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Emergy Evaluation of Treatment Methods for Solid Medical Waste in Bujumbura-Burundi

Edouard Niyongabo[1], Rénovat Nkunzimana[2], Aloys Ndiziye[3]

[1]Department of Public Health Sciences, East Africa Health Center, National Institute of Public Health (INSP), Bujumbura, Burundi
[2]Department of Mathematics, University of Burundi, Bujumbura, Burundi
[3]OXFAM Novib in Burundi, Bujumbura, Burundi
Email: niyongaboedouard@gmail.com

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Abstract

Introduction: Treatment of solid medical waste (SMW) is a complex task requiring the proper practices with specific treatment methods corresponding to each type of SMW during pretreatment and final treatment. This study targeted three treatment methods identified as the main used by the majority of health care facilities (HCFs) and treating a large amount of SMW. It aimed: 1) to evaluate the current practices by calculating the emergy investment and emergy costs that are required to treat one ton of SMW through the three treatment methods and 2) to evaluate and compare better technologies and provide policy suggestions for the final treatment of SMW in Burundi. **Materials and Methods:** This study used the emergy methodology to evaluate the relative efficiencies of three treatment methods used for to treat SMW in twelve HCFs in Bujumbura. **Results and Conclusion:** The total emergy input was 1.36E+20 seJ/yr, 3.54E+17 seJ/yr, and 1.681E+18 seJ/yr for low temperature incinerator, landfill and organic pit, respectively. **Conclusion:** Rapid improvement of 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 by respecting its maintenance (fence, roof and monitoring evaluation) for reducing the risk.

Keywords

Emergy Evaluation, Treatment Methods, Solid Medical Waste

1. Introduction

Treatment of solid medical waste (SMW) is a complex task requiring the proper practices with specific treatment methods corresponding to each type of SMW during pretreatment and final treatment [1]. The improper treatment of SMW, however can lead a potential diseases according each type of waste (**Table 1**) [2]. World Health Organization (WHO) has identified the major final treatment methods of SMW, like high temperature incinerator with air control pollution, sanitary landfill, and recycling as the best treatment methods that should be implemented in all countries for medical waste treatment [2]. Developed countries, however, the inappropriate treatment methods have been abandoned in reason of their high risk to human health and environmental, following to their low capacity for ensuring the complete treatment of wastes [2] [3].

Developing countries, however, it has become a serious problem in most of countries, because the low temperature incinerator (<300˚C - 400˚C), open dumping, disposal in nature and uncontrolled landfill are the main final treatment methods currently used. In addition, these treatment methods do not have the capacity to destroy completely the wastes [3]-[8].

Burundi, SMW generated by HCFs is treated by using low temperature incinerator, medium temperature incinerator, organic pit, open dumping or disposal in nature and uncontrolled landfill [9]. Therefore, these treatment methods are not based on the evidence as recommended by WHO and they lead a high risk to the human and environment [2] [10] [11]. Thereby, the appropriate measures based on emergy evaluation should be considered for ensuring the efficiencies treatment of SMW although it was used for assessment of municipal solid waste management only [12] [13] [14].

This study targeted three treatment methods identified as the main used by the majority of HCFs and treating a large amount of SMW [7] or [8]. It aimed 1) to evaluate the current practices by calculating the emergy investment and emergy costs that are required to treat one ton of SMW through the three treatment methods (incineration, organic pit, and landfill) and 2) to evaluate and compare better technologies and provide policy suggestions for the final treatment of SMW in Burundi.

2. Literature Review

Emergy Evaluation and Its Application for SMW

Emergy is defined as "the available energy of one kind of previously used up directly and indirectly to make a service or product". The unit used for emergy is explained in emjoule [15]. The main contribution of a service or product is assessed by the sum of inputs that were required to produce a service (emergy memory). Practically, the emergy methodology uses solar energy to compare different items that constitute all process. The emergy is called solar emergy with specific unit of solar emjoules (sej). The emergy methodology requires conversion factors to compare different types of energy storages and flows because they do have same ability to do work. All energies should be converted to equivalents energy that is used in emergy practices. Several conversion factors are used

Table 1. Potential diseases according each type of SMW.

Type	Potential diseases
Sharps waste	AIDS, viral hepatitis A, B, and C.
Infectious waste	Gastroenteritis infection, respiratory infection, ocular infection, genital infection, anthrax and skin infection.
Pathological waste	AIDS, viral hepatitis A, B, and C, hemorrhagic fevers, septicemia, bacteraemia and candidemia.
Pharmaceutical waste, cytotoxic waste	Skin infection, gastroenteritis infectious, respiratory infection and cancer.
Chemical waste	Cancer.
Radioactive waste	Skin infectious, respiratory infections and cancer.

during emergy methodology such as transformity for energy unit (sej/j), specific emergy for mass unit (sej/g), and emergy-money ratio for monetary unit (sej/$), and generic name of unit emergy value (UEV) [15]. The emergy methodology uses available emergy in order to compare the current treatment methods referring to their implementation processes, that are required for ensuring their functioning of a system consideration [16].

3. Materials and Methods

Study Area

Burundi has an area of 27,834 km^2, 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 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 km^2. Burundi is ranked among the African countries most densely populated which the fertility rate is 6.4 children per woman [17]. The average temperature is 23˚C and annual precipitation is 1274 mm [18].

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 [19] [20]. 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 were 187,046, 172,120, and 138,000, respectively [17] [21]. Bujumbura has primary and secondary health care services, with three levels of administration of health care systems at national, provincial, and district levels [22]. 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 (**Figure 1** and **Figure 2**).

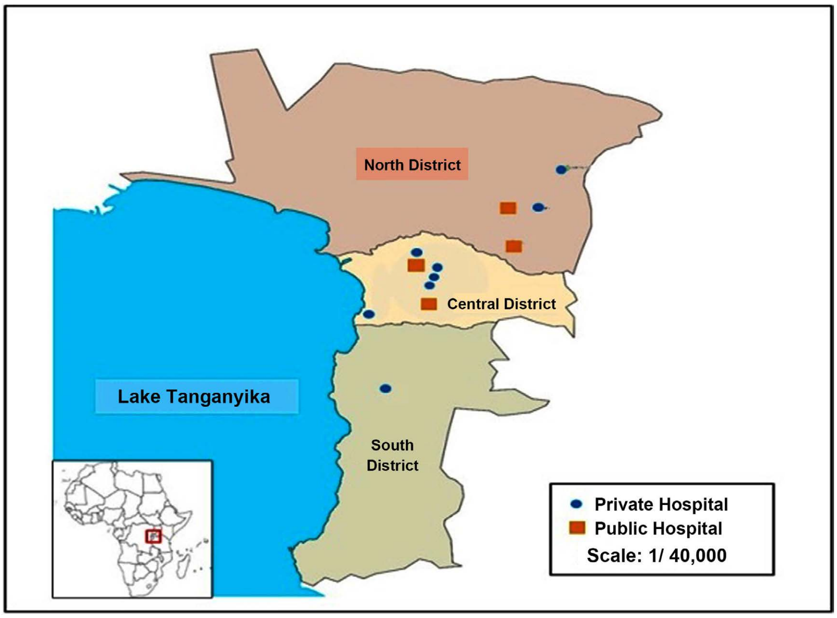


Figure 1. Map showing the health care facilities selected to assess the generation and management status of HSMW in Bujumbura, Burundi [23].

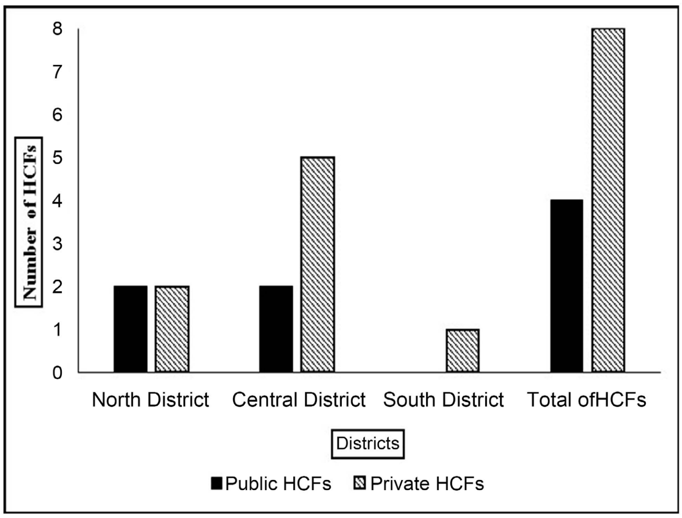


Figure 2. Health Care Facilities in the study area.

4. Data Collection and Analysis

This study used the emergy methodology to evaluate the relative efficiencies of three treatment methods used for to treat SMW in twelve HCFs in Bujumbura such as low temperature incinerator, organic pit and landfill. The details information was obtained from the ministry of health of Burundi and some societies in charge of construction in Burundi [24]. These data are detailed in the following situation: weight for machine, work hours for machine, life hours for machine, life time for treatment method, total quantity used for each item, work hours for worker, money paid for labor (all people involved during construction and operation phases) during one hour, and money paid for purchases (services)

(**Appendix A**: Note 1, 2, and 3). The raw data (annual use) for the three treatment methods selected were based on the construction and operation phases.

The first step was the definition of an evaluation boundary for a system under consideration where a system diagram was constructed using the energy systems language (Table 3). The evaluation boundary of this study was conducted referring to final treatment methods of SMW at on-site and off-site in Bujumbura-Burundi (Figure 3).

The second step was corresponding to the emergy calculation, where the first is divided in two sections such as construction and operation. The raw data (annual use) was calculated for each item in these three treatment methods for construction and operation phases (**Appendix A**: footnotes for incinerator, footnotes for organic pit, and footnotes for landfill). This study used the unit emergy values (UEVs) in the fifth column in Tables 5-7 obtained from published literature, statistical references, or personal communications.

Emergy evaluation tables are constructed in the third step of evaluation. Raw data that are corresponding with their specific items, services and labor for each treatment method were included in the third column of emergy table (Tables 5-7). Emergy of each item (sixth column) was then calculated by multiplying raw data by its specific EUV. Based on the characteristics of types of wastes treated and regulations for these three methods assessed in this part. It is important to compare the money-equivalent cost and pure market-based cost or money cost of low temperature incinerator and organic pit (Table 5, Table 6).

Emergy cost for to treat one ton of SMW for low temperature incinerator and organic pit were converted in money-equivalent cost by dividing the emergy cost use per ton per year by emergy-money ratio (1.27E+13). Then, the money-

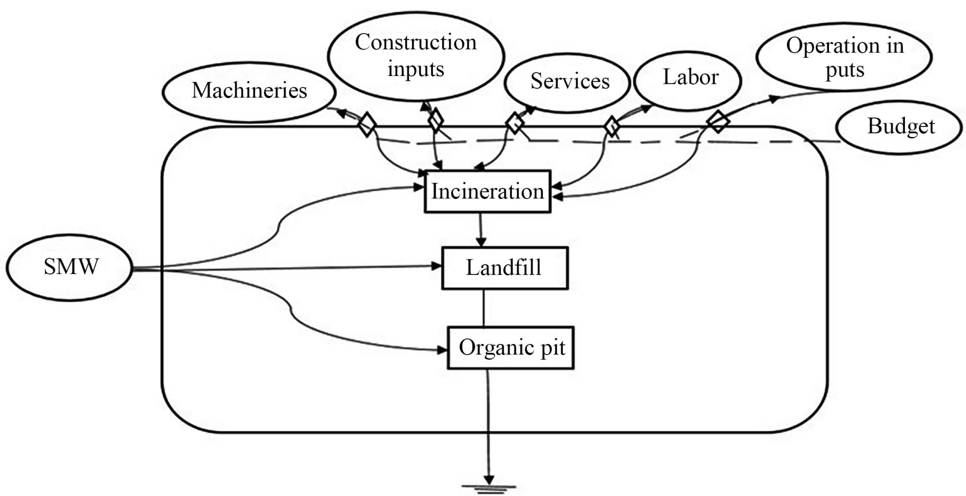


Figure 3. Energy systems diagram for SMW treatment methods in Bujumbura-Burundi. Final treatment was the main target for the emergy evaluation of final treatment methods. Three treatment methods were selected for the evaluation: Low temperature incineration, landfill and organic pit.

equivalent cost of low temperature incinerator was compared with the money-equivalent cost of organic pit (Table 5, Table 6). Pure market-cost or money cost of low temperature incinerator was compared with pure market-cost or money cost of organic pit, where the cost (USD)/ ton /yr of low temperature incinerator was divided by the cost (USD)/ ton /yr of organic pit (Table 8, Table 9). To improve the SMW treatment in Bujumbura, Burundi, emergy use to treat one ton of SMW for low temperature incinerator and landfill was compared with the emergy use per ton to treat one ton of solid municipal waste developed through different previous studies or literature conducted in different countries. Based on the comparison, some improvements were suggested to the Burundi government.

5. Results and Discussion

5.1. Results

Yearly Quantity of SMW Generated in 12 HCFs

The detailed classification and 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 period of 2011-2014 (Table 4). Pathological waste and

Table 2. Types of SMW in Bujumbura and their methods treatment.

Types of waste	Treatment methods
Medical sharps waste	Incineration method
Infectious waste	Incineration method
Pathological waste and placenta	Organic pit
Chemical and Radioactive waste	Incineration method
Absorbent cotton, discarded medical plastics	Uncontrolled landfill

Table 3. Energy systems symbols that are used in this study [16].

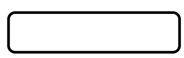
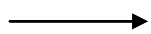
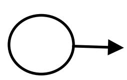
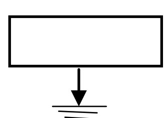
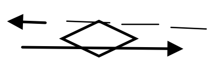
Symbols	Description
	System boundary: a rectangular box drawn to represent the boundaries of the system under evaluation.
	Pathway: flow of energy, material, or information.
	Source: outside source of energy of energy delivering forces according to a program controlled from outside.
	Box: miscellaneous 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).

Table 4. 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, and placenta*	Pharmaceutical waste	Chemical and radioactive waste	Absorbent cotton discarded medical plastics,	Total
HCF 1	150,625	8100	512,550(2,325)	339,475	8825	289,000	1,308,575
HCF 2	700	375	6500 (182.5)	4357	500	3250	15,682
HCF 3	6500	4500	252,580 (1,725)	178,985	3880	130,080	576,525
HCF 4	1100	1050	16,000 (108.7)	9750	2580	6125	36,605
HCF 5	1800	565	16,480 (98.7)	12,900	705	4650	37,100
HCF 6	205,750	9750	645,000 (4,800)	503,750	200,362	315,187	1,879,800
HCF 7	2406	1400	15,225 (95)	12,251	2250	4812	3,8345
HCF 8	13,750	1267	72,150 (420.5)	51,750	7520	24,000	170,438
HCF 9	1587	75	5507 (44.7)	3810	312	2501	13,794
HCF 10	6500	3725	50,000 (25.2)	32,300	3000	21,250	116,775
HCF 11	3000	2050	10,000 (815)	8809	3025	4500	31,385
HCF 12	1550	566	5052 (161.2)	4380	712	2400	14,661
Total	395,268	33,424	1,607,045 (10801.7)	1,162,518	233,673	807,756	4,239,687

* The value in parentheses is placenta only.

tissue accounted for 37.9% of SMW, mostly from services such as maternity and surgery [2]. 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 [25] [26].

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 and the poor treatment, the amount of infectious waste can be much larger than that shown in **Table 2** and **Figure 4**, **Figure 5**, 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 [27]. 18.83% of infectious wastes and 8.11% of pathological wastes are the largest part of medical wastes in India except for general wastes [28]. 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. In addition, the treatment methods used in Bujumbura are not adequate, therefore, the wastes are not completely treated and the risk to the people and environment is still highly. The need by changing the treatment is an emergency situation in Bujumbura.

(a) (b)

Figure 4. Incinerators used to treat solid medical wastes in 12 HCFs in Bujumbura, Burundi. (a) Low temperature incinerator (<300˚C - 400˚C) used by 11HCFs and (b) Medium temperature incinerator (700˚C) used by 1 HCF.

(a)

(b) (c)

Figure 5. 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).

5.2. Current Treatment of Five Types of SMW in 12 HCFs of Bujumbura

5.2.1. Emergy Evaluation of Incineration Method

Table 5 shows the emergy evaluation of low temperature incinerator in 12 HCFs of Bujumbura. The total emergy input to treat 1284 tons of SMW by 12 HCFs was calculated as 1.36E+20 seJ/yr (Table 5). The machineries (bulldozer, compactor and truck) used for land area preparation such was a total of 21,200 g/yr (Table 5). The materials for the construction of furnace and small building such as sand, fire bricks, gravel, stone, galvanised metal, nails, wood, concrete and water was a total of 1.92E+07 g/yr and 8.80E+10 J/yr, 4.44E+10 J/yr and

1.80E+10 J/yr for fuel, lubricants and electricity, (estimated with 3.52E+7 J/liter, 3.70E+7 J/liter, and 3.6E+6 J/kWh), respectively. In other hand, the materials used for construction of septic tank for metal residues such as sand, fire bricks, gravel, galvanised metal and concrete was a total of 1.84E+06 g/yr. Labor cost of masons, help masons and drivers of trucks that were involved for land preparation and construction process was calculated to be 19,152 USD. Services related to the different items used during land preparation and construction process were 22,725 USD.

Table 5. Emergy evaluation of incinerator in 12 HCFs of Bujumbura.

No.	Item	Raw Data		UnitEmergy Value (sej/unit)		UEV source	Emergy (sej/yr)
			Construction				
			Machinery for preparation				
1	Bulldozer	7778	g/yr	2.20E+10	sej/g	A	1.71E+14
2	Compactor	6222	g/yr	2.20E+10	sej/g	A	1.37E+14
3	Truck	7200	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	9.20E+04	sej/J	D	5.52E+09
11	Concrete	3.33E+05	g/yr	3.04E+09	sej/g	E	1.01E+15
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	3.04E+09	sej/g	D	1.52E+14
			Labor and services				
21	Labor	1277	USD/yr	1.27E+13	sej/$	I	1.62E+16
22	Services	1515	USD/yr	1.27E+13	sej/$	I	1.92E+16

Continued

			Operation				
			Materials				
23	Fuels(diesel)	1.69E+11	J/yr	1.89E+05	sej/J	G	3.19E+16
24	Chemical: Chlolexidine	3.82E+05	g/yr	1.27E+13	sej/g	J	4.85E+18
			Labor and services				
25	Labor	4262	USD/yr	1.27E+13	sej/$	I	5.41E+16
26	Services	8880	USD/yr	1.27E+13	sej/$	I	1.13E+17
Total					1.36E+20 sej/yr		
Total of SMW treated					1284 ton/yr		
Emergy per Ton of SMW					1.06E+17 sej/ton SMW treated		

>UEV [12] [16] [29]-[34]. >All UEVs were adjusted to the global renewabel emergy baseline of 15.83. > Data related use life of different materials and life time of incinerator were collected from the ministry of health public of Burundi through its department in charge of construction and infrastructures and in some societies in charge of construction in African.

Chemical like chlolexidine used yearly for to treat SMW was 3.82E+05 g/yr (estimated with 1.06 g/ml of density). The fuel used during operation phase was the largest quantity compare to that used during construction processes (1.69E+11 J/yr to 8.80E+10 J/yr). Labor cost (yearly) to treat SMW was 1277 USD/yr and services cost was 1515 USD/yr. The cost for labor and services during operation was highest compare to the cost for labor and services during construction processes with 4262.4 USD, and 8880 USD, respectively. The cost to treat one ton of SMW was calculated to be 2.12E+14 USD/ton/yr (**Table 9**). Labor and services to treat SMW accounted different percentages among the expenses, *i.e.* 34.7% and 65.3%, respectively (**Table 8**). The contribution of labor for the treatment was (smaller or highest) that that in emergy investment.

5.2.2. Emergy Evaluation of Organic Pit

The emergy evaluation of organic pit in twelve HCFs of Bujumbura is presented in **Table 6**. The total emergy input to treat 1617.85 tons of SMW by 12 HCFs was calculated as 1.68E+18 sej/yr (**Table 6**). Truck used for land area preparation was a total of 5000 g/yr (**Table 6**). Moreover, the materials used for construction such as gravel, sand, cement, galvanised metal, fire bricks, metallic cover, PVC and water was a total of 1.E+07 g/yr. Labor cost such as masons, help masons and driver of truck during the land area preparation and construction processes was 215 USD/yr and the cost related to the services was 825 USD/yr. The materials used during operation such as wheelbarrow (with life time of 2 years) and charcoal was a total of 15,000 g/yr, 60,000 g/yr, respectively. Labor cost to treat SMW was 595 USD/yr and services cost was 1250 USD/yr. The total money used for labor and services during construction was 2580 USD and 9905

USD, respectively. The annual cost for labor and cost was 215 USD and 825 USD, respectively. The labor cost and services cost used during construction and operation was in the following situation 28.04%, and 71.96%, respectively (Table 8). The cost to treat one ton of SMW was calculated to be 2.27E+13 USD/ton/yr (Table 6).

Table 6. Emergy evaluation of organic pit in 12 HCFs of Bujumbura.

No.	Item	Raw Data		Unit Emergy Value (sej/unit)		UEV source	Emergy (sej/yr)
				Construction			
				Machinery			
1	Truck	5000	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	3.04E+09	sejg	b	1.90E+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	USD/yr	1.27E+13	sej/$	e	2.73E+15
11	Services	825	USD/yr	1.27E+13	sej/$	e	1.05E+16
	Operation						
12	Wheelbarrow	15,000	g/yr	1.39E+10	Sej/g	b	2.09E+14
13	Charcoal	6.00E+04	g/yr	1.18E+05	Sej/J	f	7.08E+09
				Labor and services			
14	Labor	595.3	USD/yr	1.27E+13	sej/$	e	7.56E+15
15	Services	1250	USD/yr	1.27E+13	sej/$	e	1.59E+16
	Total						1.68E+18sej/yr
Total of SMW treated							1617.85 Ton/yr
Emergy use per ton of SMW treated							1.04E+15 sej/ton SMW treated

>UEV [12] [16] [29] [30] [31]. >All UEVs were adjusted to the global renewabel emergy baseline of 15.83. > Data related use life of different materials and life time of organic pit were collected from the ministry of health public of Burundi through its department in charge of construction and infrastructures and in some societies in charge of construction in African.

5.2.3. Emergy Evaluation of Landfill

Table 7 shows the emergy evaluation for landfill in twelve HCFs of Bujumbura. The total emergy input to treat 4060 tons of municipal solid (77.74%) and 1162.53 tons of SMW (22.26%) by 12 HCFs was calculated as 3.54E+17 seJ/yr (Table 7). The machineries used for land area preparation such as bulldozer, compactor and truck was a total of 38,000 g/yr (Table 7). The materials used for landfill area preparation such as dry mund, clay and sand was a total of 1.47E+07 g/yr. The materials used for the office building construction such as sand, fire bricks, gravel, galvanised metal, sheet metal, concrete, wood and water was a total of 3.04E+07 g/yr. Labor cost related to the masons, help masons and drive of truck was 3098 USD/yr, and service cost was 2257 USD/yr for the total of 46,468 USD and 33,860 USD, respectively. The machineries used during operation such as excavator and truck was a total of 280,800 g/yr. Moreover, the raw data for chemical, fuels and electricity used during operation phase was 3.05E+06 g/yr, 1.06E+12 J/yr, 1.74E+09 J/yr, (estimated with 1.06 g/ml, 3.52E+7 J/liter, and 3.6E+6 J/kWh), respectively. In the same phase of operation, labor cost such as driver of excavator and workers for landfill was 17,164.8$/yr and service was 64,710$/yr. The cost to treat one ton of SMW was calculated to be 2.12E+14 USD/ton/yr (Table 9). Labor and services to treat SMW accounted different percentages among the expenses, *i.e.* 23.22% and 76.78%, respectively (Table 8).

Table 7. Emergy evaluation of landfill in 12 HCFs of Bujumbura.

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	8000	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	2.90E+09	sej/g	b	7.73E+15
5	Clay	8.00E+06	g/yr	2.90E+09	sej/g	b	2.32E+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	3.04E+09	sej/g	d	2.53E+15

Continued

13	Water	1.00E+06	g/yr	8.14E+04	sej/g	e	8.14E+10
14	Wood	8.50E+04	g/yr	9.20E+04	sej/J	f	7.82E+09
			Labor and services				
15	Labor	3098	USD/yr	1.27E+13	sej/$	g	3.93E+16
16	Services	2257	USD/yr	1.27E+13	sej/$	g	2.87E+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: Chlolexidine	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	USD/yr	1.27E+13	sej/$	g	2.18E+17
23	Services	64,710	USD/yr	1.27E+13	sej/$	g	8.22E+17
Total					1.59E+18 sej/yr		
Solid municipal waste treated					4060 Ton/yr		
SMW treated					1163 Ton/yr		
Total of wastes treated					5223 Ton		
% of Solid municipal waste treated					77.7%		
% of SMW treated					22.3%		
Total emergy used for SMW					3.54E+17 sej/yr used for SMW		
Emergy use per ton of SMW					3.04E+14 sej/ton SMW treated		

*Total of SMW and general wastes treated into the landfill. >UEV [12] [16]-[34]. >All UEVs were adjusted to the global renewabel emergy baseline of 15.83. > Data related use life of different materials and life time of landfill were collected from the ministry of health public of Burundi through its department in charge of construction and infrastructures and in some societies in charge of construction in African.

Table 8. Cost for treating one ton of SMW through three treatment methods.

Treatment methods	Steps	Raw data	Units	Percentage (%)
Organic pit	**Construction**			
	Labor	2.73E+15	USD/yr	7.45
	Services	1.05E+16	USD/yr	28.60
	Operation			
	Labor	7.56E+15	$/yr	20.62
	Services	1.59E+16	$/yr	43.31

Continued

	Total	3.66E+16		
	SMW treated	1617.85	ton	
	Cost per ton of SMW	2.27E+13	USD/yr/ton	100.0
Landfill		**Construction**		
	Labor	3.93E+16	$/yr	3.55
	Services	2.87E+16	$/yr	2.59
	Operation			
	Labor	2.18E+17	$/yr	19.67
	Services	1.26E+18	$/yr	74.18
	Total	1.11E+18 (5222.53 Ton*)		
	SMW treated	1162.53 (22.26%)	Ton	
	Emergy cost for SMW	2.74E+17		
	Cost per ton of SMW	2.12E+14	USD/yr/ton	100.0
Incinerator		**Construction**		
	Labor	1.62E+16	$/yr	8.01
	Services	1.92E+16	$/yr	9.50
	Operation			
	Labor	5.41E+16	$/yr	26.75
	Services	1.13E+17	$/yr	55.72
	Total	2.02E+17		
	SMW treated	1284.365	ton	
	Cost per ton of SMW	1.57E+14	USD/yr/ton	100

*Total of SMW and general wastes treated into the landfill.

5.3. Discussion

5.3.1. Comparison between Low Temperature Incinerator and Organic

Table 9 presents the comparison of money-equivalent cost and pure market-based cost of SMW treatment between low temperature incinerator and organic pit. The emergy invested for one ton per year (seJ/ton/yr) was 1.06E+17 seJ, 1.04E+15 seJ, respectively for low temperature incinerator, and organic pit. This shows that the high money-equivalent cost was observed for the low temperature with 8,346.4 times compare to the organic pit presenting 81.8 times (Table 9). The monetary cost invested or pure market-based cost of these two methods for treating one ton of waste per year (USD/ton/yr) was 1.57E+14, and 2.27E+13 for temperature incinerator and organic pit, respectively. The findings show that the low temperature incinerator was highest with 6.91 times compare to organic pit (Table 9). The organic pit presents the lowest money-equivalent cost and pure market-based cost in this study. It is explained by the fact that the construction

Table 9. Comparison of money-equivalent cost and pure market-based cost of SMW treatment.

Treatment methods	Emergy (seJ/ton/yr)	Money-equivalent cost	Pure market-based cost	Ratio
Incineration	1.06E+17	3.E+02	1.57E+14	6.91
Organic pit	1.04E+15	3.E+00	2.27E+13	1

and operation phases of organic pit presented few materials and equipment compare to those used for low temperature incinerator (**Appendix A**, footnotes Tables 5-7). Moreover, the materials allocated for construction and operation present a total different amount (**Table 5**, **Table 6**). In addition, the services and labor account in all two treatment methods were totally different and it is the same for their ratios (**Table 9**). Even the organic pit in this part was assessed to be the method with lowest money-equivalent cost and pure market-based cost, it cannot explain to be a better method than low temperature incinerator even if it was used for treating a large quantity of wastes compare to the low temperature incinerator ((6471.4 tons (38.15%) than 5837.4 tons (34.42%)) (**Table 3**, **Table 4**). It was used to treat one type of SMW (pathological waste and tissues, and placenta), however, the low temperature was used for several types of wastes (sharps wastes, infectious wastes, chemical and radioactive wastes, and absorbent cotton waste). In term of safety, the organic pit is recommended by WHO in the case of absence of the incinerator with high temperature (WHO, 2014). Therefore, the low temperature incinerator should be replaced by the high temperature with air control pollution recommended by WHO to treat different types of wastes including pathological waste (infectious waste, pharmaceutical waste, chemical waste, absorbent waste, pathological waste, and placenta) (WHO, 2014). Currently, in Bujumbura, these two methods are not protected and covered (**Figure 4(a)**, **Figure 5(c)**). This shows that the risks could happen during the rainy season or flooding, especially for the organic pit and 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) for low temperature incinerator [2] [35]. Based on the lowest emergy cost and safety treatment of organic pit, it is important to maintain it temporary by ensuring its improvement first with fence, roof, drainage channel, and adequate maintenance (monitoring always). Burundi government should take account to the high risk caused by the low temperature incinerator and replace it by a high temperature incinerator with air pollution control in the reason of its capacity for to treat several types of wastes [2]. In all situations, the distance between the resident area of site area of treatment and households should be respected as recommended by WHO [2].

5.3.2. Current Analysis Practices Compare to the New Technologies

Even if the emergy evaluation was not conducted for SMW, however, it was applied for the municipal solid wastes management in some countries [12] [13] [14]. The results of this study can be compared to the results developed in the previous studies or literature in other countries. It is important to compare the emergy investment per ton/yr with the capacity of new technologies for to reduce the potential risks in Bujumbura. Through these results, Burundi government can improve the current treatment methods by focusing on cost and the reducing risks. In this study, the emergy investment per ton/yr for low temperature incinerator and uncontrolled landfill was 1.06E+17, and 3.04E+14, respectively. The results of this study show that the low temperature incinerator present a high emergy investment, but it was used for to treat several types of wastes in twelve HCFs of Bujumbura. However, the landfill was used for to treat one type of waste (**Table 3**). A study conducted in Italy for emergy assessment of incineration and landfilling of municipal solid waste in Italy has shown that the incineration and landfilling require almost the same emergy investment per ton/yr with 1.27E+14 and 1.47E+14 Sej/t/yr, respectively. The incineration was found to be more efficient compare to the landfill, because it presents the advantage for reducing the final volume of wastes to less than 30% and it was found to contribute for preventing the environmental problems because its air control pollution. However, the landfilling has been assessed with the largest inputs for construction materials and management, and with a big land surface required for wastes disposal [13]. Based on the results developed in the previous study in Italy, Burundi government can plan how to improve the final treatment of SMW by considering in priority to change the low temperature incinerator by high temperature incinerator with air control pollution, considering its advantages related to the treatment of several times of wastes and its capacity of reducing risks to human health and environment. The study conducted in China (Beijing) on the emergy-LCA analysis of municipal solid waste management: Modelling source-separated collection and transportation based on the emergy investment per ton/yr of two types of landfill (with leachate disposal and without leachate disposal), and high temperature incinerator. The results have shown that the cost was significantly different between different types of landfills and incinerators. The landfill without leachate disposal system was the least expensive (1.02E+13 seJ/t), the landfill with leachate disposal system was expensive (1.35E+13 seJ/t), but it was assessed to be adequate method with safety. The more emergy in puts were observed for fluidized bed incineration for 4.27E+13 seJ/t. In this study, they have considered the sanitary landfill as the best performance, considering the demand for ecological services and negative impact related to the emission [12]. This study can help Burundi government for to choose the type of landfill (leachate disposal) based on the efficiencies in terms of ecological, human health and current economic situation of the country.

In conclusion, the results developed in these two countries could help Burundi government to improve the final treatment methods currently used by replacing the low temperature incinerator with the high temperature with air control of pollution and uncontrolled landfill with sanitary landfill for reducing the risk caused.

5.3.3. Implication for Improvement of Evaluated Treatment Methods

Except the organic pit that can be used for treating the SMW when it respects the engineering condition as recommended by WHO, however, the low temperature incinerator and landfill are not recommended by WHO in reason of their incapacity to treat completely the wastes and their bad design (engineering condition). High temperature incinerator with air pollution control and sanitary landfill are highly recommended by WHO [2]. Developed countries like USA, EU and Canada use the high temperature incinerator with air pollution control and sanitary landfill for to treat the SMW and general wastes in the majority HCFs, respectively [36] [37]. High temperature incinerator with air pollution control is the first method used for to treat several types of wastes. In this study, except organic pit recommended by WHO for to treat the pathological waste and placenta, however, low temperature incinerator and landfill used in Bujumbura were not adequate for to treat safely the SMW (**Figures 4(a)**, **Figure 4(b)**, **Figures 5(a)-(c)**).

Considering the current situation, organic pit could be more efficient treatment method than low temperature incinerator and landfill in terms of cost and safe (reducing of risks to human health and environment), however its poor design (lack of fence, roof, drainage channel) could cause a high risk to the ground water, soil, surrounding environment, nearby resident, and waste workers. Therefore, its maintenance in all HCFs by fence, roof, drainage channel and regular monitoring is an emergency situation. It could be used temporal by pending the implementation the high temperature incinerator with air pollution control by the government. Because several types of wastes (sharps waste, infectious waste, pharmaceutical waste and discarded medical plastics, chemical waste, radioactive waste and absorbent cotton) were treated by using low temperature incinerator. For to reduce the risk in all HCFs, high temperature incinerator with air pollution control should be implemented. The area should be protected by fence for avoiding the entrance of people and animals inside of its location area. The distance between the residence area of incinerator and households should be respected. One type of SMW (pharmaceutical waste and discarded medical waste) was treated by using uncontrolled landfill. Therefore, to reduce the risk to the human health and environment, Burundi government should introduce the sanitary landfill with leachate disposal. The distance separating the households and landfill should be respected for preventing the transmission of diseases. In addition, a national program for SMW treatment could be an option for resolving the great issue related to the improper SMW treatment in Bujumbura and could contribute for reducing the impacts on human health and environment. However, the effectiveness of the programs varies according to the condition of countries [38]. In developed countries like USA and Korea, there are different centers where the wastes from different HCFs are treated referring to the norms set out by the program in charge of medical waste management. For example, in Korea, a work process of RFID system was set out, that system covers all process, from generation to final disposal [2] [12] [35] [36]. Specific policies and proper treatment methods based on the emergy and money cost should be introduced by Burundi government in order to promote the proper SMW management.

5.4. Conclusion and Suggestion for Optimization of Three Treatment Methods

The using of treatment methods that are not corresponding to the norms required for SMW treatment could impact negatively on the human health and ecological services [2]. It is extremely important to improve the proper treatment methods of SMW in Bujumbura, Burundi. In this study, through the emergy evaluation, three treatment methods used in twelve HCFs of Bujumbura were assessed. The process was based on construction and operation phases for each type of treatment method where the emergy (seJ/ton/yr) and Cost (USD/ton/yr) were assessed. The total emergy input was 1.36E+20 seJ/yr, 3.54E+17 seJ/yr, and 1.681E+18 seJ/yr for low temperature incinerator, landfill and organic pit, respectively. The emergy and cost invested for treatment methods were divided as follows: 1.06E+17 seJ/ton/yr, 1.58E+14 USD/ton/yr for low temperature incinerator, 3.04E+14 seJ/ton/yr, 2.12E+14 USD/ton/yr for landfill, 1.04E+15 seJ/ton/yr 2.27E+13 USD/ton/yr for organic pit.

For assessing the cost and safety of each treatment method, the comparison of money-equivalent cost and pure market-based cost between low temperature incinerator and organic pit were assessed in this study, and the analysis practices (low temperature incinerator and uncontrolled landfill) were compared with new technologies. Low temperature incinerator was found to be highest for money-equivalent cost with 8346.4 times compare to the organic pit presenting 81.8 times, and for pure market-based cost with 6.91 times compare to organic pit.

Rapid improvement of 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 energy and cost requirement and is desirable to be maintained in all HCFs by respecting its maintenance (fence, roof and monitoring evaluation) for reducing the risk. Low temperature incinerator has the advantages to treat several types of SMW compare to the rest of treatment methods. Landfill is commonly used for all HCFs and it is used also to treat municipal solid wastes. These two improper treatment methods should be replaced for respecting the effectiveness and efficiency related to human health and environment, as recommended by WHO [2]. 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 treat completely most of infectious medical wastes types. Sanitary landfill is indicated for to treat general wastes after pretreatment [2].

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix A: Footnotes of Raw Data Related to Low Temperature Incinerator, Organic Pit and Landfill in 12 HCFs

Footnote 1. Raw data related to low temperature incinerator.

A. Construction			
Machinery for preparation			
1. Bulldozer (one bulldozer used)			ETRACO
Weight of bulldozer used	=	25,000 kg	
Total work hours of bulldozer	=	56 hrs	
Life hours of bulldozer	=	12,000 hrs	
Bulldozer used for the construction	=	Weight of bulldozer × Work hours/Life hours of bulldozer	
	=	117 kg	
Life time of incinerator	=	15 yrs	
	=	Bulldozer used/Life time of incinerator	
Annual use of bulldozer		7778 g/yr	
2. Compactor (one compactor used)			ETRACO
Weight of compactor used	=	20,000 kg	
Total work hours of compactor	=	56 hrs	
Life hours of compactor	=	12,000 hrs	
Compactor used for the construction	=	Weight of compactor × Work hours/Life hours of compactor	
	=	93 kg	
Annual use of compactor	=	Compactor used/Life time of incinerator	
	=	6222 g/yr	
3. Truck (one truck used)			ETRACO
Weight of truck used	=	9000 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	
Life time of incinerator	=	15 yrs	
Annual use of truck	=	Truck used/Life time of incinerator	
	=	7200 g/yr	
Materials used for the landfill preparation			
4. Sand			ETRACO
Total quantity used	=	100,000	
Annual use of sand	=	Total quantity used/Life time of incinerator	
	=	6.67E+05 g/yr	
5. Fire bricks			AGCOL
Total quantity used	=	50,000	

Continued

Annual use of fire bricks	=	Total quantity used/Life time of incinerator	
	=	3.33E+06 g/yr	
6. Gravel			
Total quantity used	=	105,000 kg	ETRACO
Annual use of gravel	=	Total quantity used/Life time of incinerator	
		7.00E+06 g/yr	
7. Galvanised metal			
Total quantity used	=	6000 kg	AGCOL
Annual use of galvanised metal	=	Total quantity used/Life time of incinerator	
		4.00E+05 g/yr	
8. Sheet metal			AGCOL
Total quantity used	=	612 kg	
Annual use of sheet metal	=	Total quantity used/Life time of incinerator	
	=	4.08E+04 g/yr	
9. Nails			ETRACO
Total quantity used	=	5 kg	
Annual use of nails	=	Total quantity used/Life time of incinerator	
	=	3.33E+02 g/yr	
10. Wood			AGCOL
Total quantity used	=	900 kg	
Annual use of concrete	=	Total quantity used/Life time of incinerator	
	=	6.00E+04 g/yr	
11. Concrete			ETRACO
Total quantity used	=	5000 kg	
Annual use of concrete	=	Total quantity used/Life time of incinerator	
	=	3.33E+05 g/yr	
12. Water			AGCOL
Total quantity used	=	20,000 liter	
Annual use of water	=	Total quantity used/Life time of incinerator	
	=	1.33E+06 g/yr	
13. Fuels			AGCOL
Annual use of diesel	=	2.50E+03 liter/yr	
Energy of fuel	=	Annual use × 3.52E7 J/liter	
	=	8.80E+10 J/yr	
14. Lubricants			AGCOL
Annual use of lubricants	=	1.20E+03 liter/yr	
Energy of fuel	=	Annual use × 3.70E7 J/liter	
	=	4.44E+10 J/yr	

Continued

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	
	=	1.00E+06 g/yr	
16. Sand			
Total quantity used	=	15,000 kg	AGCOL
Annual use of sand	=	Total quantity used/Life time of incinerator	
	=	1.00 E+06g/yr	
17. Fire bricks			ETRACO
Total quantity used	=	4000 kg	
Annual use of fire bricks	=	Total quantity used/Life time of incinerator	
	=	2.67E+05 g/yr	
18. Gravel			ETRACO
Total quantity used	=	7000 kg	
Annual use of gravel	=	Total quantity used/Life time of incinerator	
	=	4.6E+05 g/yr	
19. Galvanised metal			ETRACO
Total quantity used	=	900 kg	
Annual use of galvanised metal	=	Total quantity used/Life time of incinerator	
	=	5.00E+04 g/yr	
20. Concrete			AGCOL
Total quantity used	=	750 kg	
Annual use of concrete	=	Total quantity used/Life time of incinerator	
	=	5.00E+04 g/yr	
21. Labor			ETRACO
Money paid for labor	=	19,152 USD	
Annual cost of labor	=	Money paid for labor/Life time of incinerator	
	=	1277 USD/yr	
22. Services		22,725 USD	ETRACO
Money paid for purchases	=	Money paid for services/Life time of incinerator	
	=	1515 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/yr	

Continued

24. Chemical (Chlorhexidine)			MHO, 2010
Annual use of chlorhexidine	=	3.60E+02 liter/yr	
Density	=	1.06 g/ml	
Mass of chlolexidine solution	=	3.82E+05 g/yr	
		Labor and services	
25. Labor			MHO, 2010
Money paid for labor	=	4262 USD/yr	
26. Services			MHO, 2010
Money paid for purchases	=	8880 USD/yr	

Footnote 2. Raw data related to organic pit.

		A. Construction	
		Machinery	
1. Truck (one truck used)			ETRACO
Weight of truck used	=	5000 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/Life time of organic pit	
	=	5000 g/yr	
		Materials used for the landfill preparation	
2. Gravel			ETRACO
Total quantity used	=	16,000 kg	
Annual use of gravel	=	Total quantity used/Life time of organic pit	
		1.33E+06 g/yr	
3. Sand			ETRACO
Total quantity used	=	15,000 kg	
Annual use of sand	=	Total quantity used/Life time of organic pit	
	=	1.25 E+06g/yr	
4. Concrete			AGCOL
Total quantity used	=	7500 kg	
Annual use of concrete	=	Total quantity used/Life time of organic pit	
	=	6.25E+05 g/yr	
5. Galvanised metal			ETRACO
Total quantity used	=	300 kg	
Annual use of galvanised metal	=	Total quantity used/Life time of organic pit	
		2.50E+04 g/yr	

Continued

6. Fire bricks			ETRACO
Total quantity used	=	75,000	
Annual use of fire bricks	=	Total quantity used/Life time of organic pit	
	=	6.25E+06 g/yr	
7. Cover			
Total quantity used	=	1 kg	ETRACO
Annual use of cover (steel griller)	=	Total quantity used/Life time oforganic pit	
	=	8.33E+0.1 g/yr	
8. Ventulation			ETRACO
Total quantity used	=	15 kg	
Annual use of water	=	Total quantity used/Life time of organic pit	
	=	8.33E+05 g/yr	
9. Water			AGCOL
Total quantity used	=	20,000 liter	
Annual use of water	=	Total quantity used/Life time of organic pit	
	=	1.33E+06 g/yr	
		Labor and services	
10. Labor			
Money paid for labor	=	2580 USD	ETRACO
Annual cost of labor	=	Money paid for labor/Life time of organic pit	
	=	215 USD/yr	
11. Services			
Money paid for purchases	=	9905 USD	ETRACO
	=	Money paid for services/Life time of 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/life time of wheelbarrows	
	=	15,000 g/yr	
13. Charcoal			MHO, 2010
Annual use of charcoal	=	60,000 g/yr	
		Labor and services	
14. Labor			MHO, 2010
Money paid for labor	=	595 USD/yr	
15. Services			MHO, 2010
Money paid for purchases	=	1250 USD/yr	

Footnote 3. Raw data related to landfill.

A. Construction			
Machinery for preparation			
1. Bulldozer (one bulldozer used)			ETRACO
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 bulldozer	
	=	250 kg	
Life time of landfill	=	15 yrs	
	=	Bulldozer used/Life time of landfill	
Annual use of bulldozer		16,667 g/yr	
2. Compactor (one compactor used)			ETRACO
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 compactor	
	=	200 kg	
Annual use of compactor	=	Compactor used/Life time of landfill	
	=	13,333 g/yr	
3. Truck (one truck used)			ETRACO
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/Life time of landfill	
	=	8000 g/yr	
Materials used for the landfill preparation			
4. Dry mud			EBATRACO
Total quantity used	=	40,000 kg	
Annual use of dry mud	=	Total quantity used/Life time of landfill	
	=	2.67E+06 g/yr	
5. Clay			EBATRACO
Total quantity used	=	120,000 kg	
Annual use of clay	=	Total quantity used/Life time of landfill	
	=	8.00E+06 g/yr	

Continued

6. Sand			EBATRACO
Total quantity used	=	60,000	
Annual use of sand	=	Total quantity used/Life time of landfill	
	=	6.67E+05 g/yr	
Materials used for the office building construction			
7. Sand			EBATRACO
Total quantity used	=	87,500	
Annual use of sand	=	Total quantity used/Life time of landfill	
	=	5.83E+06 g/yr	
8. Fire bricks			EBATRACO
Total quantity used	=	45,000	
Annual use of fire bricks	=	Total quantity used/Life time of landfill	
	=	3.00E+06 g/yr	
9. Gravel			EBATRACO
Total quantity used	=	105,000 kg	
Annual use of gravel	=	Total quantity used/Life time of landfill	
		7.00E+06 g/yr	
10. Galvanised metal			EBATRACO
Total quantity used	=	190,000 kg	
Annual use of galvanised metal	=	Total quantity used/Life time of landfill	
		1.27E+07 g/yr	
11. Sheet metal			AGCOL
Total quantity used	=	10,020 kg	
Annual use of sheet metal	=	Total quantity used/Life time of landfill	
	=	6.68E+04 g/yr	
12. Concrete			ETRACO
Total quantity used	=	12,500 kg	
Annual use of concrete	=	Total quantity used/Life time of landfill	
	=	8.33E+05 g/yr	
13. Water			
Total quantity used	=	15,000 liter	AGCOL
Annual use of water	=	Total quantity used/Life time of landfill	
	=	1.00E+06 g/yr	
14. Wood			AGCOL
Total quantity used	=	1275 kg	
Annual use of concrete	=	Total quantity used/Life time of landfill	
	=	8.50E+04 g/yr	

Continued

		Labor and services	
15. Labor			ETRACO
Money paid for labor	=	46,468 USD	
Annual cost of labor	=	Money paid for labor/Life time of landfill	
	=	3098 USD/yr	
16. Services		33,860 USD	ETRACO
Money paid for purchases	=	Money paid for services/Life time of landfill	
	=	2257 USD/yr	
		B. Operation	
17. Excavator (one excavator used)			ETRACO
Weight of excavator used	=	17,000 kg	
Total work hours of excavator	=	104 hrs	
Life hours of excavator	=	10,000 hrs	
Annual use of excavator	=	Weight of excavator × Work hours/Life hours	
	=	176,800 g/yr	
18. Truck (one truck used)			ETRACO
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	=	3.05E+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/yr	
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	

Continued

	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	

*ETRACO: Company works and construction in Bujumbura-Burundi; *AGCOL: Agency for Housing Construction and Office Automation in Bujumbura-Burundi; *EBATRACO: Company for Buildings and Construction Work in Bujumbura-Burundi.