following steps:

1. The management practices of SMW from generation to final disposal in urban and rural areas.

2. The matrix of RRA on a large sample of HCFs of Burundi because it shows clearly how the SMW can be managed safely.

3. To apply the emergy evaluation from generation to final treatment in selected HCFs of Burundi considering their status.

4. How to improve data reliability

5. The assessment of attitude and knowledge of workers regarding the waste management practice in hospitals.

6. The management practices of SMW from generation to final disposal for small HCFs.

7. Economic analysis needs to be conducted for SMW management in Burundi

8. The hazards risks of SMW

9. Radio frequency identification (RFID) based on medical waste management in Burundi.

10. Evaluation of SMW management practices in selected HCFs.

11. Assessment of stakeholders involved in SMW management practices process.

부룬디 부줌브라의 의료폐기물 관리 실태 평가

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요약

고형 의료 폐기물(Solid Medical Wastes)은 잘못 관리되거나 폐기될 경우 인간의 건강과 환경에 해로운 영향을 야기할 수 있으므로 발생 단계에서부터 최종 처분까지 안전하게 관리되는 것이 매우 중요하다. 본 연구는 부룬디 부줌부라의 의료 시설 12곳에 대하여 의료폐기물의 발생단계부터 최종 처분(분리, 수거, 측정, 의료 시설 내부 및 외부 현장으로의 운반, 보관, 최종 처분)까지 관리 및 처분 상태를 조사하였다. 의료폐기물로 발생할 수 있는 잠재적 위험성 및 위해도를 파악한 후 현재 폐기물관리시스템에서 발생할 수 있는 위해도 감소 방안을 제시하기 위하여 간이위해성평가(RRA)를 수행하였으며, 또한 현재 부줌부라에서 SMW 처리를 위해 현재 사용되는 3가지 처리 방법(저온 소각로, organic pit, 매립)에 대하여 비용효율에 중점을 둔 에머지(emergy) 평가도 수행하였다.

본 연구 결과 현재 부른디의 의료폐기물 관리 지침상의 SMW 분류 체계가 잘못되어 있어서 SMW를 안전하게 수거하여 처리하는데 문제가 있는 것으로 나타났다. 주로 발생하는 SMW의 유형은 병리계 의료 폐기물, 제약 폐기물, 폐의료 플라스틱, 탈지면 그리고 태반 등 이었는데, 이는 전체 조사 의료시설의 SMW 발생량의 84.38%인 14,308톤을 차지했다. 공공 의료시설에서 SMW의 92.8% 가 발생하였는데, 88.8%는 3개의 주요 공공 병원에서 집중되어 있었다. 부룬디의 의료폐기물 관리지침은 세계보건기구(WHO)의 가이드라인을 제대로 따르고 있지 않았으며 최종 처분에 대한 가이드라인은 아예 마련되어 있지 않았다. 그럼에도 불구하고 국가 의료폐기물 지침을 완전히 따르고 있은 의료시설은 없었으며, 대부분의 의료시설에서 의료 폐기물이 발생원의 분류 단계에서부터 제대로 관리되고 있지 않았다. SMW의 저장단계가 의료 폐기물의 관리단계에서 가장 열악했다. 12 곳 의료 시설에서 발생한 SMW의 92.8%(15,736톤)가 불법 매립되거나 저온 소각 처리되는 등 적절하지 못하게 폐기되고 있었다.

본 연구에서 수행된 간이위해성평가 (RRA) 결과에 의하면, 모든 고

형 의료 폐기물과 의료 시설, 주변 환경뿐만 아니라 12곳 의료시설에서 직간접적으로 SMW관리에 관련된 사람들의 위해성이 높은 것으로 나타났다.

에머지 평가결과 organic pit이 부룬디에서 사용되는 3가지 처리방법 중 에머지와 화폐 비용이 가장 적었으며, 비위생 매립의 에머지 비용은 각각 저온소각로의 1.27배, organic pit의 7.4배 높은 것으로 분석되었다. 또한 다른 나라에서 사용되는 고온소각로나 위생매립의 에머지 비용과 부른디에서 사용되고 있는 저온소각로와 비위생 매립의 에머지 비용간의 차이가 크지 않은 것으로 나타났다. 따라서 비용 효율과 안전성을 고려할 경우 현재 부른디에서 사용되고 있는 비위생매립과 저온소각로는 궁극적으로 고온소각로로 대치하여야 될 것이다.

본 연구 결과 SMW의 생성부터 최종 폐기까지의 적합한 정부지침과 정부 정책의 엄격한 이행, 폐기물 분류 시스템의 개정, 병원관계자와 폐기물 관리자에 대한 정기적인 교육과 훈련, 안전한 폐기물 저장 시스템, 폐기물의 안전한 운송, 안전한 SMW 최종 처분시설 (대기정화 설비를 구비한 고온소각로)의 구축 등이 부룬디에서 SMW를 보다 안

전하게 관리하기 위하여 우선적으로 조치 해야 될 사항들이다. 부룬디 정부는 의료 폐기물 처리 추적 시스템을 기반으로 하여 전자태그(RFID)를 도입해 안전한 관리 시스템을 향상시키는 것도 중요하다.

SMW로부터 발생할 수 있는 위해도를 낮추기 위하여 감염성폐기물과 손상성 의료폐기물의 소독, 독성화학폐기물이나 방사능폐기물의 안전한 관리를 위한 상세한 지침의 실행 등 추가적인 조치가 필요할 수도 있다. 신속한 SMW 관리개선 효과를 갖기 위해서 부른디 정부는 SMW 발생량이 많은 공공의료시설의 개선에 우선적으로 초점을 맞출 필요가 있다.

본 연구의 결과는 부룬디 정부가 SMW의 발생단계에서부터 최종처분까지 모든 단계에서의 SMW를 안전하게 관리하고, 건강과 생태계의 미칠 수 있는 잠재 위해도를 최소화하는데 사용될 수 있다. 이와 더불어 이러한 정책을 구현하기 위해 우선적으로 필요한 재원을 확보하는 것도 중요하다..

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APPENDIX A: Information on the management practices in Chapter III

A.1. Pictures: Separation, collection, transportation, storage in HCFs and landfill

(a) Separation and collection inside of services of HCFs

(b) Transportation of medical wastes at on-site of treatment

(c)Temporal storage of medical wastes inside of HCFs

(d) Open dumping at On site in Bujumbura, Burundi

(d) Open dumping at off-site in Bujumbura, Burundi

APPENDIX B: Footnotes of raw data related to low-temperature incinerator, organic pit, and landfill in Chapter IV

Footnotes to Table 4-2

A. Construction			
Machinery for preparation			
Bulldozer (one bulldozer used)			http//Africatip.net
Weight of bulldozer used	=	25,000 kg	
Total work hours of the bulldozer	=	56 hrs	
Life hours of the bulldozer	=	12,000 hrs	
Bulldozer used for the construction	=	Weight of bulldozer × Work hours / Life hours of the bulldozer	
	=	117 kg	
Lifetime of incinerator	=	15 yrs	
	=	Bulldozer used / Lifetime of incinerator	
Annual use of the bulldozer		7,778 g/yr	
2.Compactor (one compactor used)			http//Africatip.net
Weight of compactor used	=	20,000 kg	
Total work hours of the compactor	=	56 hrs	
Life hours of compactor	=	12,000 hrs	
Compactor used for the construction	=	Weight of compactor × Work hours / Life hours of the compactor	
	=	93 kg	

Annual use of the compactor	=	Compactor used / Lifetime of incinerator	
	=	6,222 g/yr	
3.Truck (one truck used)			http//Africatip.net
Weight of truck used	=	9,000 kg	
Total work hours of truck	=	120 hrs	
Life hours of truck	=	10,000 hrs	
Truck used for the construction	=	Weight of truck × Work hours / Life hours of truck	
	=	108 kg	
Lifetime of incinerator	=	15 yrs	
Annual use of truck	=	Truck used / Life time of incinerator	
	=	7,200 g/yr	
Materials used for the landfill preparation			
4.Sand			http//Africatip.net
Total quantity used	=	10,0000	
Annual use of sand	=	Total quantity used / Life time of incinerator	
	=	7.00E+06 g/yr	
5.Fire bricks			http//Africatip.net
Total quantity used	=	50,000	
Annual use of fire bricks	=	Total quantity used / Lifetime of incinerator	
	=	3.00E+06 g/yr	
6.Gravel			
Total quantity used	=	105,000 kg	http//Africatip.net

Annual use of gravel	=	Total quantity used / Lifetime of incinerator	
		7.00E+06 g/yr	
7.Galvanised metal			
Total quantity used	=	6000 kg	http//Africatip.net
Annual use of galvanised metal	=	Total quantity used / Lifetime of incinerator	
		4.00E+05 g/yr	
8. Sheet metal			http//Africatip.net
Total quantity used	=	612 kg	
Annual use of sheet metal	=	Total quantity used / Lifetime of incinerator	
	=	4.08E+04 g/yr	
9. Nails			http//Africatip.net
Total quantity used	=	5 kg	
Annual use of nails	=	Total quantity used / Lifetime of incinerator	
	=	3.00E+02 g/yr	
10. Wood			http//Africatip.net
Total quantity used	=	900kg	
Annual use of concrete	=	Total quantity used / Lifetime of incinerator	
	=	6.00E+04 g/yr	
11. Concrete			http//Africatip.net
Total quantity used	=	5,000 kg	
Annual use of concrete	=	Total quantity used / Lifetime of incinerator	

	=	3.00E+05 g/yr	
12. Water			http//Africatip.net
Total quantity used	=	20,000 liter	
Annual use of water	=	Total quantity used / Lifetime of incinerator	
	=	1.33E+06 g/yr	
13. Fuels			http//Africatip.net
Annual use of diesel	=	2.50E+03 liter/yr	
Energy of fuel	=	Annual use × 3.52E7 J/liter	
	=	8.80E+10 J/litter	
14. Lubricants			http//Africatip.net
Annual use of lubricants	=	1.20E+03 liter/yr	
Energy of fuel	=	Annual use × 3.70E7 J/liter	
	=	4.44E+10 J/liter	
Materials for construction of septic tank for metal residues			
15. Electricity			MOH,2010
Annual use of lubricants	=	5000 kWh/yr	
Energy of electricity	=	Annual use × 3.6E6 J/kWh	
	=	1.80E+10 J/yr	
16. Sand			
Total quantity used	=	15,000 kg	http//Africatip.net
Annual use of sand	=	Total quantity used / Lifetime of incinerator	
	=	1.00 E+06g/yr	
17.Fire bricks			http//Africatip.net
Total quantity used	=	4,000 kg	

Annual use of fire bricks	=	Total quantity used / Lifetime of incinerator	
	=	3.00E+05 g/yr	
18.Gravel			http//Africatip.net
Total quantity used	=	7,000 kg	
Annual use of gravel	=	Total quantity used / Lifetime of incinerator	
	=	5.00E+05 g/yr	
19.Galvanised metal			http//Africatip.net
Total quantity used	=	900 kg	
Annual use of galvanised metal	=	Total quantity used / Lifetime of incinerator	
	=	6.00E+04 g/yr	
20.Concrete			http//Africatip.net
Total quantity used	=	750 kg	
Annual use of concrete	=	Total quantity used / Lifetime of incinerator	
	=	5.00E+04 g/yr	
21. Labor			http//Africatip.net
Money paid for labor	=	19,152 USD	
Annual cost of labor	=	Money paid for labor / Lifetime of incinerator	
	=	1,277 USD/yr	
22. Services		22,725 USD	http//Africatip.net
Money paid for purchases	=	Money paid for services / Lifetime of incinerator	
	=	1,515 USD/yr	

B. Operation			
Materials			
23. Fuels			MHO,2010
Annual use of diesel	=	4.80E+03 liter/yr	
Energy of fuel	=	Annual use × 3.52E7 J/liter	
	=	1.69E+11 J/litter	
24. Chemical (Chlorhexidine)			MHO,2010
Annual use of chlorhexidine	=	3.60E+02 liter/yr	
Density	=	1.06 g/ml	
Mass of chlolexidine solution	=	3.60E+05 g/yr	
Labor and services			
25. Labor			MHO,2010
Money paid for labor	=	4,262 USD/yr	
26.Services			MHO,2010
Money paid for purchases	=	8,880 USD/yr	

Footnotes to Table 4-3

A. Construction			
Machinery			
1.Truck (one truck used)			http//Africatip.net
Weight of truck used	=	5,000 kg	
Total work hours of truck	=	120 hrs	
Life hours of truck	=	10,000 hrs	
Truck used for the construction	=	Weight of truck × Work hours / Life hours of truck	
	=	60 kg	
Life time of organic pit	=	12 yrs	
Annual use of truck	=	Truck used / Lifetime of the organic pit	
	=	5,000 g/yr	
Materials used for the landfill preparation			
2.Gravel			http//Africatip.net
Total quantity used	=	16,000 kg	
Annual use of gravel	=	Total quantity used / Lifetime of the organic pit	
		1.00E+06 g/yr	
3. Sand			http//Africatip.net
Total quantity used	=	15,000 kg	
Annual use of sand	=	Total quantity used / Lifetime of organic the pit	
	=	1.00 E+06g/yr	

4. Concrete			http//Africatip.net
Total quantity used	=	7,500 kg	
Annual use of concrete	=	Total quantity used / Lifetime of the organic pit	
	=	6.00E+05 g/yr	
5.Galvanised metal			http//Africatip.net
Total quantity used	=	300 kg	
Annual use of galvanised metal	=	Total quantity used / Lifetime of the organic pit	
		3.00E+04 g/yr	
6.Fire bricks			http//Africatip.net
Total quantity used	=	75,000	
Annual use of fire bricks	=	Total quantity used / Lifetime of the organic pit	
	=	6.00E+06 g/yr	
7. Cover			
Total quantity used	=	1kg	http//Africatip.net
Annual use of cover (steel griller)	=	Total quantity used / Lifetime of organic pit	
	=	8.00E+01 g/yr	
8.Ventilation			http//Africatip.net
Total quantity used	=	15 kg	
Annual use of water	=	Total quantity used / Lifetime of the organic pit	
	=	1.00E+03 g/yr	

9. Water			http//Africatip.net
Total quantity used	=	20,000 liter	
Annual use of water	=	Total quantity used / Lifetime of the organic pit	
	=	8.33E+05 g/yr	
Labor and services			
10. Labor			
Money paid for labor	=	2,580 USD	http//Africatip.net
Annual cost of labor	=	Money paid for labor / Lifetime of the organic pit	
	=	215 USD/yr	
11. Services			
Money paid for purchases	=	9,905 USD	http//Africatip.net
	=	Money paid for services / Lifetime of the organic pit	
	=	825 USD/yr	
B. Operation			
12. Wheelbarrows			MHO,2010
Number of wheelbarrows used	=	2 ea/yr	
Weight of wheelbarrow	=	15,000 g/ea	
Life time of wheelbarrows	=	2 yrs	
Annual use of wheelbarrows	=	Number of wheelbarrows used*weight of wheelbarrows/lifetime of wheelbarrows	
	=	15,000 g/yr	
13. Charcoal			MHO,2010

Annual use of charcoal	=	6.00E+04 g/yr	
Labor and services			
14. Labor			MHO,2010
Money paid for labor	=	595 USD/yr	
15.Services			MHO,2010
Money paid for purchases	=	1,250 USD/yr	

Footnotes to Table 4-4

A. Construction			
Machinery for preparation			
1.Bulldozer (one bulldozer used)			http//Africatip.net
Weight of bulldozer used	=	25,000 kg	
Total work hours of bulldozer	=	120 hrs	
Life hours of bulldozer	=	12,000 hrs	
Bulldozer used for the construction	=	Weight of bulldozer × Work hours / Life hours of the bulldozer	
	=	250 kg	
Life time of landfill	=	15 yrs	
	=	Bulldozer used / Lifetime of landfill	
Annual use of bulldozer		16,667 g/yr	
2.Compactor (one compactor used)			http//Africatip.net
Weight of compactor used	=	20,000 kg	
Total work hours of compactor	=	120 hrs	
Life hours of compactor	=	12,000 hrs	
Compactor used for the construction	=	Weight of compactor × Work hours / Life hours of the compactor	
	=	200 kg	
Annual use of the compactor	=	Compactor used / Lifetime of landfill	
	=	13,333 g/yr	
3.Truck (one truck used)			http//Africatip.net
Weight of truck used	=	10,000 kg	
Total work hours of truck	=	120 hrs	
Life hours of truck	=	10,000 hrs	

Truck used for the construction	=	Weight of truck × Work hours / Life hours of truck	
	=	120 kg	
Life time of landfill	=	15 yrs	
Annual use of truck	=	Truck used / Lifetime of landfill	
	=	8,000 g/yr	
Materials used for the landfill preparation			
4. Dry mud			http//Africatip.net
Total quantity used	=	40,000 kg	
Annual use of dry mud	=	Total quantity used / Lifetime of landfill	
	=	2.67E+06 g/yr	
5. Clay			http//Africatip.net
Total quantity used	=	120,000 kg	
Annual use of clay	=	Total quantity used / Lifetime of landfill	
	=	8.00E+06 g/yr	
6.Sand			http//Africatip.net
Total quantity used	=	60,000	
Annual use of sand	=	Total quantity used / Lifetime of landfill	
	=	4.00E+06 g/yr	
Materials used for the office building construction			
7.Sand			http//Africatip.net
Total quantity used	=	87,500	
Annual use of sand	=	Total quantity used / Lifetime of landfill	
	=	6.00E+06 g/yr	

8.Fire bricks			http//Africatip.net
Total quantity used	=	45,000	
Annual use of fire bricks	=	Total quantity used / Lifetime of landfill	
	=	3.00E+06 g/yr	
9.Gravel			http//Africatip.net
Total quantity used	=	105,000 kg	
Annual use of gravel	=	Total quantity used / Lifetime of landfill	
		7.00E+06 g/yr	
10.Galvanised metal			http//Africatip.net
Total quantity used	=	190,000 kg	
Annual use of galvanised metal	=	Total quantity used / Lifetime of landfill	
		1.00E+06 g/yr	
11. Sheet metal			http//Africatip.net
Total quantity used	=	10,020 kg	
Annual use of sheet metal	=	Total quantity used / Lifetime of landfill	
	=	7.00E+04 g/yr	
12. Concrete			http//Africatip.net
Total quantity used	=	12,500 kg	
Annual use of concrete	=	Total quantity used / Life time of landfill	
	=	8.00E+05 g/yr	
13. Water			
Total quantity used	=	15,000 liter	http//Africatip.net
Annual use of water	=	Total quantity used / Lifetime of landfill	
	=	1.00E+06 g/yr	

14. Wood			http//Africatip.net
Total quantity used	=	1,275kg	
Annual use of concrete	=	Total quantity used / Lifetime of landfill	
	=	9.00E+04 g/yr	
Labor and services			
15. Labor			http//Africatip.net
Money paid for labor	=	46,468 USD	
Annual cost of labor	=	Money paid for labor / Lifetime of landfill	
	=	3,098 USD/yr	
16. Services		33,860 USD	http//Africatip.net
Money paid for purchases	=	Money paid for services / Lifetime of landfill	
	=	2,257 USD/yr	
B. Operation			
17. Excavator(one excavator used)			http//Africatip.net
Weight of excavator used	=	17,000 kg	
Total work hours of excavator Life hours of excavator	= =	104 hrs 10,000 hrs	
Annual use of excavator	=	Weight of excavator × Work hours / Life hours	
	=	176,800 g/yr	
18.Truck (one truck used)			http//Africatip.net
Weight of truck used	=	10,000 kg	
Total work hours of truck	=	104 hrs	
Life hours of truck	=	10,000 hrs	

Annual use of truck	=	Weight of truck × Work hours / Life hours of truck	
	=	120 kg	
Life time of landfill	=	15 yrs	
Annual use of truck	=	Weight of truck × Work hours / Life hours	
	=	104,000 g/yr	
19. Chemical (Chlorhexidine)			MHO,2010
Annual use of chlorhexidine	=	2.88E+03 liter/yr	
Density	=	1.06 g/ml	
Mass of chlolexidine solution	=	2.88E+06 g/yr	
20. Fuels			MHO,2010
Annual use of diesel	=	3.00E+04 liter/yr	
Energy of fuel	=	Annual use × 3.52E7 J/liter	
	=	1.06E+12 J/liter	
21. Electricity			MHO,2010
Annual use of lubricants	=	482 kWh/yr	
Energy of electricity	=	Annual use × 3.6E6 J/kWh	
	=	1.74E+09 g/yr	
Labor and services			
22. Labor			MHO,2010
Money paid for labor	=	17,165 USD/yr	
23.Services			MOH,2010
Money paid for purchases	=	64,710 USD/yr	