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ScienceDirect
Waste Management 27 (2007) 584–587
wasteWmanagement
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A mathematical model to predict the composition and generation of hospital wastes in Iran

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Accepted 31 May 2006

Abstract

The aim of this study is to investigate the quality and quantity of hospital wastes in Iran. The generated hospital wastes have been estimated by the number of hospitals and the number of active beds in each province of Iran in 2001. All data and information have been gathered from: (i) Iran Statistics Center, (ii) literature review, and (iii) hospital waste investigations for an average hospital. Physical analyses have been conducted in terms of various materials (plastic, textile, paper, metal, and others) and components (biological, infectious, medical, and regular wastes). Based on the above-mentioned investigation and information, a mathematical model has been developed to calculate the generation of (infectious) hospital wastes for any desired year. Utilizing the model, generated infectious hospital wastes has been estimated as 698,937 tonnes for 2008 (short-term) and 3,494,387 tonnes for 2028 (long-term period). If the real infectious wastes are collected separately, then the generated infectious wastes will be reduced by 15.1% of the above-mentioned amount (139,787 tonnes for 2008, and 698,877 tonnes for 2028). Results of physical analysis show the components of the hospital waste as: (a) infectious, 67.3%; (b) medical, 8.8%; (c) biological, 1.8%; and (d) common municipal wastes, 22.1%. An appropriate collection method requires training the staff at hospitals along with preparation of the required facilities. Of course, both of these requirements are cost intensive.

1. Introduction

Environment and natural resources can be polluted, and consequently human beings, animals and plants can be impacted. Hospital wastes, because of their infectious nature, are one of the most dangerous causes of this pollution (Sadeghi, 2002). As a result of developing healthcare technology, the amount of hospital wastes being generated is increasing due to the use of more disposable products (Omrani, 1998). Statistical data confirm this issue, as well. For example, 8 kg hospital wastes per bed are generated in Germany every day (Omrani, 1995), while field investigations show that less than 4 kg are generated in Tehran, Iran. These wastes are categorized as hazardous wastes and in most industrial countries there are special control measures for dealing with them. Hospital wastes include different kinds of wastes such as infectious, radioactive, chemical, heavy metals and regular municipal wastes (DoE, 1998). Transporting this mixed waste to the waste dumping sites causes soil and groundwater pollution, and consequently health hazards for live species (Shirazinejad, 1996). Proper management of hospital wastes through an appropriate method of separation from the source, transportation and disposal can prevent environmental pollution. One of the essential requirements of this management is the availability of reliable data and analysis corresponding to hospital wastes (HCW). Unfortunately, appropriate investigations and statistical analyses have not been conducted in this regard for Iranian HCW (Karimzadeghan, 1996).

The components of hospital wastes have been investigated and a mathematical model has been developed to estimate future HCW generation. As the first step, hospital statistics have been obtained from the Iranian Statistics Center, and on this basis an equation has been introduced to predict the generated HCW. This equation is a function of the

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doi:10.1016/j.wasman.2006.05.010

number of hospitals and beds. Based on more than 10 years of statistics, a mathematical model has been developed to predict the growth rate of the number of hospitals and beds.

At the same time, physical analysis of HCW was conducted in Alborz Hospital. Utilizing the developed model and the results of physical analyses, HCW generation and its physical analysis are presented for short- and long-term periods in the future.

2. Material and methods

Physical analyses for HCW were conducted in terms of both quality and quantity to investigate the current stream of hospital wastes. In this paper, all percentages are presented by weight.

2.1. Physical analysis of hospital wastes in terms of material

Knowing the composition of the wastes is extremely helpful in developing a suitable method for separation, transportation, and final disposal. The composition of wastes varies based on the social and economic conditions of patients and also varies during the week. In order to be more realistic, Alborz Hospital, as an average hospital, has been selected to examine its infectious wastes (within yellow bags) for 7 days a week. In each test, at least 90 kg of wastes has been separated and investigated. Table 1 shows the physical analysis of hospital wastes. As shown in the table, plastic has the highest percentage by weight (43.47%) and glass has the lowest percentage (0.77%).

2.2. Physical analysis of components of hospital wastes

Hospital wastes are classified into eight components as: (i) biological, (ii) infectious, (iii) medical, (iv) sharp, (v) radioactive, (vi) chemical, (vii) regular municipal wastes, and (viii) under pressure cylinders (WHO, 1995). Performing the same physical analysis as in Section 2.1, Table 2 shows the percentage of each category. Sharp wastes are omitted because of the very low weight percentage. Chemical wastes and radioactive wastes are not observed in hospital wastes, because of separate collection from the source (within the sections of the hospitals). Under pressure cylinders are recharged and reused in Iran and they are not observed in hospital wastes either. Table 2 shows the percentage of the remaining components.

Other tests are conducted to determine the percentage of non-infectious wastes and infectious ones. Lack of separation of infectious and non-infectious wastes at the source increases the percentage of infectious wastes within the yellow bags. This is due to the contamination of regular wastes through direct contact with infectious materials. Table 2 shows the results of this practice, as well.

As it is shown in Table 2, the percentage of infectious wastes is increased by 15.1% due to contamination of regular and medical wastes by coming in contact with infectious wastes. If source separation is conducted properly, the percentage of infectious wastes is reduced to 67.3%, which is 20% more than the percentage of infectious waste in developed countries (MOT, 2003).

2.3. Hospital wastes generation in 2001 (Existing situation)

As mentioned earlier, there are no certain statistical data for hospital wastes generation in Iran. Reviewing the literature, a mathematical model had been proposed to estimate daily generation of hospital wastes in terms of the number of hospitals and number of active beds as follows (Abdoly, 1991):

$$W = 181.153B + 1.54H \quad (1)$$

where W is generated hospital wastes per day in each province (in tonnes), B is the number of active beds, and H is the number of hospitals.

Using this model, an average generation of hospital wastes per bed for each province is estimated. As a matter of fact, almost all design parameters of hospitals are related to the number of active beds. Waste generation is also estimated as a function of number of active beds. This estimation, based on the number of active beds in each province (CSI, 2003), is listed in Table 3.

2.4. Mathematical models for estimation of generated hospital wastes in the future

Hospital wastes management has a lack of proper data associated with the quantity of wastes generated at hospitals. This issue has an adverse impact on all steps of their management such as collection, temporary storage, transportation and final disposal (Roostaee, 1998). On this basis, a mathematical model to predict the generation of hospital wastes in Iran is a great help in this regard.

Table 1
Physical analysis of hospital wastes

Material	Percentage (by weight)
Textile	15.47
Plastic	43.47
Paper	15.47
Glass	0.77
Metal	2.27
Others	22.55
Total	100

Table 2
Percentages by weight of hospital wastes components

Component	Percentage (current situation)	Percentage (after separation of infectious wastes at source)
Infectious	82.4	67.3
Medical	6.7	8.8
Biological	1.8	1.8
Regular	9.1	22.1
Total	100	100

Table 3
Average daily generation of hospital wastes per bed for each province (2002)

Province	Weight (kg)	Province	Weight (kg)	Province	Weight (kg)	Province	Weight (kg)
Ardebil	3.53	Gilan	3.16	Khorasan	2.86	Qazvin	2.88
Azarbayejan Gharbi	3.20	Golestan	4.09	Khouzestan	2.86	Qum	2.87
Azarbayejan Sharghi	3.16	hamedan	2.97	Kohkiluye va Boyerahmad	3.43	Semnan	3.60
Bushehr	3.8	Hormozgan	3.89	Kordestan	2.87	Sistan va Baluchestan	3.37
Cheharmah Bakhtiari	2.89	Ilam	4.80	Lorestan	4.03	Tehran	2.67
Esfehan	3.14	Kerman	3.01	Markazi	3.24	Yazd	3.45
Fars	3.30	Kermanshah	3.60	Mazandaran	3.32	Zanjan	2.92

2.4.1. Estimation of growth for number of beds and hospitals in Iran

Referring to Eq. (1), the production of hospital wastes is a function of number of hospitals and active (occupied) beds. In order to find out the growth pattern for the number of hospitals and beds in Iran (or a particular province in the country), historical data have been plotted in graphs. Various curves have been examined to find the curve that has the best fit with the graph points.

Among different possible alternative functions, the linear and exponential functions provided the best fits with the graph points. However, between these two equations, the linear curve has been selected as the optimum one.

The linear equations had a standard deviation (SD) of 14.4 and 5080 for number of beds and hospitals growth, respectively. But, the exponential one had a SD of 15.4 and 5732 for number of beds and hospitals growth, respectively. As a result, the two linear equations (Eqs. (2) and (3)) present the pattern of increasing number of beds and hospitals in Iran after 1991, respectively. Statistical data only are available from 1989, but the statistics for the first 2 years are not very accurate; thus 1991 has been considered as the first year to have the more reliable data for this purpose.

$$H = 8(X - 621) + 640.6 \tag{2}$$

$$B = 2245.5(X - 621) + 85,694 \tag{3}$$

where X is the difference between the desired year and year 1991.

Fig. 1 and 2 show the growth number of hospitals and beds (and their optimum mathematical model), respectively.

2.4.2. Estimation of generation of hospital wastes in next years in Iran

In order to find out the weight of hospital waste generation for a desired year, Eqs. (1)–(3) are combined. Eq. (4) is a combination of these equations, as follows:

$$W_{\text{total}} = 4960X + 248,000 \tag{4}$$

where W_{total} represents the quantity of hospital wastes generation per day in Iran for the desired year in kg/day.

Fig. 3 shows the application of Eq. (4) and the pattern of HCW generation growth.

There is just one survey in statistical data for HCW generation in Iran, which is related to Gilan (one of the provinces of Iran) in 1993. This survey shows that 3.2 kg of HCW per bed was generated in that year (Piraste, 1993). Utilizing Eqs. (3) and (4), the number of active beds and generated HCW are estimated at 90,185 and 257,920 kg/day, respectively. On this basis, 2.86 kg/day per bed of hospital waste was generated in 1993. There is about a 10% difference between the results of the survey and the results from the model. This comparison indicates a good relation between the two results, and it proves that the results of the mathematical model are reliable.

2.4.3. Estimation of cumulative generation of hospital wastes in next years in Iran

To calculate the cumulative weight of generated wastes for the desired year, Eq. (4) is used in combination with series theory. The result is presented as Eq. (5):

$$(W_{\text{total}})_t = [1791(n+1)(X + n/2) + 90,520(n+1)] \tag{5}$$

where t is the desired year and $(W_{\text{total}})_t$ is the total generation of hospital wastes in tonnes from year X until next n (number of) years in Iran.

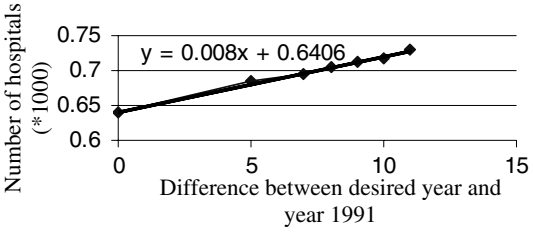

Fig. 1. Mathematical model for growth of number of hospitals in Iran.

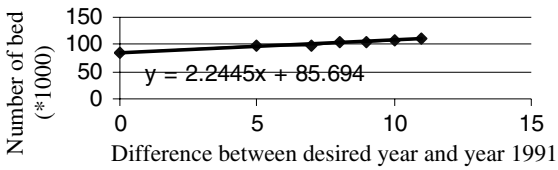

Fig. 2. Mathematical model for growth of number of active beds in Iran.

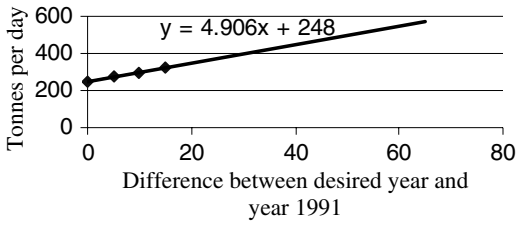

Fig. 3. Hospital wastes generation in Iran for the desired year.

Table 4
Estimated cumulative weight of each material in 2003, 2008, and 2028 in tonnes

Year	Cumulative weight of HCW	Textile	Plastic	Glass	Paper	Metal	Regular
2003	112,008	17,328	48,690	17,325	862	2,543	25,258
2008	698,937	108,125	303,828	108,125	5,381	15,866	157,610
2028	3,494,387	540,582	1,519,010	540,582	26,907	79,322	787,984

Table 5
Quantity of each hospital wastes component until 2008 and 2028 in Iran in tonnes

Component	With source separation		Without source separation	
	2008	2028	2008	2028
Infectious	470,385	2,351,722	575,924	2,879,375
Medical	61,506	307,506	46,828	234,124
Biological	12,581	62,899	12,581	62,899
Regular	154,465	772,259	63,604	317,989
Total	698,937	3,494,387	698,937	3,494,387

3. Results and discussion

Management and planning for collection, storage, transportation, and disposal of hospital wastes is a function of the quality and quantity of HCW. The results of Eq. (4) are used for planning a short-term (5 years) and long-term (25 years) schedule from 2003. On this basis, there will be 689,937 tonnes hospital wastes in 2008 and 3,494,387 tonnes in 2028.

Since each component of hospital wastes needs its own method of disposal, identification of each type of material is necessary. Table 4 shows the cumulative weight of each component in the years 2003, 2008, and 2028. These values have been calculated, based on Eq. (5), and the percentages are presented in Table 2. Utilizing the components and their percentages within hospital wastes in previous tables, quantities of each component are calculated and summarized in Table 5.

As clear from the above mentioned tables, 2,879,375 tonnes of infectious hospital wastes are estimated to be produced in 2028. If good source-separation is implemented, infectious hospital wastes would be reduced to 2,351,722 tonnes. This result shows that appropriate management reduces infectious waste generation up to 15% (out of the entire hospital wastes).

4. Conclusion

This study concludes that:

(i) weight percentages of hospital wastes component are: (a) plastic 43.47, (b) textile 15.47, (c) paper 15.47, (d) metal 2.27, (e) glass 0.77, and others 22.55,

(ii) percentage of physical analysis in terms of wastes components are: (a) infectious 67.3, (b) medical 8.8, (c) biological 1.8, and (d) common municipal wastes 22.1,

(iii) the quantity of infectious wastes is increased by about 15%, because of contamination of regular and medical wastes through direct contact with infectious wastes, and

(iv) there will be almost 3.5 million tonnes of hospital wastes generated from 2003 through 2028.

Accordingly, a good source-separation program should be implemented to reduce the amount of infectious wastes and the required preparation is to be carried out to achieve proper disposal.

5. Recommendation

Investigations show that an appropriate management reduces infectious wastes generation by up to 15%, causing less environmental and health problems in storage, handling and disposal of hospital wastes. On this basis, training hospital staff and preparing a guideline for separation of infectious wastes at the source will be an appropriate measure toward a more effective waste management system.

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