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System dynamics model for hospital waste characterization and generation in developing countries

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Abstract

Waste management policy makers always face the problem of how to predict the future amount and composition of medical solid waste, which, in turn, helps to determine the most appropriate treatment, recycling and disposal strategy. An accurate prediction can assist in both the planning and design of medical solid waste management systems. Insufficient budget and unavailable management capacity are the main reasons for the scarcity of medical solid waste quantities and components historical records, which are so important in long-term system planning and short-term expansion programs. This article presents a new technique, using System Dynamics modeling, to predict generated medical solid waste in a developing urban area, based on a set of limited samples from Jenin District hospitals, Palestine. The findings of the model present the trend of medical solid waste generation together with its different components and indicate that a new forecasting approach may cover a variety of possible causative models and track inevitable uncertainties when traditional statistical least-squared regression methods are unable to handle such issues.

Keywords

Hospital waste, generation rate, characterization, System Dynamics, developing countries

Introduction

Although healthcare is important in every country, various types of waste are generated that may have adverse effects on human health and the environment (Birpinar *et al*., 2009; Chaerul *et al*., 2008). Hospital waste generated from healthcare activities can be classified into two major groups: general waste and hazardous waste. The majority of waste, which is 75–90% of the waste produced by healthcare, is non-risk or general waste that is comparable with domestic or municipal solid waste (Chaerul *et al*., 2008; Karamouz *et al*., 2007; Pruss *et al*., 1999). As general waste is not regulated or defined as hazardous or potentially dangerous waste, it requires no special handling, treatment or disposal (Lee *et al*., 2004). As such, it should be dealt with via municipal waste disposal mechanisms (Farzadkia *et al*., 2009; Pruss *et al*., 1999). The remaining 10–25% of healthcare waste is regarded as hazardous or special waste, according to definitions given by the World Health Organization and US Environmental Protection Agency.

The hazardous or special waste materials consist of infectious waste, pathological waste, geno-toxic waste, pharmaceutical waste, chemical waste, waste with high heavy metal content, pressurized containers and radioactive waste, most of which are toxic, harmful, carcinogenic and infectious materials (Cheng *et al*., 2010; Marinkovic *et al*., 2008; Pruss *et al*., 1999). These types of hazardous hospital waste need to be properly managed so that the effect on public health and the environment is minimal (Chaerul *et al*., 2008). Although the proportion of infectious and hazardous waste is relatively small, any improper waste management, where infectious waste is mixed with general waste, can render all the waste potentially infectious and hazardous (Chaerul *et al*., 2008; Cheng *et al*., 2009).

The generation of solid waste in hospitals depends on many factors, such as the type of healthcare establishment, the level of instrumentation and location. According to Hamoda *et al*. (2005), Mohee (2005) and Sawalem *et al*. (2009), developing countries have low waste generation rates compared with industrialized countries in Europe or the Americas. The difference is consistent with different living habits and standards, and is due to the availability of treatment facilities.

The accurate calculation of the unit generation rates and composition of hospital waste generated from medical facilities is necessary in order to design hospital waste treatment and management systems (Diaz *et al*., 2008). The problems associated with hospital waste treatment exist at all levels: collection,

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Table 1. Characteristics of Jenin city hospitals.

Characteristics of hospital	Hospital		
	Dr Khalil	Al-Razi	Al- Amal
Hospital type	Governmental	Non-governmental	Private
Number of beds	129	38	14
Number of employees	295	125	39
Departments			
Surgery	A	A	A
Pediatrics	A	NA	NA
Male	A	A	NA
Female	A	A	NA
Emergency	A	A	NA
Neonates	A	NA	NA
Intensive care unit	A	A	NA
Kidney dialysis	A	NA	NA
Maternity	A	A	A
Orthopedic	A	NA	NA
Support departments and units			
Pharmacy; laundry; physiotherapy; X-ray unit; laboratory; maintenance; kitchen	A	A	A

A: available; NA: not available.

segregation, transport and storage (Stanković *et al*., 2008). All the techniques for the treatment of hazardous hospital waste have both advantages and disadvantages. The choice of technique should not be based on economic characteristics but on safety characteristics that will enable reliable care of both human health and the environment. Proper management of medical waste requires the careful separation of the hospital waste stream, as a different treatment technique is expected to be suitable for each fraction (Bdour *et al*., 2007; Komilis *et al*., 2011).

Methodology

Hospital waste generation rate and characterization

A survey of three hospitals from Jenin, a city in the North West Bank, Palestine, was conducted. The basic characteristics of Jenin city hospitals are summarized in Table 1. The survey was designed to collect data about healthcare waste in government, private and non-governmental hospitals. A letter was sent to the head of each hospital to solicit their collaboration and support. Site visits were conducted at all selected hospitals to gather basic information and assess working conditions in addition to other administrative arrangements. Before the beginning of the survey all field workers involved in the research project attended a training course to raise awareness of the purpose of the study, the hazards associated with working with hospital waste, and the accurate procedures for categorization and weighing hospital waste. In this study, the classification criteria were based on potential risks and divided into two categories: hazardous and general waste. Hazardous waste was divided into tissue and pathological waste, absorbent cotton items, discarded medical plastic, waste sharps and waste mixed with infectious waste. General waste was also categorized into metals, paper and cardboard, plastics, textiles, glass and others.

Waste from the hospitals was separated into its different components with a high level of precision by the survey team. The quantities (kg/day) and rate of waste generation (kg/bed/day) of medical and general solid waste were recorded outside the hospital building. Solid waste of both types (general and medical) was weighed individually on a suspension spring scale (±100 g) with the assistance of the staff, and the weight was recorded by the field workers. The different categories of waste were weighed separately and results recorded. Finally, data forms were completed and stored for further analysis. The data were analyzed using statistical Excel. The amount of all general and hazardous waste materials generated in each hospital was determined and recorded for each day over seven consecutive days during March, April and May 2011. The value of hazardous waste cost treatment of $US0.9 per kg was taken from the records of the Palestinian Ministry of Heath based on actual treatment cost.

A System Dynamics methodology was developed to predict amounts of waste that will have accumulated in a couple of years' time. This information could be used by the government and interested parties to take further action regarding recycling, disposal and the potential effect on public health.

System Dynamics methodology

Jay Forester introduced the System Dynamics approach in the 1960s at Massachusetts Institute of Technology. This approach is used as a modeling and simulation methodology for long-term decision-making analysis of management problems, such as waste management, which is the theme of this article. It helps modelers and decision makers to conceptualize and rationally analyze the structure, interactions and mode of behavior of complex systems and sub-systems to explore, assess and prognosticate their effects in an integrated, holistic manner (Chaerul *et al.*, 2008).

System Dynamics has the ability to deal with assumptions about system configuration and structures in a stringent way, and facilitate the monitoring and control of the effects of changes in subsystems and their relationships. System Dynamics is also differentiated from simple spreadsheet packages as it offers a more quantitative, sophisticated simulation, and is capable of more robust and reliable outcomes by generating mathematical equations to perform the required calculations (Kollikkathar *et al.*, 2010). As computer-assisted decision making in the public policy field has become more common in recent years, with policymakers facing increasing demands for accountability, many software packages have become commercially available to facilitate modeling using the System Dynamics theme (Rubenstein-Montano and Zandi, 2000).

A causal loop diagram is a System Dynamics technique used to capture major feedback mechanisms, as shown simply in Figure 1. The diagram includes variables and arrows (causal links) linking these variables together in the same manner and a sign (either + or –) on each link. These signs have the following meanings:

- the causal link between waste and waste recycled is positive (+), which means that as the waste generated increases then the waste recycled will increase, as it depends on the amount of waste generated;
- the causal link between waste recycled and waste is negative (–) which means that, as the waste recycled increases, it will cause the waste to decrease.

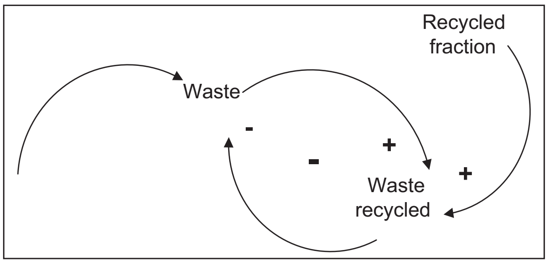

Figure 1. Waste causal loop diagram.

The causal loop shows causal relations between the different variables, as the waste recycled depends on the waste generated and the recycled fraction, which means when both the waste generated and the recycled fraction are increased, the waste recycled will be increased.

In addition to the sign of each causal link between any successive variable, the whole loop is also given a sign. If the sum of negative signs in a loop is even then the whole loop is given a positive sign, which means the loop is reinforcing and the system is in unstable equilibrium (exponential growth). However, if the sum of negative signs is odd, as in Figure 1, then the whole loop is assigned a negative sign, which means the loop is balancing and the system seeks to return to an equilibrium situation.

After the casual loop is generated for a whole system and encompasses all of the required variables, the next step in System Dynamics modeling is to convert the generated causal loop diagram into a process model, called a stock and flow diagram, as shown in Figure 2.

A System Dynamics model is constructed by the building blocks of four main types: stocks, flows, connectors and converters (Figure 2). Stock variables (symbolized by rectangles) are the state variables and they represent the major accumulations in the system. Flow variables (symbolized by valves) are the rate of change in stock variables and they represent those activities that fill in or drain the stocks. Converters (represented by circles) are intermediate variables used for miscellaneous calculations. Finally, the connectors (represented by simple arrows) are the information links representing the cause and effects within the model structure. Figure 2 shows a simple example of a stock and flow model. It shows that of the quantity of waste generated (flow 1) and the quantity of waste recycled (flow 2) depends on the recycling rate (converter) and the total quantity of the waste accumulated (stock).

The System Dynamics model is built using high-level graphical simulation software—the ithink 8.0 simulation tool—which is a simulation modeling software used in System Dynamics

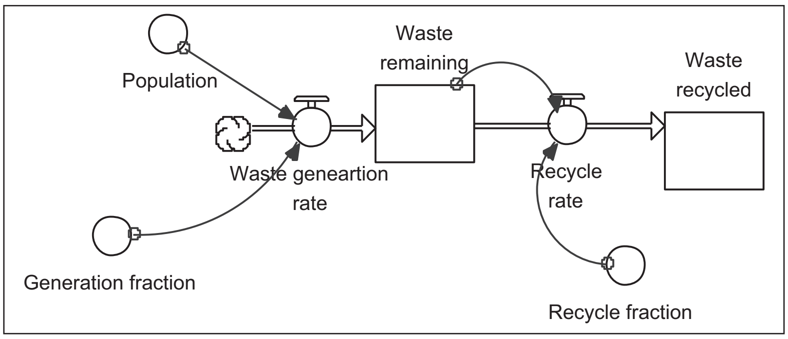

Figure 2. Waste stock and flow diagram.

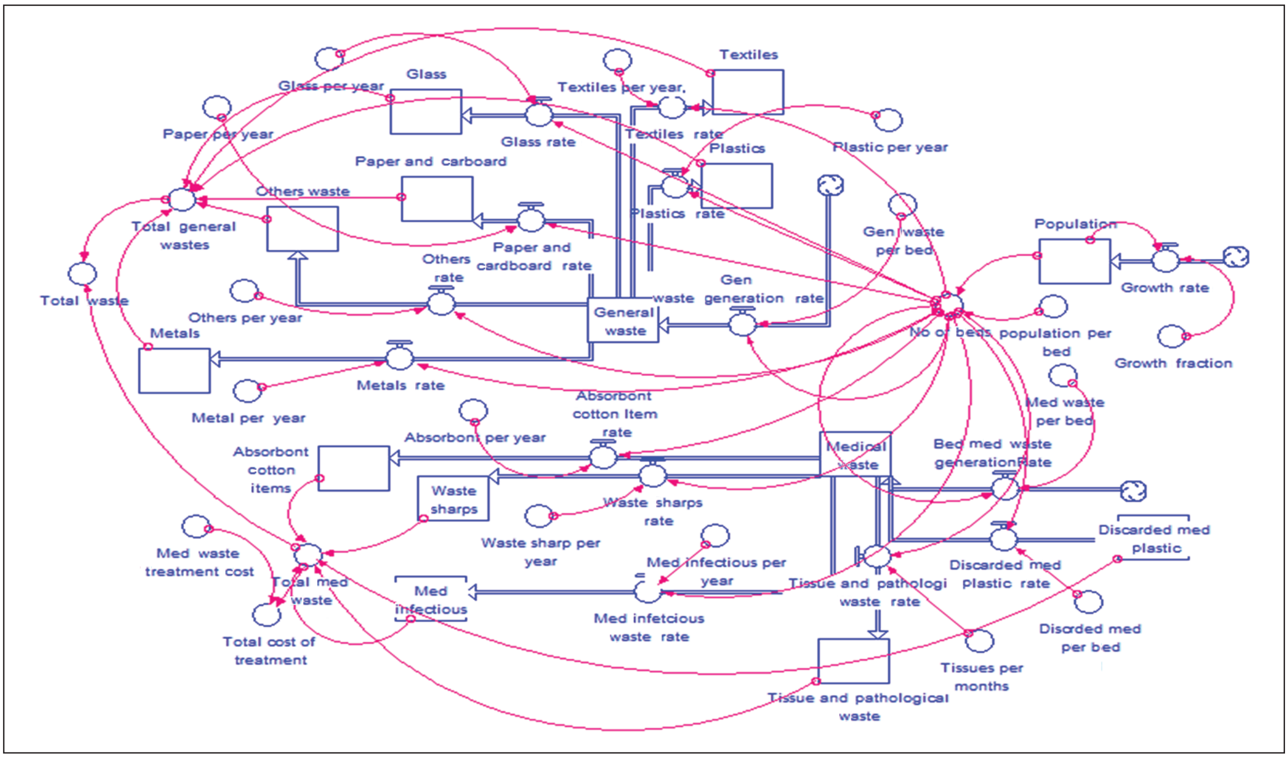

Figure 3. Hospital general and medical waste model.

(others are ithink, Stella, Vensim and Powersim) to support the analysis and study of these systems.

Using ithink software a mathematical mapping of a System Dynamics stock and flow diagram can be generated automatically via a system of differential equations, which is solved numerically via simulation. The stock and flow model is used to simulate different situation scenarios to explore the optimal situation and switch all of the variables accordingly to the values that generate the situation.

A variety of different systems that consider feedback systems can be modeled using System Dynamics modeling. For example, business systems, ecological systems, socio-economic systems, agricultural systems, political decision making systems and environmental systems, including waste management systems, can be addressed using System Dynamics methodology (Dyson and Chang, 2005). In relation to environmental concerns, System Dynamics modeling has been applied to a number of issues, including salt accumulation in lowlands under continuous irrigation practice (Saysel and Barlas, 2001); value of water conservation (Stave, 2003); the consequences of dioxin to the supply chain of the chicken industry (Minegishi and Thiel, 2000); the eutrophication problem in shallow freshwater lakes (Guneralp and Barlas, 2003); the effect of environmental issues on long-term behavior of a single product supply chain with product recovery (Georgiadis and Vlachos, 2004); sustainability of ecological agricultural development at a county level (Shi and Gill, 2005); estimation of methane emissions from rice Welds (Anand *et al*., 2005); a basin's environmental management system (Guo *et al*. 2001); and waste management (Dyson and Chang, 2005; Karavezyris *et al*., 2002; Sudhir *et al*., 1997; Ulli-Beer, 2003).

System Dynamics model of general and hazardous wastes

As far as waste management is concerned, more attention needs to be paid to hazardous waste management and the prediction of its generation, as it plays an important role in the waste management system. Traditional forecasting methods frequently rely on demographic and socio-economic factors on a per capita basis. In order to forecast the solid waste generation of a complex waste management system, a system dynamic model has been proposed in this article. The stock and flow model in Figure 3 represents the hospital hazardous and general waste management model. This model encompasses all the relevant parameters that influence waste generation, including the hazardous one. It shows the two main types of waste generated by the hospital: general and medical waste. It is an abstract and conceptual model focused on selected elements and hypotheses of their interactions. The dynamics of the model are determined by the feedback of the stock and flow model.

The main two stocks the model is focusing on are the general waste and the hazardous waste. The general waste stock is calculated by the ithink model in Figure 3 as follows, showing the inflows and outflows:

```
General_Waste(t) = General_Waste(t - dt) + (Gen__Waste_Generation_Rate - Plastics_Rate -
Textiles_Rate - Glass_Rate - Paper_and__Cardboard_Rate - Others__Rate - Metals_Rate) * dt
INIT General_Waste = 0
INFLOWS:
    Gen__Waste_Generation_Rate = Gen_Waste___per_bed*No_of_Beds
OUTFLOWS:
    Plastics_Rate = Plastic_per_year*No_of_Beds
    Textiles_Rate = Textiles_per_year*No_of_Beds
    Glass_Rate = Glass_per_year*No_of_Beds
    Paper_and__Cardboard_Rate = Paper_per_year*No_of_Beds
    Others__Rate = Others_per_year*No_of_Beds
    Metals_Rate = Metal_per__year*No_of_Beds
```

The hazardous waste is also calculated by the ithink model in Figure 3 as follows, showing the inflows and outflows:

```
Hazardous__Waste(t) = Hazardous__Waste(t - dt) + (Hazardous_Waste__generationRate -
Discarded_Med__Plastic_Rate - Absorbont_Cotton_Item__Rate - Waste_Sharps__Rate -
Med_Infetcious__Waste_Rate - Tissue_and_Pathological__Waste_Rate) * dt
INIT Hazardous__Waste = 0
INFLOWS:
    Hazardous_Waste__generationRate = Med_waste__per_bed*No_of_Beds
OUTFLOWS:
    Discarded_Med__Plastic_Rate = Discrded_Med__Per_Bed*No_of_Beds
    Absorbont_Cotton_Item__Rate = Absorbont_per_year*No_of_Beds
    Waste_Sharps__Rate = No_of_Beds*Waste_sharp_per_year
    Med_Infetcious__Waste_Rate = Med_infectious_per_year*No_of_Beds
    Tissue_and_Pathological__Waste_Rate = No_of_Beds*Tissues_per__months
```

the increasing disposal rate will certainly shorten the lifetime of the disposal site.

This model also segregates general and hazardous waste into its original components. For example, general waste is segregated into textiles, plastics, glasses, paper and cardboard, and metals. Medical waste is segregated into discarded medical plastics, tissues and pathological waste, medical infectious, absorbent cotton items and waste sharps.

The model shown in Figure 3 has been simulated and tested using real data obtained from Jenin city, which is located at the north of Palestine. The population of Jenin is 256,000 and the annual growth rate is 2.9%. The total number of beds considered is 57, which is equivalent to one bed for every 4492 persons.

The model also calculated the total cost of hazardous waste treatment according to the following equation by considering a hazardous waste treatment cost of \$US0.9 per kg.

$$\text{Total cost of treatment} = \text{Hazardous waste treatment cost} \times \text{Total hazardous waste}$$

Table 2. Average hazardous waste generation rates in all surveyed hospitals.

Generation rate	Hazardous waste components					
	Waste sharps	Pathological	Waste mixed with infectious waste	Absorbent cotton items	Discarded medical plastic	Total hazardous healthcare waste
g bed^{-1}day^{-1}	25.7	17.8	426.8	133.1	243.9	847.3
g inpatient^{-1}day^{-1}	61.1	42.4	1013.7	316.0	579.4	2012.6
g total patients^{-1} day^{-1}	10.1	0.3	8.0	2.5	4.6	15.8
g employee^{-1} day^{-1}	8.8	6.1	145.7	45.4	83.3	289.3

Table 3. Average general waste generation rates in all surveyed hospitals.

Generation rate	Type of general healthcare waste						Total general healthcare waste
	Plastics	Textiles	Glass	Metals	Paper	Others	
g bed^{-1}day^{-1}	371.5	19.9	27.8	5.0	357.2	334.7	1116.0
g inpatient^{-1}day^{-1}	882.3	47.3	66.0	11.8	848.4	794.9	2650.7
g total patients^{-1} day^{-1}	145.7	7.8	10.9	1.9	140.1	131.3	437.7
g employee^{-1} day^{-1}	126.8	6.8	9.5	1.7	121.9	114.2	381.0

The population and its growth rate, and the generation rate of each type of general and medical waste have been considered as the main parameters of the system dynamics model.

Hospital medical and general waste generation would be directly proportional to the population and the number of beds available for the community. This model provides segregation to medical waste and displays separated quantities of both infectious and general waste. The performance of the waste segregation process depends on the knowledge of the hospitals' staff at the points of generation. The collected waste is treated (in the case of medical waste) and disposed of at a final disposal site, but

Results and discussion

Tables 2, 3 and 4 show the mean values of generated hazardous, general and total hospital wastes, respectively, in terms of gbed^{-1} day^{-1}, gin-patient^{-1}day^{-1}, g total patients^{-1}day^{-1} and g employee^{-1} day^{-1} in the surveyed hospitals. Waste mixed with infectious waste was the largest component of hazardous waste, which was approximately 0.4 kg bed^{-1}day^{-1}, while pathological waste was the smallest component, being approximately 0.002 kg bed^{-1} day^{-1}. The mean value of total hazardous waste was approximately 0.85 kg bed^{-1}day^{-1}. When considering the total number of patients attending the hospitals, the generation rate is much less than that when considering only inpatients, as the number of outpatients attending the external clinics in the hospitals was high. For example, in Al-Razi hospital during the field work, it was found that the number of outpatients ranged from 87 to 250, while the number of inpatients ranged from 8 to 15. These are the main sources of hospital waste and normally little waste is generated during consultations/treatment.

Regarding the general waste generation rate, plastics were the largest component generated at hospitals, with a mean value of approximately 0.37 kg $bed^{-1}day^{-1}$, while metals were the smallest value at approximately 5 g $bed^{-1}day^{-1}$. The mean value of total general waste at the three hospitals was approximately 1.12 kg $bed^{-1}day^{-1}$, and the mean total hospital waste generation rate was approximately 1.96 kg $bed^{-1}day^{-1}$.

These results were compared with the generation rates determined in other studies from different countries, as shown in Table 5. Table 5 indicates that the generation rate of hospital waste differs not only from country to country but also within countries. For example, in Iran, the generation rate ranged between 2.75 and 4.58 kg $bed^{-1}day^{-1}$ and between 1.86 and 2.3 kg $bed^{-1}day^{-1}$ in Palestine.

The variation in waste generation among hospitals may be attributed to a variety of reasons, such as the type of healthcare establishment, income level, welfare of patients and visitors, diversity of departments (e.g. surgical, general, pediatric), type of hospital in terms of private or public, level of instrumentation and location, hospital specialization, proportion of disposable substances used in healthcare activities and efficiency of segregation of the hazardous hospital waste from the non-hazardous hospital waste stream. It is also reported that the range of generation rate values for countries of similar income levels is probably as wide in high-income countries as in less wealthy countries (WHO, 1999).

Societies are continually looking to improve their public and private healthcare services, and there are various ways in which this can be achieved. However, besides their benefits, healthcare services generate a number of different types of wastes, which can have bad effects on the environment and human health. Therefore, proper management of healthcare waste is needed to minimize the effect on public health and the environment. Relatively large quantities of waste with a broad range of compositions and characteristics can be generated by healthcare establishments, such as hospitals. Such waste carries a higher potential for injury, infection and environmental pollution than any other type of healthcare waste (WHO, 2001, 2004). Chaerul (2008) shows that between 75% and 90% of hospital waste is non-risk or 'general' healthcare waste, analogous to municipal solid waste. Table 6 supports these percentages and shows around 41% of hospitals' waste in Palestine is hazardous waste, 21% of them are medical infectious and 3% are waste sharps. Although the proportion of infectious and hazardous waste is relatively small, improper waste management in which infectious waste is mixed with general waste can contaminate all of the waste.

Although hospital waste poses potential health risks, a safe and reliable infrastructure for its management is not available in most developing countries, such as in Palestine. Table 6 shows a prediction of 20 years of total hospital waste, total general waste and total waste (which is the sum of total

Table 4. Average hospital waste generation rates in all surveyed hospitals.

Generation rate	Category of hospital waste		Total hospital waste
	Total general	Total hazardous	
g $bed^{-1}day^{-1}$	1116.0	847.3	1963.3
g $inpatient^{-1}day^{-1}$	2650.7	2012.6	4663.4
g total $patients^{-1}$ day^{-1}	437.7	15.8	453.5
g $employee^{-1}$ day^{-1}	381.0	289.3	670.2

Table 5. Comparison of hospital waste generation rates in different countries.

Country	Generation rate (kg $bed^{-1}day^{-1}$)	Reference(s)
Brazil	3.2–4.5	Da Silva *et al.* (2005)
China	0.5	Shen *et al.* (2003)
Greece	1.9	Tsakona *et al.* (2007)
Iran	2.75–4.58	Askarian *et al.* (2004); Bazrafshan and Mostafapoor (2011); Farzadkia *et al.* (2009); Masoumbeigi *et al.* (2008); Taghipour and Mosaferi (2009);
Jordan	0.83	Abdulla *et al.* (2008)
Libya	1.3	Sawalem *et al.* (2009)
Norway	3.9	Bdour *et al.* (2007)
Palestine	1.86–2.3	Al-Khatib *et al.* (2009); present study
Portugal	3.9	Diaz *et al.* (2008)
Spain	4.4	Bdour *et al.* (2007)
Taiwan	2.41–3.26	Cheng *et al.* (2009)
Thailand	1.0	Kerdsuwan (2000)
Turkey	0.63	Birpinar *et al.* (2009)
Vietnam	1.42	Diaz *et al.* (2008)

hospital waste and total general waste). For example, the total waste generated in the first year is 33,808.07 kg—14,189 kg is hospital waste and 19,618 kg is general waste. After 10 years, the table shows that the total waste generated will be 304,369.36 kg, with 127,746.41 kg being hospital waste. This information would put the policy makers in a better position to plan for medical solid waste management.

Figure 4 shows the annual hazardous waste generation rate and its components (e.g. absorbent cotton, plastic medical infectious). The graph shows that increases in the different rates are consistent with the number of beds.

Table 6. Prediction of annual total, hazardous and general solid wastes (kg/year).

Years	Total waste	Total hazardous waste	Total general wastes
2	986,968.73	414,239.17	572,729.55
3	1,975,168.20	828,994.90	1,146,173.30
4	2,964,599.96	1,244,267.83	1,720,332.13
5	3,955,265.55	1,660,058.61	2,295,206.94
6	4,947,166.49	2,076,367.87	2,870,798.62
7	5,940,304.33	2,493,196.27	3,447,108.06
8	6,934,680.62	2,910,544.46	4,024,136.16
9	7,930,796.89	3,328,413.08	4,601,883.81
10	8,927,154.70	3,746,802.79	5,180,351.91
11	9,925,255.59	4,165,714.22	5,759,541.36
12	10,924,601.11	4,585,148.04	6,339,453.06
13	11,925,192.81	5,005,104.89	6,920,087.92
14	12,927,032.25	5,425,585.43	7,501,446.82
15	13,930,120.99	5,846,590.31	8,083,530.68
16	14,934,460.58	6,268,120.18	8,666,340.39
17	15,940,052.57	6,690,175.70	9,249,876.87
18	16,946,898.55	7,112,757.52	9,834,141.02
19	17,955,000.06	7,535,866.30	10,419,133.75
20	18,964,358.67	7,959,502.70	11,004,855.97
21	19,974,975.95	8,383,667.37	11,591,308

Table 7 shows the total cost of hazardous waste treatment, which helps in predicting the total costs in a number of years. For example, the total cost of treatment in year 19 will be $296,333.01 according to the equation of total cost of treatment.

Model validation

The System Dynamics model has been validated using two different sources of data: one from Palestine and the other from Iran. From Table 8 it was found that:

$$\text{Hazardous waste} = \text{Infectious} + \text{Sharp}$$
$$\text{Hazardous waste} = 2526.9 + 39.15 = 2566.05 \text{ kg day}^{-1}$$

The model is then fed with the essential data of population of the three counties (Zahedan, Zabol and Iranshahr), which is 805,246 people, the average growth fraction of 1.247%. From population and number of beds the proportion of population per bed is calculated followed by general waste per bed. After running the model the predicted amount of both hazardous and general wastes generated is shown (Table 9). This table shows population, number of beds, hazardous waste generation rate, hazardous waste accumulated and general waste generation rate. The first year, 2005, shows a population of 805,246, with 1663 beds generating 936,397.95 kg hazardous waste and 632,159.70 kg of general waste. The hazardous waste accumulated column shows the aggregation of hazardous waste generated. If the second lines of Tables 8 9 are compared, the following is found:

- general waste generated in Table 8 equals 1732.55 kg day^{-1}, which means 632,380 kg year^{-1}, while Table 9 shows 632,948 kg year^{-1} with around 100% accuracy;
- the same is for hazardous waste, where Table 8 shows the hazardous waste generated is 936,608 kg year^{-1}, while Table 9 shows 1,044,968 with 89% accuracy.

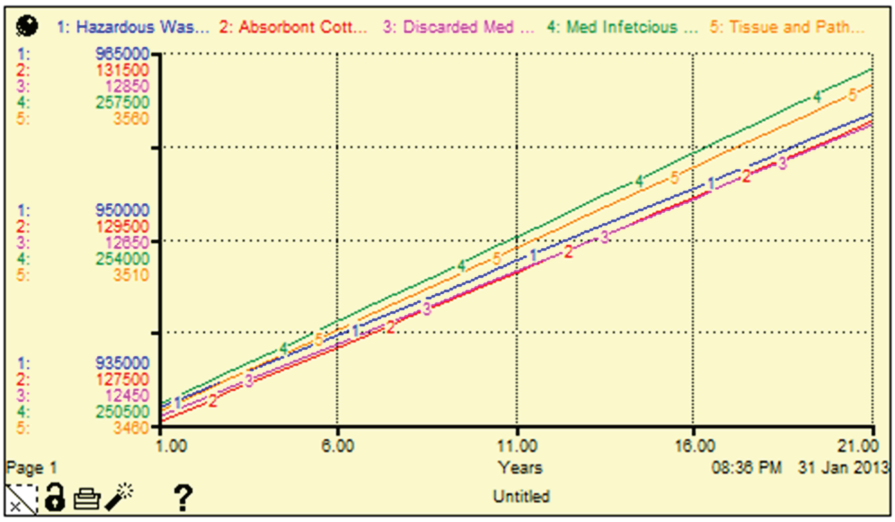

Figure 4. Annual hazardous waste generation rate per bed and its components (kg/year).

Table 7. Total cost of treatment of hazardous waste (US$/year).

Year	Total hazardous waste	Total cost of treatment
2007	764,275.78	687,848.20
2008	1,147,199.13	1,032,479.22
2009	1,53,646.91	1,377,582.22
2010	1,914,619.72	1,723,157.75
2011	2,299,118.15	2,069,206.33
2012	2,684,142.80	2,415,728.52
2013	3,069,694.27	2,762,724.84
2014	3,455,773.16	3,110,195.84
2015	3,842,390.06	3,458,142.05
2016	4,229,515.58	3,806,564.02
2017	4,617,180.31	4,155,462.28
2018	5,005,374.86	4,504,837.37
2019	5,394,099.83	4,854,689.84
2020	5,783,355.81	5,205,020.23
2021	6,173,143.43	5,555,829.08
2022	6,563,463.27	5,907,116.94
2023	6,954,315.94	6,258,884.35
2024	7,345,702.06	6,611,131.85
2025	7,737,622.22	6,963,860.00
Final	8,130,077.04	7,317,069.34

Table 8. Average total hospital waste generation rate (kg day^{-1}) (Bazrafshan and Mostafapoor, 2011).

City	Population	No. of beds	Infectious waste	General waste	Sharps waste
Zahedan	552,015	904	1757.15	848.45	27.4
Zabol	121,989	471	381.5	653.1	4.4
Iranshahr	131,242	289	388.25	231	7.35
Total	805,246	1664	2526.9	1732.55	39.15

Table 9. Prediction of hazardous and general wastes for Iranian counties (kg/year).

Years	Population	No. of beds	Hazardous waste generation rate	Hazardous waste accumulated	General waste generation rate
	805,246	1664	936,397.95	0.00	632,159.70
	806,250	1666	937,565.63	936,397.95	632,948.01
	807,256	1668	938,565.63	1,873,916.54	633,737.29
	808,262	1670	939,905.38	2,812,557.23	634,527.56
	809,270	1672	941,077.44	3,752,321.48	635,318.82
	810,279	1674	942,250.97	4,693,210.75	636,111.06
	811,290	1676	943,425.95	5,635,226.50	636,904.29
	812,301	1678	944,602.41	6,578,370.19	637,698.51
	813,314	1680	945,780.33	7,522,643.29	638,493.72
	814,328	1682	946,959.71	8,468,047.27	639,289.92
	815,344	1685	948,140.57	9,414,583.59	940,087.12
	816,361	1687	949,322.90	10,362,253.72	640,885.31
	817,379	1689	950,506.71	11,311,059.14	641,684.49
	818,398	1691	951,691.99	12,261,001.32	642,484.67
	819,419	1693	952,878.75	13,212,081.74	643,285.85
	820,440	1695	954,066.99	14,154,301.88	644,088.03
	821,463	1697	955,256.71	15,117,663.21	644,891.20
	822,488	1699	956,447.92	16,072,167.22	645,695.38
	823,513	1701	957,640.61	17,027,815.39	646,500.57
	824,540	1704	958,834.79	17,984,609.21	647,306.75
	825,569	1706	960,030.45	18,942,550.16	548,113.94

Conclusions and recommendations

Most developing countries and Palestine, used as an example in this article, are experiencing increases in the quantity and variety of the generation of medical waste. Therefore, the management of such waste is of major concern owing to the potentially high risks to human health and the environment as a whole.

It is clear from past experience that estimations of medical solid waste generation is crucial for solid waste management planning in a metropolitan region, from both short- and long-term perspectives. However, a complete record of medical solid waste composition and generation is not always available. This article puts forward an effective method, using System Dynamics modeling, for tackling forecasting problems. Other techniques tend to lack the utilization of significant amounts of data for determining regression models, and have vague relationships between dependent variables and socio-economic factors. The System Dynamics model was developed for the prediction of medical solid waste generation in a developing area of Palestine, Jenin District. Additionally, the model is used as a planning model, which was considered based on an assumption that the existing population growth rate will remain in the entire planning horizon. Thus, the system will constantly maintain the same trend in generation rate and the same percentage of the different components. The modeling results are useful for associated system planning with regard to future site selection and capacity planning of medical solid waste.

The System Dynamics model has the potential to predict future generated quantities of different medical waste components and assess the cost of treatment. Solid waste management has interwoven and interdependent issues, which are addressed in this article from a system perspective. Finally, this article shows that the model can be used as a tool or resource to support medical waste management policy analysis. It provides a prediction of future generated quantities of each component and enables policy makers and planners to be in a better position to understand a situation and set up plans to alleviate negative consequences and effects in both human health and the environment.

For future studies, the following additional aspects should be taken into consideration in developing new dynamic models: the influence of the development of the gross domestic product, occupation rate of hospitals, type of hospital, waste generation per inpatient and outpatient treatment days, the service level of the hospital (e.g. primary, secondary or tertiary level hospital), spending on health sector, length of stay in hospital and expectancy of life.

Conflict of interest

The authors do not have any potential conflicts of interest to declare

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