A system dynamics approach for hospital waste management in a city in a developing country: the case of Nablus, Palestine

Issam A. Al-Khatib & Derar Eleyan & Joy Garfield

I. A. Al-Khatib Institute of Environmental and Water Studies, Birzeit University, P.O. Box 14BirzeitWest Bank, Palestine e-mail: ikhatib@birzeit.edu

D. Eleyan Computer Science Department, Birzeit University, West Bank, Palestine

J. Garfield Worcester Business School, University of Worcester, Worcester, UK

Abstract

Hospitals and health centers provide a variety of healthcare services and normally generate hazardous waste as well as general waste. General waste has a similar nature to that of municipal solid waste and therefore could be disposed of in municipal landfills. However, hazardous waste poses risks to public health, unless it is properly managed. The hospital waste management system encompasses many factors, i.e., number of beds, number of employees, level of service, population, birth rate, fertility rate, and not in my back yard (NIMBY) syndrome. Therefore, this management system requires a comprehensive analysis to determine the role of each factor and its influence on the whole system. In this research, a hospital waste management simulation model is presented based on the system dynamics technique to determine the interaction among these factors in the system using a software package, ithink. This model is used to estimate waste segregation as this is important in the hospital waste management system to minimize risk to public health. Real data has been obtained from a case study of the city of Nablus, Palestine to validate the model. The model exhibits wastes generated from three types of hospitals (private, charitable, and government) by considering the number of both inpatients and outpatients depending on the population of the city under study. The model also offers the facility to compare the total waste generated among these different types of hospitals and anticipate and predict the future generated waste both infectious and non-infectious and the treatment cost incurred.

Keywords Hazardous waste, Hospitals, Generation rate, System dynamics, Developing countries, Palestine.

Introduction

Background

Hospitals and healthcare centers are among leading sources of infectious and non-infectious waste in any country. They provide patient care services, and it is their duty to look after public health and make sure that medical waste is treated and disposed of in proper ways directly through patient care or indirectly by ensuring a clean, healthy environment for their employees and the community. Governments have enacted different laws and regulations to organize the disposal of waste together with treatments to minimize the risks on public health, which can produce extra government expenditure. It is highly important to recognize the types of infectious and non-infectious waste and to segregate, collect, and dispose or treat them in an acceptable manner. Lots of research has been conducted in this regard, and focus on waste management includes waste generation, segregation, collection, and disposal. This research focuses on the current situation of waste generation and does not anticipate and predict the future quantities and how much will it cost to treat and dispose of waste. System dynamics modeling is a famous technique used to simulate the current situation and predict the future to portray a clear and obvious picture of waste generation and can assist the decision maker in validating decisions and their consequences. This research is conducted using data extracted from different types of hospitals according to their level of services and finds out the waste generated dependent on the number of beds together with other variables.

Hospital waste management

Hospital waste is produced from different sources and is mainly generated when treating, preventing, and diagnosing or conducting research on human and animal disease. On a yearly basis, huge quantities estimated in millions of tons of medical waste are produced by healthcare facilities throughout the world (Bdour et al. 2007; Birpinar et al. 2009; Cheng et al. 2009, 2010; Yong et al. 2009). Developed countries produce much more medical waste than developing countries due to the technology used in the different healthcare centers making medical waste a critical problem attracting more attention (Abd El-Salam 2010; Manga et al. 2011).

Treating or disposing of hospital waste presents environmental and public health risks and can contribute to the spread of infectious diseases. Diseases including the human immunodeficiency virus (HIV), hepatitis viruses B and C, cholera, and diphtheria are known among many others. Such diseases can be easily transferred to human beings through medical waste if it is not properly managed (Pruss-Ustun et al. 2005; Shiferaw et al. 2012).

According to the absence of universal consent, different terms are normally used to define waste generated from health centers and hospitals. Some researchers use the term health care waste; others use medical or clinical waste (Abd El-Salam 2010; Prem Ananth et al.2010; Patwary et al. 2011; Hossain et al. 2011). Therefore, in this paper, hospital solid waste is divided into two components: general (non-hazardous) waste and hazardous waste.

Normally, wastes generated from hospitals and medical centers have both hazardous and non-hazardous components. Olko and Winch (2002) found that in England, approximately 50 % of healthcare waste generated annually could be classified as municipal (non-hazardous) waste. Alagöz and Kocasoy (2008) indicated that 65 % of healthcare waste generated is municipal (general) waste, thus only 35 % of this waste could be considered as a hazardous waste and should be successfully segregated and diverted with special attention. In spite of the small proportion of hazardous healthcare waste annually generated, there are still poor practices in segregating general waste from hazardous healthcare waste streams, which consequently show that the entire waste is potentially infectious. Many studies in waste management indicate the adoption of much more stringent segregation practices especially after enacting hazardous waste regulations (DEFRA 2005). Surveys in developing countries showed scarcity of segregation in this context; Bendjoudi et al. (2009) showed that the general waste fraction represents 75–90 % of the total Algerian healthcare waste. Also, segregation could be an important economic factor due to large differences in costs associated with healthcare waste disposal, as Lee et al. (2004) showed in his study conducted in typical Massachusetts' city hospitals.

Healthcare waste management is similar to any waste management system; it includes generation, segregation, collection, storage, treatment, and final disposal (Ciplak and Barton 2012). Hospital waste, if not properly managed, consequently becomes a leading cause of death worldwide, where many infectious diseases once thought conquered are increasing and continue to be a serious public health problem. This raises the necessity for hospital waste to be carefully and properly managed (Mohamed et al. 2009; Taghipoura and Mosaferi 2009; Haylamicheal et al. 2011). Healthcare waste management is mainly concerned with health and safety hazards associated with the handling of waste generated from healthcare centers (Blenkharn 2006). The major risks can be summarized as follows: personnel risks due to their involvement in handling waste containing blood or bodily fluids, final disposal or incineration of waste, pharmacy and laboratory activities, public health risks through transportation of hazardous and infectious waste, and the pollution of air, water, and soil (Health and Safety Executive (HSE) 2008; Askarian et al. 2010).

Khalaf (2009) shows in a study of Jenin District hospitals that staffs are still unqualified in medical waste collection and lack temporary waste storage areas. Also, healthcare waste is disposed of in centralized sanitary landfill, which is designated to domestic waste and not for healthcare waste. The study also shows the scarcity of legislation concerning the management and treatment of medical waste, and the medical waste generated is dumped with general waste. The study highlights the necessity of sustained collaboration among all key actors (government, hospital, and waste managers) to implement a safely reliable medical waste strategy besides the legislation and policy formation especially the monitoring and enforcement process.

Hospital managers usually consider the hospital waste generation rate as an important indicator to evaluate the performance of hospital waste management. This indicator is used to measure achievements and to perform comparisons between hospitals. When hospital managers aim to measure hospital waste generation, they consider different factors, such as purchasing, handling, segregation, collection, treatment, and disposal. The comparison process between hospitals is quite a complicated process as hospitals differ in size, type, specialization, technical level, quality, and efficiency (Debere et al. 2013).

System dynamics models and its applications

In the 1960s, Jay Forrester introduced system dynamics modeling at the Massachusetts Institute of Technology as a methodology for the modeling and simulation of complex systems for business management decision making. A waste management system is a good example of a complex system to be simulated using system dynamics, as it encompasses a variety of variables with interrelationships having variable values over a period of time. System dynamics has the capability to deal with and monitor assumptions about system structures and the effects of changes on theses sub-systems in a stringent fashion (Chaerul etal. 2008) and generate simulated scenarios depending on the variations of variables.

System dynamics has been used for a long time as a simulation tool in different aspects of life. Areas include global environmental sustainability (Forrester 1971; Meadows et al. 1992), environmental sustainability in agricultural development (Saysel and Barlas 2001), modeling strategies for promoting agricultural development (Drew 1990), regional sustainable development issues (Bach and Saeed 1992; Saeed1994), environmental management (Mashayekhi 1990; Sudhir et al. 1997), and ecological modeling (Saysel and Barlas 2001).

The feedback concept and feedback loops, which are based on control theory, are the core concepts of the system dynamics approach (Bala1999). Feedback loops are converted into a stock and flow model, which constitutes three main building blocks: stock, flow, and convertor. The stock variable represents an accumulated state in the target system and is symbolized by a rectangle. Flow variables represent the rate of change in the stock and the activities, and decision functions in the same system are symbolized by a valve. A converter is an intermediate variable used for miscellaneous calculations and symbolized by a circle. Connectors are required to connect the aforementioned blocks with each other to represent interlinkages and effects between them (Bala 1999). The original simulation computer model was developed and used as a part of thesis (Sufian 2001) using STELLA Research software (HPS 1996), which is a well-known software designed for dynamic feedback modeling of complex systems. Full details are available in Sufian (2001).

Chaerul et al. (2008) proposed a hospital waste system dynamics model. This model showed a direct proportion between the number of beds available and the hospital waste generation rate. A segregation process is needed to separate hazardous from non-hazardous waste. This process is affected by the knowledge and experience of hospital staff. The collected waste is either general or infectious waste, which is treated and disposed of at a final disposal site. The disposal rate affects the lifetime of the disposal site, as increasing the disposal rate shortens the lifetime of the disposal site. Finding a new disposal site in a highly populated area is quite difficult and results in increasing the not in my backyard (NIMBY) syndrome. The model also showed that public education programs and raising awareness by various forms of media on disposal issues could reduce the NIMBY syndrome. Also, more expenditure and investment on health services will positively affect and increase the life expectancy as it reduces the health risks relevant to untreated hazardous waste.

Ciplak and Barton (2012) proposed another system dynamics model. This model has been developed by relying on both literature review and authors' observations from a case study in Istanbul. The literature review focused on the factors affecting origin, definition, composition, and weight flows of health care waste. The model depicted sub-models using a detailed breakdown of parameters, which reflected the availability of data for Istanbul. The model also showed that healthcare waste generation relied on the population and capacity of the hospital in terms of bed availability for both inpatients and outpatients. The model also depicted the segregation rate, which is used to separate hazardous waste from non-hazardous waste, which is affected by the knowledge of the hospital's staff and visitors at the point of generation. The proposed system dynamics model will portray the phases of hospital waste management and the associated factors influencing each phase and how to handle them efficiently.

Methodology

Nablus city was the study area of the case study in this paper. Four hospitals were selected: two of them are government funded, one private, and one charitable hospital. The main part of this study was the measurement of generated solid waste and its components resulting from the four hospitals. Solid waste was divided into two categories: general (non-hazardous) and hazardous waste. The measurements included both the weight of general and hazardous wastes resulting from four hospitals in the study area over seven consecutive days in each hospital. The essential factors, which were considered in the model, are the number of beds in each hospital, type of hospital, the service level of the hospital, the number of inpatients, number of outpatients, number of staff at the hospital, and hospital departments through cooperation with the administrative director in each of the four hospitals.

A causal loop diagram has been constructed to exhibit the causal relations between the variables under study in the population and how it is affected by both the birth and death rates. It also portrays the inpatient and the outpatient waste generation, waste treated, and waste disposal. A stock and flow diagram has been generated from the causal loop diagram using ithink software. Furthermore, the stock and flow model was tested using the data collected from the different hospitals under study.

The research focuses on building a simulated system dynamics model for hospital waste management to be used as a prediction tool to assist decision makers dealing with waste management to plan accordingly. The model shows different future scenarios of the hospital waste situation in Palestine, considering Nablus city as a case study and considering different relevant factors.

The model also shows the quantities generated of each type of hospital waste for the next 10 to 20 years by considering the population, birth rate, death rate, number of beds, number of hospital's employees, number of patients, and level of service among hospitals. The decision makers will rely on this tool to examine different approaches to treat and recycle waste depending on the recycling rate. The model is validated using collected data from Nablus city hospitals. The results can be generalized and portray the management of hospital waste in a developing country.

The proposed system dynamics model for hospital waste management in developing countries. The proposed model is developed using the system dynamics modeling methodology. Firstly, a causal loop diagram has been developed as shown in Fig. 1.

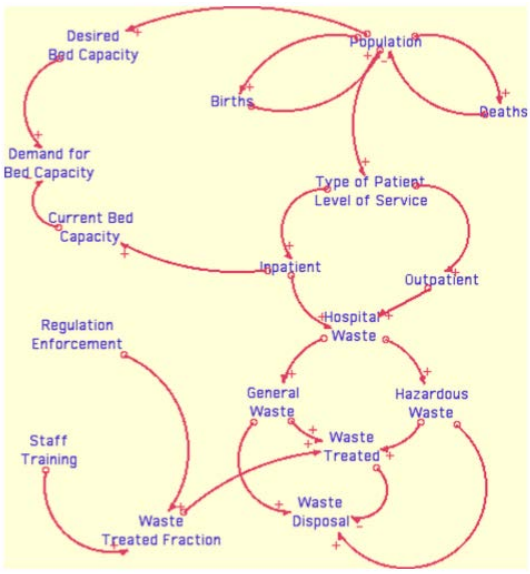

Fig. 1 Causal loop diagram of healthcare waste management system

This diagram shows the causal relations between the relevant variables (factors). It shows that the waste generation is accumulated from inpatient and outpatient generated waste. However, the inpatient waste generation is already affected by the current bed capacity in a hospital. It also shows that waste separation is affected by regulation enforcement and training. Secondly, a stock and flow diagram (Fig. 2) has been developed on the proposed causal loop diagram and simulated using real data.

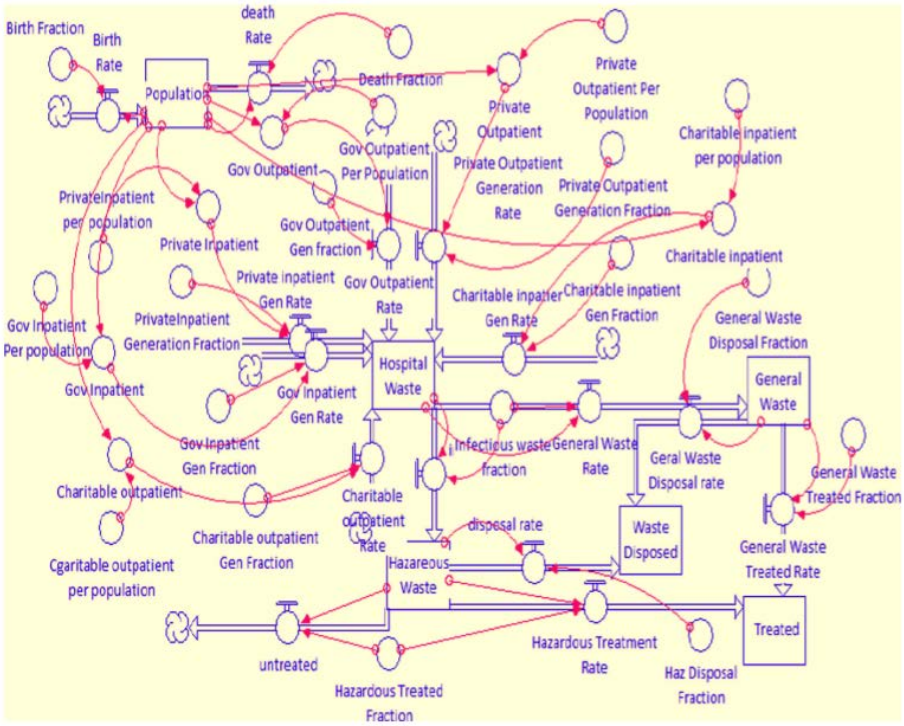

Fig. 2 Hospital waste stock and flow diagram

Table 1 classifies the waste generated according to the level of service, for example, government hospitals generate less waste than private hospitals and the private hospital generates waste more than the charitable one.

Table 1 Hospital characteristics and average daily waste generation in 2013

Variables	Hospitals			
	Rafidia	Al Watani	Al Ittihad	Al Arabi
Level of service	Gov. (1)	Gov. (1)	Charitable (2)	Private (3)
Number of beds	204	110	50	100
Number of employees	511	218	120	220
Mean of general waste generation (kg/day)	676.4	453.0	176.47	328.21
Mean of hazardous waste generation (kg/day)	137.0	94.0	37.35	73.48
Mean of hazardous to general hospital solid waste generation ratio (%)	20.3	20.8	21.4	22.3

The table also shows that the average fraction of hazard/ general waste is nearly the same for government, private, and charitable hospitals. It can be clearly noticed from Table 1 that the mean hazardous to general hospital solid waste generation ratio is nearly the same for all hospitals (private, government, and charitable). This mean will be used in the simulation model to verify the hazardous waste from the general waste. Table 2 exhibits the general and hazardous waste generation fractions for both inpatients and outpatients in government, charitable, and private hospitals.

Table 2 Daily quantities of healthcare waste generation rates in the surveyed hospitals in Nablus city, Palestine in 2013

Hospital level of Service	Generation rate	General waste	Hazardous waste
Government	kg/inpatients/day	2.03	0.293
	kg/outpatients/day	0.65	0.088
	kg/total patient/day	1.34	0.275
Charity	kg/inpatients/day	4.45	0.87
	kg/outpatients/day	2.18	0.51
	kg/total patient/day	3.32	0.68
Private	kg/inpatients/day	7.57	1.64
	kg/outpatients/day	3.35	0.56
	kg/total patient/day	5.45	1.10

The employee patient ratio in government hospitals equals 0.8, while in the private hospital, it equals 3.2, which means the level of service in the private hospital is much better than in the government one. Therefore, the waste generation rate in the private hospital is also greater than the government hospitals.

Total outpatients visiting government hospitals on a yearly basis equals 0.82 of the total population. While government inpatients equal to 0.1 of the total population, the private outpatients and inpatients per population are 0.046 and 0.023, respectively. Also, the charitable inpatient and outpatient ratios are 0.023 and 0.033, respectively (Ministry of Health, 2012). The disposal and treated fractions for both general and hazardous waste are clearly obtained from the study. For example, 83.1% of general waste is disposed of, while 16.9% of hazardous waste is disposed of. There is no treatment of general waste, while 20.0% of the total hazardous waste is treated. Debere et al. (2013) showed that generated waste from inpatients and outpatients was 3.9 and 2.77 kg of waste per day, respectively, in private hospitals in Ethiopia. While in Palestine, the waste generated from private hospitals for both inpatients and outpatients are 7.57 and 3.35 kg, respectively. This shows that inpatients in Palestine generate higher levels of waste than in Ethiopia. However, outpatients in both countries generate waste close to each other as government hospitals both in Palestine and Ethiopia generated 0.65 kg/outpatient per day.

Results and discussion

Stock and flow diagram

Figure 2 shows the stock and flow diagram of hospital waste. The model encompasses three types: private, charitable, and government hospitals in the city of Nablus Palestine. Each hospital has both inpatients and outpatients. The model shows the waste generated from the three types of hospitals (private, charitable, and government). The model also classifies hospital waste into both general and hazardous wastes. The model considers the population as the main driver for determining the inpatients and outpatients for each type of hospital. As shown in the model, the hospital waste stock accumulates waste from inpatients and outpatients of government hospitals, private hospitals, and charitable hospitals. The accumulated waste is then filtered into two main types, namely, general waste and hazardous waste. The amount of hazardous waste is determined from the product of infectious waste fraction and hospital waste. The infectious rate is obtained from the case study as an average of the infectious waste from the total waste. General waste is the remainder of the total waste after subtracting the hazardous waste. The hazardous waste is either treated or disposed of or left untreated. The general waste is also either treated or disposed of. Table 3 exhibits the number of patients (inpatient, outpatient) in the private hospital on a yearly basis along with their yearly waste generated rate for the subsequent 12 years.

Table 3 Annual total hospital waste generated in the private hospitals (kg/year)

Years	Private inpatient	Private outpatient	Private inpatient gen rate	Private outpatient gen rate
1	8603	17,206	63,614	56,303
2	8933	17,866	66,053	58,462
3	9275	18,551	68,586	60,703
4	9631	19,262	71,215	63,031
5	10,000	20,000	73,946	65,447
6	10,384	20,767	76,781	67,957
7	10,782	21,563	79,724	70,562
8	11,195	22,390	82,781	73,267
9	11,624	23,248	85,955	76,076
10	12,070	24,140	89,250	78,993
11	12,533	25,065	92,672	82,021
12	13,013	26,026	96,225	85,166

The numbers of inpatients and outpatients are obtained for the case study on a daily basis and converted into a yearly basis and fed into the stock and flow model to generate future generated quantities. Table 4 is the same as Table 3, however, it considers the charitable hospitals, showing (inpatient, outpatient) on a yearly basis along with their yearly waste generated rate for the subsequent 12 years.

Table 4 Annual total hospital waste generated in charitable hospitals (kg/year)

Years	Charitable inpatient	Charitable outpatient	Charitable inpatient gen rate	Charitable outpatient gen rate
1	8229	12,343	35,769.68	26,284.68
2	8544	12,817	37,141.06	27,292.42
3	8872	13,308	38,565.02	28,338.79
4	9212	13,818	40,043.57	29,425.27
5	9565	14,348	41,578.81	30,553.41
6	9932	14,898	43,172.90	31,724.81
7	10,313	15,469	44,828.12	32,941.11
8	10,708	16,062	46,546.79	34,204.05
9	11,119	16,678	48,331.36	35,515.40
10	11,545	17,318	50,184.34	36,877.03
11	11,988	17,982	52,108.37	38,290.87
12	12,447	18,671	54,106.16	39,758.91

It is noticed from the above two tables that the numbers of both inpatients and outpatients in private hospitals are more than the charitable hospitals and also the annual waste generation rates. Table 5 portrays the government hospitals showing the inpatients and the outpatients along with their generation rates on a yearly basis. For example, in the first year, the inpatients and outpatients are 37,404 and 306,714 kg, respectively.

Table 5 Annual total hospital waste generated in governmental hospitals (kg/year)

Years	Gov inpatient	Gov outpatient	Gov inpatient gen rate	Gov outpatient rate
1	37,404	306,714	74,170	194,742
2	38,838	318,474	77,014	202,208
3	40,327	330,684	79,966	209,961
4	41,873	343,362	83,032	218,010
5	43,479	356,526	86,215	226,369
6	45,146	370,195	89,521	235,048
7	46,877	384,388	92,953	244,059
8	48,674	399,125	96,517	253,416
9	50,540	414,427	100,217	263,132
10	52,478	430,316	104,059	273,220
11	54,490	446,814	108,049	283,695
12	56,579	463,944	112,192	294,572

Table 6 Annual total hospital, general and hazardous wastes generated in four hospitals in Nablus city (kg/year)

Years	Hospital waste	General waste	Hazardous waste	Waste disposed	Treated
1	309,241	96,327	23,265	17,114	987
2	418,943	250,887	54,563	153,636	8205
3	465,964	355,728	72,058	408,362	20,613
4	493,624	418,227	81,145	737,981	35,791
5	515,649	457,111	86,621	1,112,344	52,464
6	536,399	484,780	90,782	1,515,732	70,111
7	557,274	507,725	94,551	1,941,002	88,552
8	578,738	529,024	98,273	2,385,307	107,741
9	600,957	550,065	102,073	2,847,784	127,679
10	624,007	571,465	105,997	3,328,461	148,385
11	647,934	593,500	110,064	3,827,758	169,887
12	672,777	616,306	114,285	4,346,275	192,214

Table 6 shows the total hospital waste, general, and hazardous wastes generated from the hospitals (private, charitable, and governmental) in Nablus city. The model also shows how much waste is disposed of and treated each year. The model considered the mean hazardous to non-hazardous waste, which is nearly 0.203. This percentage is almost equal if it is compared with a study conducted by Patil and Pokhrel (2005), which shows the percentage of hazardous to non-hazardous waste as 0.19, while this percentage is quite large if it is compared with a study conducted by Rao et al. (2004), which shows the percentage of hazardous to non-hazardous waste as 0.10 for all types of hospitals (government, private, and charitable). This leads to a question of why it is larger than India, while Palestine and India are both developing countries. Is it because of rigorous legislation and rules or the classification of hazardous to non-hazardous is different. According to Matin (2006), hazardous medical waste should be carefully separated at the point of generation from the non-hazardous waste to minimize the management costs mainly of handling and treatment.

Conclusions

This research shows that system dynamics modelling can provide a more comprehensive and sophisticated simulation method for the forecasting of hospital waste. The developed stock and flow model differentiates between private, charitable, and government hospitals, according to the level of service. The level of service determines the type of hospital: private, government, or charitable establishment. Each hospital has two types of patients, namely, inpatients and outpatients, both of which generate waste. The Systems Dynamics model is generic and could be used in any country to simulate waste generation according to the level of service. The model can help waste planners to optimize waste management systems related to environmental protection. It is shown that the waste treated fraction is affected by staff training and the enforcement of legislation. The amount of waste treated could be increased, consequently reducing the health risks and improving public health. The level of service in the private hospital was much better than the government hospital, which leads to excess of waste generation. For example, the hazardous waste generation in the private hospital per inpatient is 1.64 kg per day, while the hazardous waste generation in the government hospital is 0.293 kg per day. The amount of hazardous waste correspondsto20.3–22.3%ofthetotalwastestreamscollected from the four hospitals, and the higher percentage was from the private hospital. The model also calculates the total waste generated from both private and government hospitals together with differentiating between general and hazardous waste. Health risks increase due to the increasing quantity of untreated hazardous hospital waste.

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