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ORIGINAL ARTICLE

Generation, management practices and rapid risk assessment of solid medical wastes: a case study in Burundi

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Abstract

Management of solid medical waste (SMW) is receiving greater attention due to potential health and environmental risks arising from inappropriate disposal and treatment of the waste. Generation of medical wastes and their management practices as well as risk from generation to storage in 12 healthcare facilities (HCFs) in Bujumbura, Burundi, were assessed. 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 main types of SMW, accounting for 84.4% from the HCFs. No HCFs followed the national guidelines completely, and most medical wastes have not been properly managed from the source separation stage. The generation rate per bed and the amounts of medical wastes per health care worker were 3.6 and 5.9 times higher in public HCFs than those in private HCFs, respectively, while the management practices of public HCFs were worse than those of private HCFs. Storage of medical wastes was the least managed step in the HCFs. All SMWs, HCFs, and people involved in SMW management were at very high risk or high risk. This study showed that Burundi's overall SMW management should be urgently improved.

Keywords Medical waste · Healthcare facility · Risk assessment · Generation rate · Exposure

Introduction

Solid medical waste (SMW), also known as medical waste, health care waste, hospital waste, or biomedical waste, is generated during various medical services, such as diagnosis, treatment, immunization of humans or animals, and biological testing. It includes blood-soaked bandages, cell culture dishes, glassware, discarded surgical gloves and instruments, needles, swabs used to inoculate cultures, and removed body organs [1]. SMW generated from health care facilities (HCFs) is categorized into hazardous and non-hazardous wastes [2]. Between 10 and 25% of SMW is considered to be hazardous [2, 3], and could pose potential health risks arising from inappropriate disposal and treatment of the waste [4, 5]. 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 treat and dispose of the waste [6–9]. Therefore, proper guidelines for safe management of SMW from their generation to final treatment should be introduced and followed by all the people who participate in SMW management processes in HCFs [10]. When SMW is treated safely and properly in HCF services, following guidelines, the negative impacts on the people in HCFs as well as surrounding community could be effectively reduced.

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 [11, 12]. In developing countries, however, SMW management practices have not received sufficient attention [13]. Some countries do not have the proper guidelines for SMW in HCFs and even others that have guidelines do not follow them appropriately and there is a lack of detailed quantitative data on healthcare waste management [14–18].

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Since the Global Alliance for Vaccines and Immunization has been working with WHO to fund projects that have helped developing countries adopt a medical waste policy, strategy and plan, Burundi established national guidelines for SMW management practices in 2008 and all HCFs should follow them [10, 19]. A recent study that was conducted in ten laboratories of HCFs in three provinces in Burundi, however, showed that 78.8% of laboratories did not follow the national guidelines [20]. 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 [21]. SMW management practices in Burundi, therefore, must be regulated properly to reduce risks to public health. 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 health care facilities and examined whether the HCFs followed the guidelines. No comprehensive analyses for SMW management practices in HCFs in Burundi have been performed so far. 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.

In this study, the status of SMW management practices, from generation to storage, in 12 HCFs in Bujumbura, Burundi, was quantitatively assessed. Generation properties of SMW for each management step were also examined. 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.

The results of this study could contribute to raising the awareness of the Burundi government, medical staffs, and general public on the risks associated with improper medical waste management, encouraging the government to improve the SMW management system. This study can also help the Burundi government to improve SMW management practices and minimize their potential risks to health and ecosystems by revealing problems and priority areas for SMW management.

Materials and methods

Study area

Bujumbura is the capital city of Burundi, located in central Africa. Bujumbura has three districts with a total area of 11,000 km^2. The populations of the northern, central and southern districts in 2008 were 187,046, 172,120, and 138,000, respectively [22, 23]. Bujumbura has primary and secondary health care services, with three levels of administration of health care systems at national, provincial, and district levels [24]. Out of 15 HCFs with inpatients in Bujumbura, 12 HCFs were selected for this study to assess the generation and management status of SMW, considering their district and operational levels (Fig. 1).

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). 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 1).

Currently, SMW in Burundi are classified into seven categories according to their properties and potential adverse effects; sharps, infectious waste, pathological waste and tissue, pharmaceutical waste and discarded medical plastics,

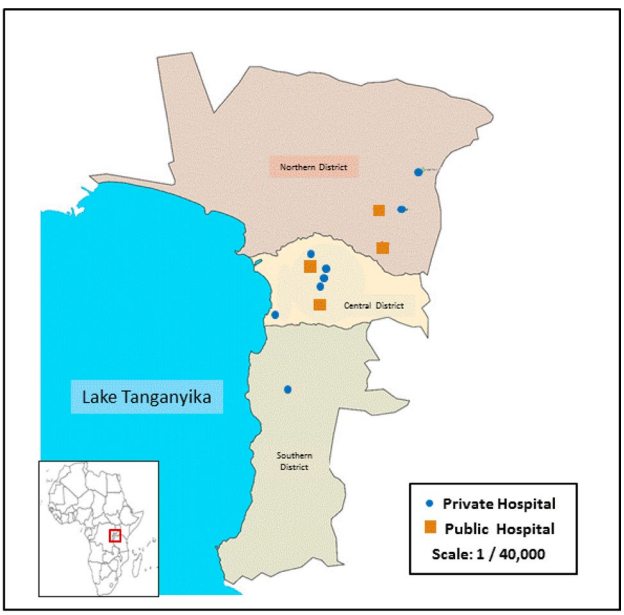

Fig. 1 Map showing the health care facilities selected to assess the generation and management status of SMW in Bujumbura, Burundi [25]

Table 1 Characteristics of 12 HCFs in Bujumbura selected for this study [26]

Name	Status	Operation type	District location	Number of beds	Number of inpatients
HCF1	Public	University	North	1536	50,927
HCF2	Private	Clinic	Center	188	898
HCF3	Public	General	Center	626	34,040
HCF4	Private	Clinic	South	243	2697
HCF5	Private	Clinic	Center	206	1761
HCF6	Public	General	Center	2099	63,707
HCF7	Private	Clinic	Center	130	1290
HCF8	Public	Military	North	710	26,132
HCF9	Private	Clinic	Center	85	1187
HCF10[a]	Private	Clinic	North	294	1718
HCF11	Private	Clinic	North	143	818
HCF12	Private	Clinic	Center	112	999

[a]Mental illnesses

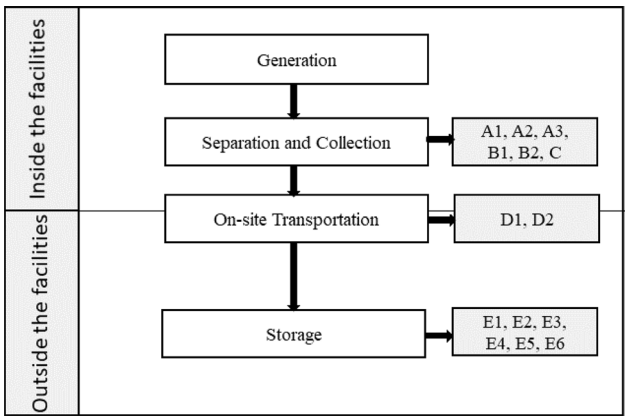

Fig. 2 Workflow of solid medical waste management practices in health care facilities of Bujumbura, Burundi (A: separation, B: collection, C: measurement, D: on-site transportation, E: storage)

chemical waste, radioactive waste, and absorbent cotton and placenta [18, 27].

The national guidelines for SMW management practices are divided into three parts, and each part has specific management steps (Fig. 2). The first part of the guidelines covers practices that are conducted inside the services of HCFs, from 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. 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 °C to 8 °C (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).

Data collection and statistical 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 and SMW management practices [26]. The questionnaire consisted of the status of waste generation and national guidelines compliance for each 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 amount handled by a worker (kg $worker^{-1}$ day^{-1}), which can be a useful indicator for whether the amount of SMW handled by worker is proper, was also calculated. To investigate whether SMW is handled safely and how much waste is mismanaged inside of HCFs, all management practice steps and the amount of waste, from collection to storage, were examined to estimate the amount of inappropriately managed SMW. 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.

Rapid risk assessment

RRA was developed to manage acute public health events by reducing or preventing diseases in affected peoples [28]. It is similar to preliminary hazard analysis that evaluates safety of the system using hazard risk matrix and thus can be applied to assess overall safety of SMW management system from generation to storage in 12 HCFs [29].

RRA has three steps to characterize risks—exposure, and context assessments [28]. Hazard assessment identifies hazards from each type of SMW, exposure assessment is the evaluation of the exposure of people to identified hazardous SMW, and context assessment evaluates the environment that the risk events occurred such as weather, 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 five levels of almost certain (is expected to occur in most circumstances), highly likely (will probably occur in most circumstances, likely (will occur some of the time), unlikely (could occur some of the time) and very unlikely (could occur under exceptional circumstances). The consequences are also defined as five levels of minimal, minor, moderate, major and severe [28]. The known hazards of SMW of 12 HCFs as well as current management practices obtained from this study were used to estimate likelihood and consequences in the risk matrix.

Results and discussion

Classification and generation of SMW in 12 HCFs

SMW is classified according to the nature, risk and origin of the waste. Depending on the nature of the 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. 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 [2]. Table 2 shows the classification and mass composition of medical waste in Burundi. Under the current classification system, it is difficult to safely manage SMW and to reduce them through recycling. Pharmaceuticals and discarded medical plastics are grouped into the same category. Discarded medical plastics may be classified as non-hazardous SMW because it can be recycled, reducing the total amount of SMW that needs to be treated. Because chemical wastes and radioactive wastes have different characteristics and disposal methods, they must be separated into different types. The absorbent cotton may be classified as infectious waste if used for the treatment of infectious diseases. The placenta that has recently been used for medical purposes can be classified as pathological waste. A good and systematic medical waste classification system is the basis for efficient and safe SMW management

Table 2 Solid medical wastes generated in 12 HCFs during 2011–2014 in Bujumbura, Burundi [26]

Health care facility	Solid medical wastes (kg/year)						
	Medical Sharps	Infectious waste	Pathological waste and tissue	Pharmaceutical waste and discarded medical plastics	Chemical and radioactive waste	Absorbent cotton and placenta[a]	Total
HCF 1	150,625	8100	512,550	339,475	8825	289,000 (2325)	1,308,575
HCF 2	700	375	6500	4357	500	3250 (182.5)	15,682
HCF 3	6500	4500	252,580	178,985	3880	130,080 (1725)	576,525
HCF 4	1100	1050	16,000	9750	2580	6125 (108.7)	36,605
HCF 5	1800	565	16,480	12,900	705	4650 (98.7)	37,100
HCF 6	205,750	9750	645,000	503,750	200,362	315,187 (4800)	1,879,800
HCF 7	2406	1400	15,225	12,251	2250	4812 (95)	38,345
HCF 8	13,750	1267	72,150	51,750	7520	24,000 (420.5)	170,438
HCF 9	1587	75	5507	3810	312	2501 (44.7)	13,794
HCF 10	6500	3725	50,000	32,300	3000	21,250 (25.2)	116,775
HCF 11	3000	2050	10,000	8809	3025	4500 (815)	31,385
HCF 12	1550	566	5052	4380	712	2400 (161.2)	14,661
Total	395,268	33,424	1,607,045	1,162,518	233,673	807,756 (43,207)	4,239,687

[a]The value in parentheses is placenta only

[30]. 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.

The detailed mass composition of SMW generated from 12 HCFs is presented in Table 2. Such composition is based on the annual average values during the four periods of 2011–2014. Pathological waste and tissue accounted for 37.9% of SMW, mostly from services such as maternity and surgery [26]. 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 [31, 32]. Thus, the low amount of infected waste in Burundi is thought to be due to poor classification and collection systems. When considering the improper classification system, the amount of infectious waste can be much larger than that shown in Table 2, 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 [33]. 18.83% of infectious wastes and 8.11% of pathological wastes are the largest part of medical wastes in India except for general wastes [34]. 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 number of inpatients of public HCFs were higher than those of private HCFs ($p < 0.01$). Public HCFs 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 5 years, which is why there is a higher number of patients in public HCFs (Table 1). 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 also shows how the Burundi government can improve the efficiency and safety of SMW management in the study area. Management priorities should be given to infectious and pathological 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.

Figure 3 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 1). 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 kg patient^{-1} day^{-1} in public HCFs (Fig. 3). 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 bed is known to be higher in university hospitals and general hospitals than primary health care centers [27]. 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, pharmaceutic 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 [35–38]. The SMW generation rates of high-income countries are 1.1–12.0 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 [2, 39, 40]. They are 7–10 kg bed^{-1} day^{-1}

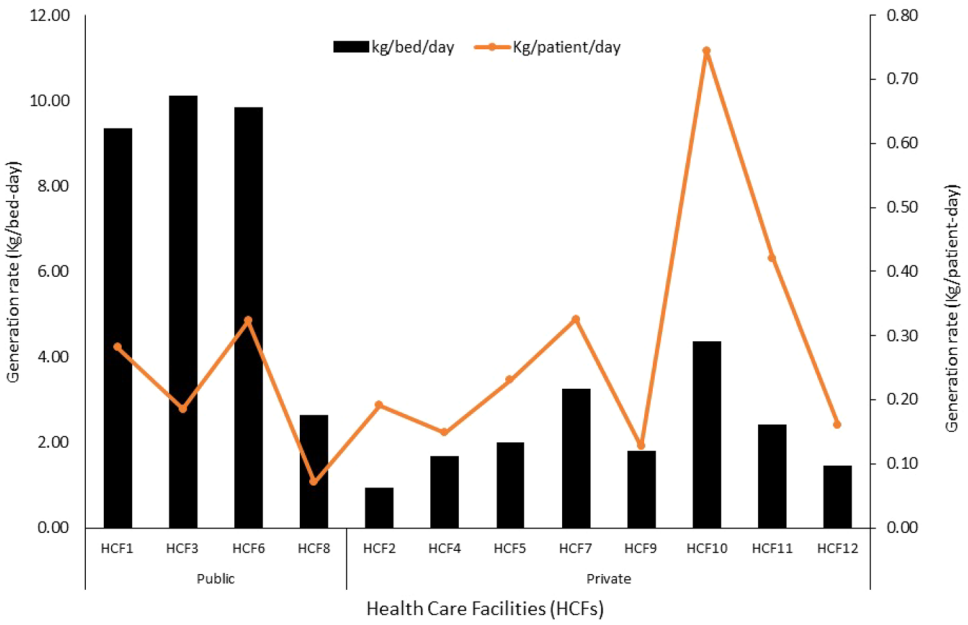

Fig. 3 Generation of SMW in public and private HCFs

in North America region, but 1.8–2.2 kg bed^{-1} day^{-1} in middle-income eastern Asia countries [35]. This reflects that SMW generation rates are closely related to socioeconomic factors and tends to be higher in countries with high GDP [41]. 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. SMW is 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 [42]. 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.

Management practice of SMW in 12 HCFs

Figure 4 shows current management practices from services to the storage area in 12 HCFs. 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, AB3) 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 medical teams as well as workers in public HCFs might have been exposed to SMW during SMW management in the services. 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 [20]. 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 HCFs 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 [43]. 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.

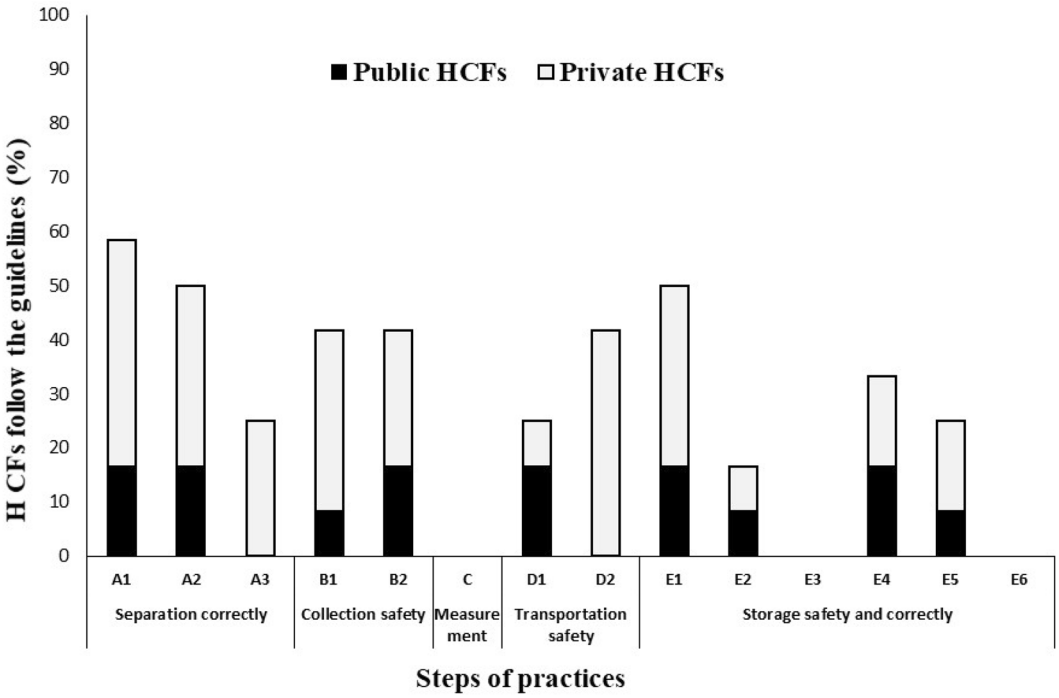

Fig. 4 Compliance status of national guidelines during SMW management steps

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 3–8 °C and duration of less 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 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 [2, 44].

SMW management practices in other African countries are similar to those of Burundi. Half of the ten public HCFs did not have containers for separately collecting hazardous and non-hazardous wastes, and the transportation of medical wastes to storage areas and storage periods were not regulated in any HCFs in Ethiopia [45]. A total of 120 healthcare centers in Ghana did not use colored or coded bins or bags during separation of medical wastes, due to the absence of the national policy, guidelines and SMW management standards [46, 47]. Mixing of medical wastes at the source and a lack of a proper management system were reported in Nigeria [14, 48].

Figure 5 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. 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 onsite 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 HCF has constructed a storage area as directed by the national guidelines (E6), and all SMWs 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

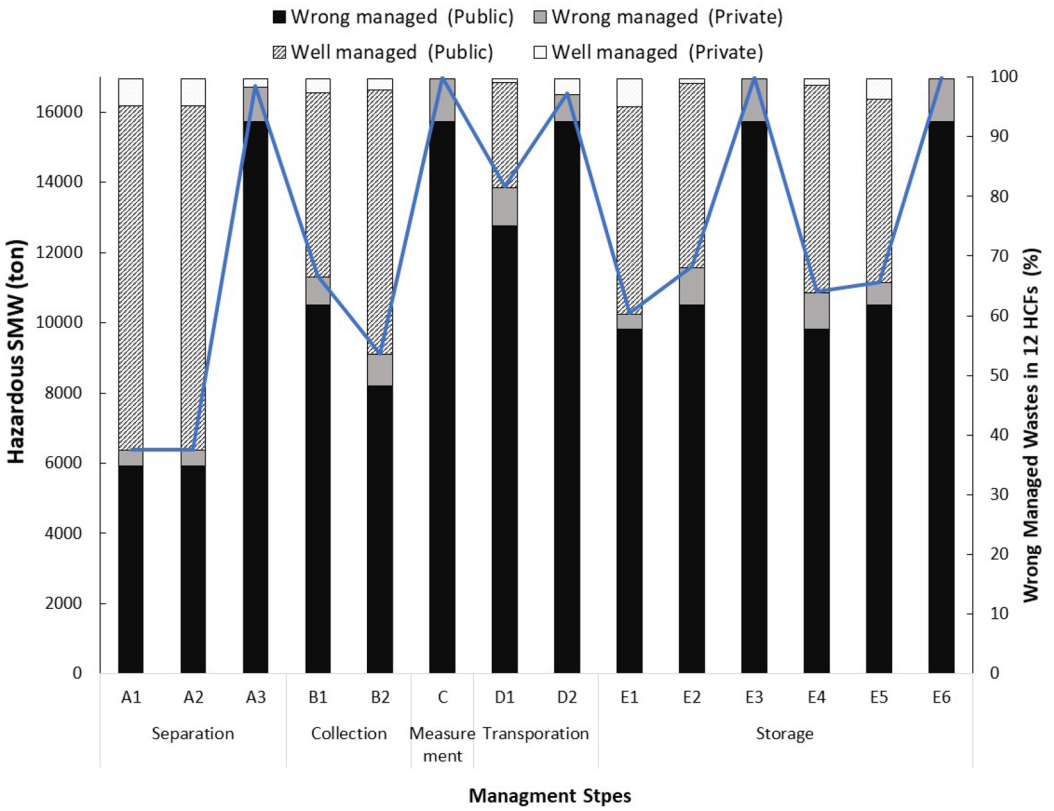

Fig. 5 Quantity of SMW in 12 health care facilities according to national guidelines

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 SMWs were mismanaged in 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 the water sources [49].

Figure 6 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 (125.5 ± 91.8 kg worker^{-1} day^{-1}) than private HCFs (21.4 ± 24.4 kg worker^{-1}day^{-1}). Waste workers in HCF6 handled the most SMWs at 234.1 kg worker^{-1} day^{-1}. The number of workers in public HCFs was 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 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 SMWs are 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 [50] 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.

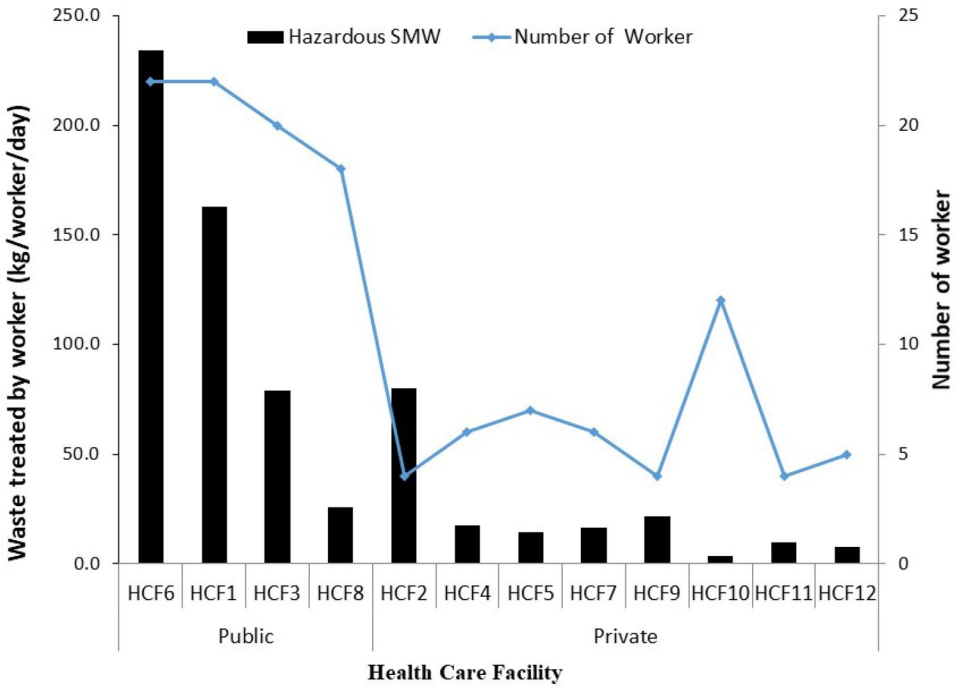

Fig. 6 Number of waste workers and the amount of SMW by each worker per day

Rapid risk assessment

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 [2]. 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 [51, 52]. It is observed from Figs. 4 and 5 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 (Fig. 6). Storage infrastructure and overall management of SMW were poor during management steps of D2, E3, E4, and E6. Therefore, there is 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 [51, 52].

Figure 7 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 as shown in the yellow region in Fig. 7a. 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 Fig. 7b, most people including staffs and neighbors are at very high or high risk levels. Doctors, nurses, waste workers and visitors are the main groups that could be exposed to risk from hazardous SMW in HCFs [53]. Their potential risk from SMW depends on the management status and the frequency of contact with the SMW in the HCFs. Medical staffs, patients and waste workers directly or indirectly involved from generation to storage and they should be exposed to SMW on a regular basis during SMW management. Because current overall SMW management practices (A1, A2, A3, B1, D2, E1) were poor and those involved are not protected safely (B2, D1), they can be classified at very high risk (red color). Visitors and residents around HCFs are less likely to be exposed directly to SMW than hospital staff, but the risk level is at least high (orange or red) considering poor SMW management status, especially the storage stages in the HCFs (E2, E3, E4, E5, E6). Safe classification and segregation can reduce the risk to a certain extent but to 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 safe storage system.

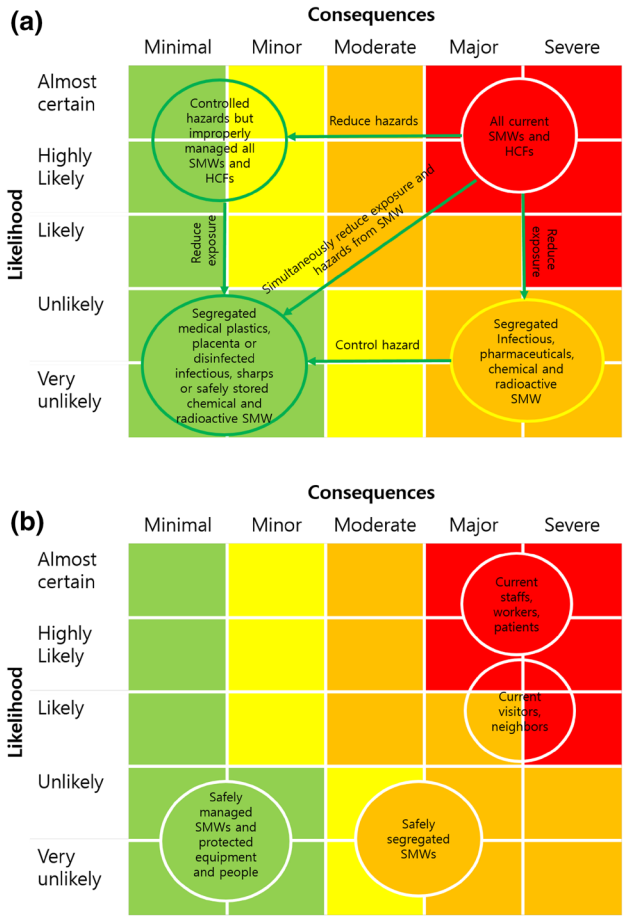

Fig. 7 Risk matrix of **a** SMW and HCFs, **b** people involved during SMW management in 12 HCFs. Red, orange, yellow and green colors indicate very high risk, high risk, moderate risk and low risk, respectively. (Color figure online)

Future challenges and suggestions for better management of SMW in Burundi

Based on this study, several suggestions can be made to improve current management practices of SMW in Burundi.

A lack or absence of policy direction and guidelines, management training, and sufficient financial supports seems to be the three main reasons for improper management of SMW in Burundi, like many African countries [19]. The government should provide well-organized and safe guidelines, and education can help health care workers understand these guidelines [13]. In this regard, the Burundi government needs to translate the current national guidelines into local languages to better educate and train all personnel involved in the SMW management in all HCFs in Bujumbura.

More specifically, separation, handling, collection/storage, and transportation are key steps for safe and proper management of SMW to avoid any potential health risks. The waste should carefully be separated, handled, collected/stored at designated storage areas, and transported to appropriate waste treatment and disposal facility. The best SMW management practice for HCFs is to prevent and minimize the generation of medical wastes. However, the potential of waste prevention and the minimization at the point of generation are known to be somewhat limited because of the nature of the waste stream (e.g., infectious characteristics) and the increased use of single-use disposable items (e.g., syringes, rubber gloves, IV bottles, or catheters).

The separation of SMW should be done at the point of generation and should be properly practiced at HCFs. The most effective way of identifying the categories of SMW is by classifying them using color-coded bags or any appropriate containers. Colored plastic bags should be kept in its containers that bear the biohazard symbol. Human and animal tissues should be placed in a container (plastic, paper board, or metal container), while pathological wastes and discarded sharps should separately be stored in puncture-proof containers. All the containers should exhibit a universal biohazard sign that is commonly used in many developed countries. Under no circumstances are medical wastes to be mixed with any other solid wastes. In many cases, all separated wastes other than tissues are then transferred to a larger medical waste container in a storage area before transportation to off-site treatment facilities for final disposal. During transportation, waste handlers and transporters should make sure that all waste bags and containers are properly sealed and labeled. Any manual handling of the bags and containers should be minimized to avoid any potential risks via direct contacts with human body. Reuse and recycling practices of any segregated SMW should be limited due to growing concerns about potential exposure to infectious materials.

Regular short- and long-term training programs for the practitioners, especially the healthcare workers, should be promoted and implemented to follow the guidelines. It is very important to recognize that medical staff engaged in healthcare activities should be regularly trained in handling medical wastes and be aware of proper way of handling medical wastes to avoid any injury and accidents during and/or after healthcare operations. In addition, patients, families, and visiting nurses at long-term care facilities (e.g., nursing home or residential care) should also be instructed in the proper management of the waste.

It is important that the HCFs increase the budget for SMW management and that they keep guiding and maintaining SMW management practices for all management steps. Proper management of SMW cannot be achieved without the budget for SMW management, especially for the construction of a safe storage area, which is a large fraction of the initial and operating expenses [2].

Conclusions

Generation of SMW and their management practices from generation to storage in 12 HCFs in Bujumbura, Burundi, were examined to better understand the problems of SMW management and provide insights for improving the management policy of SMW in the country. The current classification system of SMW in the national guidelines of Burundi was not appropriate for safe and adequate collection and disposal of SMW and should be improved first. Large amounts of infectious and pathological wastes were generated from the HCFs. However, most SMWs were not well managed safely and properly inside the HCFs, increasing the risk of exposure to hazardous SMW for patients, medical staffs, and workers inside the facilities. Public HCFs were responsible for 92.8% of SMW generated, while their management of SMW from the public HCFs was worse than that of private HCFs. Because no HCFs have a safe storage facility, different types of SMW can be mixed and there is a high risk of decaying and spreading of SMW to the surrounding communities and ecosystems.

The results of RRA for SMW management in 12 HCFs showed that all SMW, HCFs, and peoples involved during SMW management were at very high risk or high risk. The government's urgent measures to reduce the risk should be implemented quickly.

Based on the results of this study, we recommend the following for the SMW management in Burundi to be improved. Strict implementation of the national guidelines, revision of the waste classification system, regular training, and construction and operation of safe storage areas are priority areas to be addressed for the safe management of medical wastes. The Burundi government needs to enforce the national guidelines more strictly. If 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 staff, and workers and to improve the overall efficiency of SMW management. This will also facilitate the active participation of hospital staff in the source separation step that affects all subsequent SMW management and can be improved without large budget. Proper and safe storage facilities are crucial for reducing 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. 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. In terms of the types of HCFs, the Burundi government should focus on improving SMW management of public HCFs.

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