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QUANTITATIVE ASSESSMENT AND STATISTICAL ANALYSIS OF MEDICAL WASTE GENERATION IN DEVELOPING COUNTRIES: A CASE STUDY IN ISFAHAN (IRAN)*

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Abstract– Quantitative assessment and statistical analysis of medical waste generation at provincial scale in Isfahan was conducted. Results indicated that 59% of the total wastes produced were non-hazardous (general) wastes and the rest were hazardous medical wastes. More than 98% of centers implemented source separation of the wastes at source. Also, more than 91% had a storage room, but only 48% of storage rooms were operated under standard conditions, i.e. storage with appropriate ventilation and temperature control. Only about 21% of medical centers had designated collection vehicles. For the remaining 79% of facilities, the medical wastes were collected (comingled) and transported together with the general or non-medical wastes. As for the treatment of medical wastes, only 7% of centers were equipped with autoclave. Although 22% of centers had incinerators, the majority of them were not functional. Collected wastes from 29% of facilities were disposed together and mixed with the municipal wastes at the same landfill trenches. Wastes from the remaining 71% of centers were landfilled in separate trenches. The waste generation rates for total waste and general (non-hazardous) waste were 3.03 and 1.84 kg/active bed/day, and 1.03 and 0.65 kg/employee/day, respectively. Using multivariate regression analysis of data an empirical equation (Y = 0.55 * NEM + 1.44 * NAB) was established to predict the total amount of waste generated at each facility (Y) as a function of number of active beds (NAB) and number of employees (NEM) of the facility. Strong correlation (R^2 = 0.97) between the observed and predicted values was observed.

Keywords– Healthcare, medical waste, waste audit, developing countries

1. INTRODUCTION

In the process of health care, wastes such as sharps, human tissues and other infectious waste materials are generated, that are classified as hazardous wastes. As such, the management of medical or healthcare wastes is of great importance in developing countries due to its potential environmental and public health risks [1]. Although medical wastes represent a small fraction of the total wastes generated in a community, mismanagement of this waste stream in developing countries may be a significant risk factor for disease transmission to municipal workers, the public and the environment [1-2]. The outbreak of severe acute respiratory syndrome (SARS) in 2003 was reported as an example of mismanagement of medical wastes [3]. World Health Organization (WHO) has also estimated that in 2000, injections with contaminated syringes caused 21 million hepatitis B infections, 2 million hepatitis C virus infections and 260,000 HIV infections [4].

Analysis of the medical waste stream and its characteristics, or a medical waste audit, is an important preliminary step in implementing an effective healthcare waste management plan. It is a useful tool to find

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the sources of waste in a healthcare facility, their compositions, rates of generation, waste flow within the facility, information on waste handling practices, and compliance with the existing regulations on waste handling and disposal. Through a medical waste audit, the authorities of healthcare facilities can determine whether or not some waste is being misclassified as biohazardous waste and can be diverted into the general or non-hazardous waste stream.

The assessment of medical waste composition and the quantification of their rates of generation have recently become a popular area of research. Results of such studies for generation rates recorded in different countries are summarized in Table 1. According to Pruss et al. [16], between 75% and 90% of the waste produced by health-care providers is general healthcare (domestic) waste. In France, 15–20% and in the USA around 15% of healthcare wastes are considered as infectious wastes [19-20]. Considering the above information it is necessary to segregate and manage healthcare wastes accordingly. Otherwise, the whole stream has to be considered as hazardous or infectious waste.

The generation rate of medical waste depends upon several factors such as: the type of healthcare facility, status, capacity, level of instrumentation, and location of the facility. Although many studies have focused on medical waste management in different parts of the world, the majority has been carried out for a limited number of healthcare facilities or facilities inside a city and few have paid close attention to a regional or provincial scale.

The Regulations and Methods for the Management of Medical and Related Wastes (RMMMRW) in Iran were established by the Ministry of Health and Department of the Environment in 2008. However, there has been no rigorous estimation of medical waste generation at provincial scale in any province in Iran including Isfahan, located in the central part of Iran. The primary aim of this study was to evaluate the production and management of medical wastes in Isfahan province through conducting a medical waste audit and statistical analysis of collected data to establish some simple predictive equations for estimation of waste generation rates. Such equations can have major practical significance, since they can be used for the prediction of medical waste generation rates in a similar healthcare facility without the need to perform a costly waste management audit. The current practices were also assessed in terms of compliance with the existing regulations and guidelines.

Table 1. Generation rates of medical wastes

Country (City)	Total waste generation rate kg/bed/day	Hazardous waste generation rate kg/bed/day	Reference
---	3.6 - 20	-	[5]
Brazil	3.2	0.6	[6]
India	0.5 – 2.0	-	[7]
India	2.3	0.4	[8]
Japan	1.5 – 3.0	0.47	[9]
Mauritius	0.4 – 0.5	0.07 – 0.18	[10]
Bangladesh (Dhaka)	1.2-1.5	-	[2, 11]
Spain	4.4	-	[12]
UK & France	3.3	-	[12]
Norway	3.9	-	[12]
Jordan	1.9-3.5	-	[12]
Turkey (Istanbul)	0.63	-	[13]
Turkey (Istanbul)	0.5 – 0.8	-	[14]
Turkey	1.9 -2.0	-	[15]
North America	3-7	-	[16]
Taiwan	2.4 – 3.3	0.2 – 0.9	[3]
Iran (Tabriz)	3.5	1.0	[17]
Iran (Shiraz)	4.5	-	[18]

2. MATERIALS AND METHODS

There are a total of 58 medical centers in Isfahan province, all of which were examined through this research. General information about these medical centers including the level of service of the center, the county or district, the number of employees, and number of active beds are presented in Table 2. The required data in this research was collected through surveys and interviews with the authorities and personnel involved in the management of the wastes of the healthcare facilities and complemented by site visits. The information was collected using a form specifically developed for this purpose. According to RMMMRW, wastes generated from healthcare facilities in Iran are classified into four main groups including infectious waste, sharps, chemical and pharmaceutical waste, and general (non-hazardous) waste. As such, the form contained sections for collecting information on the generation of these 4 different categories of medical wastes. The survey form also contained sections for collecting information on main aspects of waste management practices. These included information on: 1) segregation and separate collection of different types of wastes, 2) existence of storage rooms and whether they were equipped with any temperature control and/or ventilation system, 3) collection and transport of medical wastes and whether they were transported separately or comingled, 4) existence of treatment equipment such as autoclave or incinerator, and 5) information on the final disposal of medical wastes generated in the healthcare facilities.

Table 2. Number of surveyed health-care centers and number of beds and employees in these centers

County or District	Number of Medical Centers*				Num. of Active Beds	Num. of Employees
	Level 1	Level 2	Level 3	Total		
Isfahan	18	6	2	26	4,226	11,831
Shahin Shahr & Meymeh	1	1	0	2	80	360
Falavarjan	1	0	0	1	92	265
Mobarake	1	0	0	1	64	280
Khomeini Shahr	0	2	0	2	128	315
Borkhar	0	0	1	1	32	50
Kashan	4	2	0	6	749	1,656
Aran & Bidgol	1	1	0	2	84	170
Najaf Abad	1	1	0	2	321	797
Tiran & Karon	0	0	1	1	11	96
Lenjan	2	0	0	2	230	737
Ardestan	0	1	0	1	60	182
Natanz	0	1	1	2	59	194
Golpayegan	0	1	0	1	100	223
Khansar	0	1	0	1	49	154
Fereidan	0	1	0	1	89	210
Fereidon Shahr	0	1	0	1	30	96
Semirom	0	1	0	1	64	220
Shahreza	1	1	0	2	174	448
Naeen	0	1	1	2	58	191
Total	30	22	6	58	6,685	18,475

* Medical centers are classified into 3 levels based on their size and services they offer

The data on waste generation rates collected through the audit was mainly based on information provided by the authorities and their existing records, however, some random sampling was conducted to check and complement the data. In the case of sharp wastes, they were measured directly using a hand held scale. For the rest, i.e. infectious waste and general (non-hazardous) waste, since they were collected and stored in plastic bags, a few bags were measured for each type to get an average weight of the bags and then it was multiplied by the number of bags to estimate the generation rates for infectious and general (non-hazardous) waste.

The collected data was first examined to eliminate any outlier and unreliable data by calculating standardized residual and eliminate any pair of data with an absolute standardized residual greater than 2. Then, the data was again analyzed using linear regression procedures to assess correlation between waste generation rates and variables such as number of active beds or the number of employees, if any, and establish some simple predictive equations for estimation of waste generation rates.

3. RESULTS AND DISCUSSIONS

a) Waste generation

The results of the survey including the amount of waste generation for the total amount of waste as well as sharps, infectious, and general (non-hazardous) waste fractions, and information on number of centers that have source separation, storage area, incinerator, and autoclave are presented in Table 3. The amount of chemical and pharmaceutical waste generated was not significant and not reported nor discussed in this paper. Total waste then refers to summation of amounts of sharps, infectious, and general (non-hazardous) waste fractions. Summary of the above results is also presented in Table 4, based on both the quantity of generated waste and the number of healthcare facilities for different management practices.

Table 3. Results of surveys for health-care centers

County or District	Medical Waste Generation Rate (Kg/d)				Num. of Centers with source separation	Num. of Centers with storage	Num. of Centers with std. storage*	Num. of Centers with Incinerator	Num. of Centers with Autoclave
	Infectious	Sharps	General	Total					
Isfahan	4,955	622	8,099	13,676	25	25	9	3	2
Shahin Shahr & Meymeh	137	4	73	214	2	1	0	1	0
Falavarjan	200	10	240	450	1	1	1	0	0
Mobarake	129	12	141	282	1	1	1	1	1
Khomeini Shahr	350	33	500	883	2	2	2	0	0
Borkhar	10	1	20	41	1	1	1	0	0
Kashan	634	55	1,151	1,840	6	5	5	1	1
Aran & Bidgol	60	9	140	209	2	2	2	0	0
Najaf Abad	335	65	750	1,150	2	2	2	1	0
Tiran & Karon	13	2	150	165	1	1	0	0	0
Lenjan	145	45	210	400	2	2	1	1	0
Ardestan	100	20	150	270	1	1	1	0	0
Natanz	75	8	90	173	2	2	1	0	0
Golpayegan	50	10	100	160	1	1	0	0	0
Khansar	50	10	70	130	1	1	0	1	0
Fereidan	50	4	50	104	1	1	0	1	0
Fereidon Shahr	70	5	35	110	1	1	0	1	0
Semirom	13	2	30	45	1	1	0	1	0
Shahreza	100	23	180	303	2	2	2	1	0
Naeen	64	11	152	227	2	0	0	0	0
Total	7,540	951	12,331	20,822	57	53	28	13	4

* Std. storage: Storage with appropriate ventilation and light and temperature control

As seen in Table 3, about 7,540 kg of infectious wastes, 951 kg of sharp wastes, 12,331 kg of general (non-medical) wastes, and 20,822 kg of total wastes were produced daily. These numbers indicate that 36.2, 4.6, and 59.2 percent of total wastes produced were infectious, sharps, and general wastes, respectively. The percentage of non-hazardous (general) waste in this study is lower than the range of 75-90% reported in the literature as stated in the introduction. This could be due to the higher range of

infectious waste production in the study area and/or the fact that no activity or program existed for waste minimization in any of the medical centers investigated in this research.

Table 4. Summary of the results of survey

	Based on amount of waste		Based on number of centers	
	Amount (kg/day)	(%)	Num. (num.)	(%)
with source separation	20,133	96.7	57	98.3
without source separation	896	4.3	1	1.7
with storage room	19,926	95.7	53	91.4
without storage room	896	4.3	5	8.6
with std. storage room	9,870	47.4	28	48.3
without std. storage room	10,952	52.6	30	51.7
with separate collection	3,451	16.7	12	20.7
commingled collection	17,371	83.4	46	79.3
autoclave treatment	415	2	4	6.9
without autoclave treatment	20,407	98	54	93.1
centers with incinerator (active)	846	4.1	13 (6)	22.4 (10.3)
centers without incinerator	19,976	95.9	45 (52)	77.6 (89.7)
separate landfill trench	17,254	84.2	17	29.3
co-disposal with municipal waste	3,298	15.8	41	70.7

b) Source separation

An important element of a healthcare waste management framework is waste segregation or separation. Commingling or mixing of different waste streams inflates the amount of waste that requires special treatment and hence increases the total cost of treatment and disposal. All facilities used rigid, puncture-proof containers to dispose of the sharp wastes such as needles, syringes, lancets, etc. As seen in Table 4, more than 98% (57 out of 58 existing centers) of facilities implemented source separation of the wastes. In terms of tonnage, 20133 kg (or 97%) of the total wastes were separated at the source.

c) Storage

Based on the data presented in Table 4, out of 58 existing centers, 53 medical centers (or 91.4 percent) had a storage room, but only 28 of them (or 48.3 percent) had standard conditions. A standard storage room for infectious waste should have good drainage, easy-to-clean surfaces, good lighting, ventilation, and should be safe from weather, animals, and unauthorized entry. In terms of tonnage, 19926 kg (or 95.7 percent) of the total wastes were stored in storage room, but only 9870 kg (or 47.4 percent) were stored under standard conditions. Figure 1 illustrates examples of storage rooms in medical centers.

Fig. 1. A storage room with appropriate ventilation and temperature control (left) and a storage room with non-standard conditions (right)

d) Collection and transport

Numbers in Table 4 show that although the majority of the wastes (98 percent in terms of number of medical centers and 97 percent in terms of wastes produced) were separated at source, they were mixed again during the collection and transport phase. Only 12 or 20.7% of medical centers had designated collection vehicles specifically used and equipped for the transport of the medical wastes. For the remaining 46 facilities (or 79.3 percent), the medical wastes were collected and transported together with the general or non-medical wastes. In terms of tonnage, 3451 kg (or 16.7) percent of total wastes generated are collected separately by designated collection vehicles and for the remaining 17371 kg (or 83.4 percent) of total wastes, medical and non-medical wastes are collected and transported mixed together. As a result of comingling of wastes the total amount of hazardous medical wastes was inflated and increased by 100 percent. Figure 2 illustrates examples of unsuitable collection and transport in medical centers.

Fig. 2. Commingling of medical and general wastes in storage rooms (left) and collection vehicles (right)

e) Treatment

As can be seen from the numbers presented in Table 4, only 6.9% of healthcare facilities were equipped with autoclave as disinfection treatment. Although 22.4% of centers had incinerators, the majority of them were not functional due to use of old technology, associated air pollution problems, and lack of experienced and trained operators. In terms of tonnage 846 kg (or 4.1%) of total wastes or about 10% of 8490 kg of infectious and sharp wastes are treated by incinerators. Figure 3 illustrates examples of autoclave and incinerator equipment used in these facilities.

Fig. 3. Examples of autoclave equipment (left) and an incinerator (right)

f) Disposal

Results presented in Table 4 show that collected wastes from 29.3% were disposed with the municipal wastes at the same landfill trenches. Wastes from the remaining 70.7% of facilities were landfilled in separate designated trenches. However, no appropriate lining system existed at these landfills and existing natural clay soil was the only barrier to reduce any leachate leakage. After the trenches were filled, they were covered by a soil layer. In terms of tonnage, 84.2% of collected wastes are landfilled separately from the municipal solid wastes of the region. Although this shows that the majority of medical wastes are landfilled separately from municipal waste, there is still some room for further improvement. An example of an open dump is illustrated in Fig. 4.

Fig. 4. Final disposal of medical wastes in open trenches

g) Statistical analysis of the results

Linear regression using a 95% confidence level ($p<0.05$) was used to analyze the results. After removing outliers, the total amount of wastes generated at each medical center was plotted against the number of active beds (NAB) and number of employees (NEM), as presented in Figs. 5 and 6. Correlation in both cases is good with an R^2 value of 0.91 for both cases. The slope of regression line for Fig. 5 indicates that the average amount of total waste generation was 3.03 kg of waste per active bed per day. Also, the slope of regression line for Fig. 6 indicates that the average amount of total waste generation was 1.03 kg of waste per each employee per day. These are generally in line and within the range of values found in the literature and reported in Table 1. For example, in a similar study Cheng et al. [3] collected data on medical waste generation at 150 health care establishments in Taiwan. The average waste generation rates ranged from 2.4-3.3 kg/bed/day for general medical wastes, and 0.2–0.9 kg/bed/day for infectious wastes. These numbers are comparable with results obtained in this research.

The correlation of results was not good in the case of infectious and sharp wastes vs. NAB or NEM and R^2 values were below 0.65 for all cases.

Since a good correlation between total amount of waste and both NAB and NEM was observed, it was decided to conduct a linear regression analysis assuming the second degree polynomial equation below:

$$Y = b_0 + b_1 NAB + b_2 NEM + b_{12} NAB * NEM + b_{11} NAB^2 + b_{22} NEM^2 \quad (1)$$

where Y is the predicted or expected value of total amount of generated waste. The statistical significance of the coefficients were assessed at 95% confidence level ($p<0.05$) and insignificant terms were eliminated. The resulting empirical model with the best fit was:

$$Y = 0.55 * NEM + 1.44 * NAB \quad (2)$$

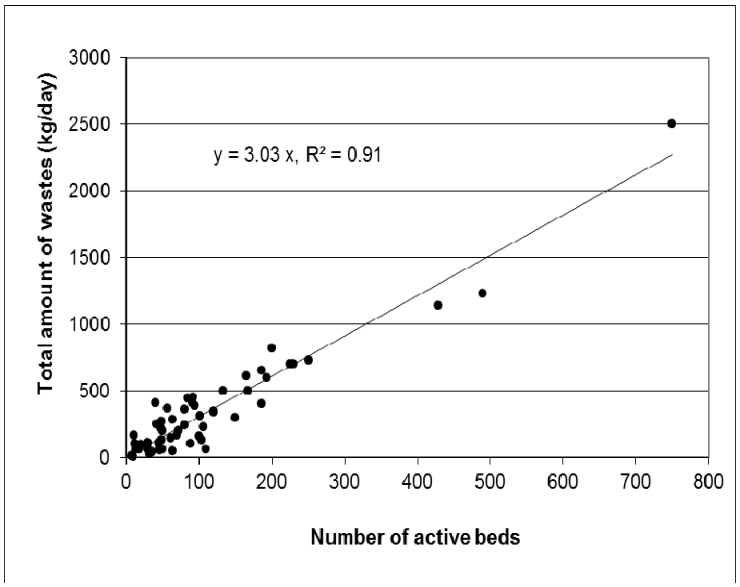

Fig. 5. Correlation between total amount of wastes and number of active beds

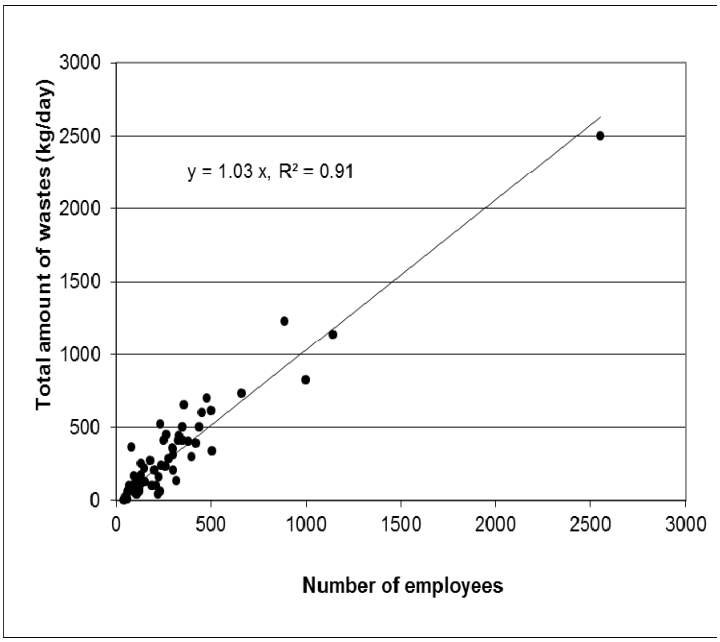

Fig. 6. Correlation between total amount of wastes and number of employees

Figure 7 shows the observed vs. predicted results with a R^2 value of 0.97 showing that the model was able to describe and predict the results well.

The same analysis was carried out for the amount of general waste vs. NAB and NEM. Figures 8 and 9 illustrate the plots of the amount of general waste vs. NAB and NEM, respectively, after removing outliers. Correlation in both cases is good with a R^2 value of 0.80 and 0.89. The slope of regression line for

Fig. 8 indicates that average amount of general waste generation was 1.84 kg per active bed per day. Also, the slope of regression line for Fig. 9 indicates that average amount of general waste generation was 0.65 kg of waste per each employee per day.

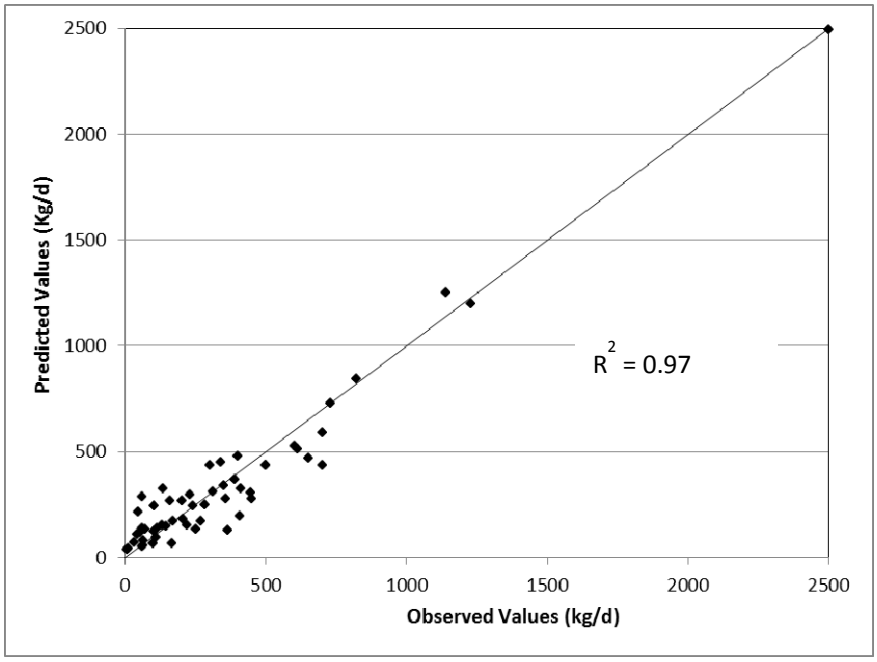

Fig. 7. Observed vs. predicted total waste generation

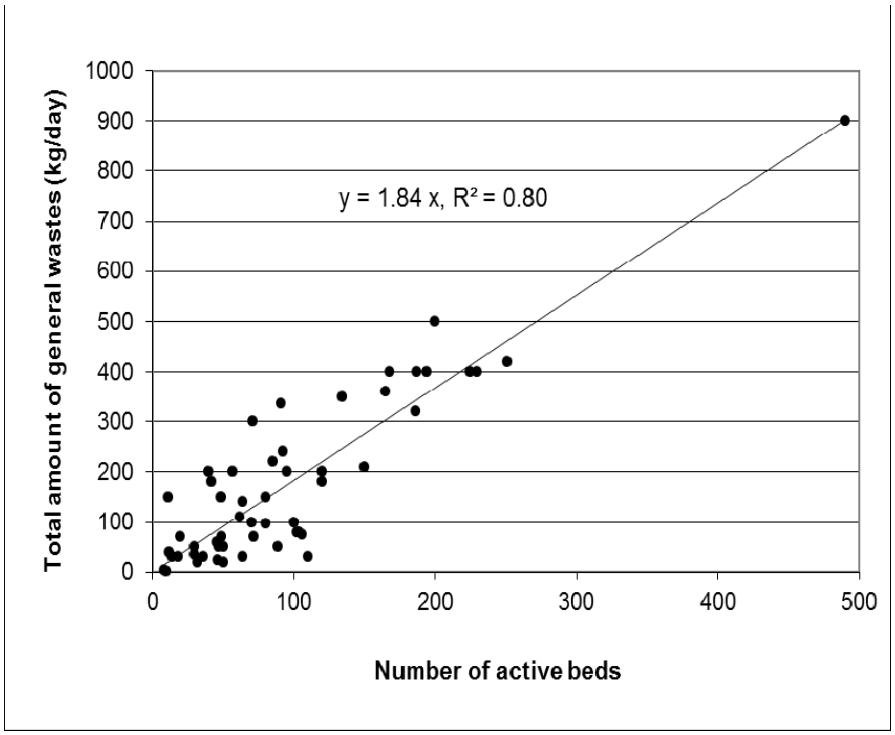

Fig. 8. Correlation between amount of general (non-hazardous) waste and NAB

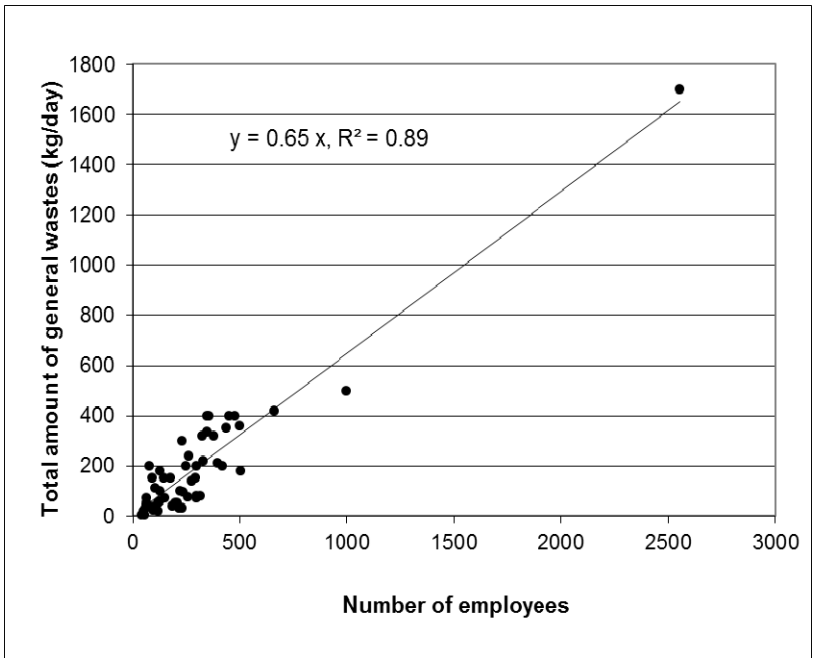

Fig. 9. Correlation between the amount of general (non-hazardous) waste and NEM

The results obtained after conducting a linear regression analysis assuming a second degree polynomial equation (Eq. (1)) is presented below:

$$Y = 0.25 * NEM + 1.15 * NAB \quad (3)$$

Figure 10 shows the observed vs. predicted results with a R^2 value of 0.84 showing that the model was able to describe and predict the result relatively well.

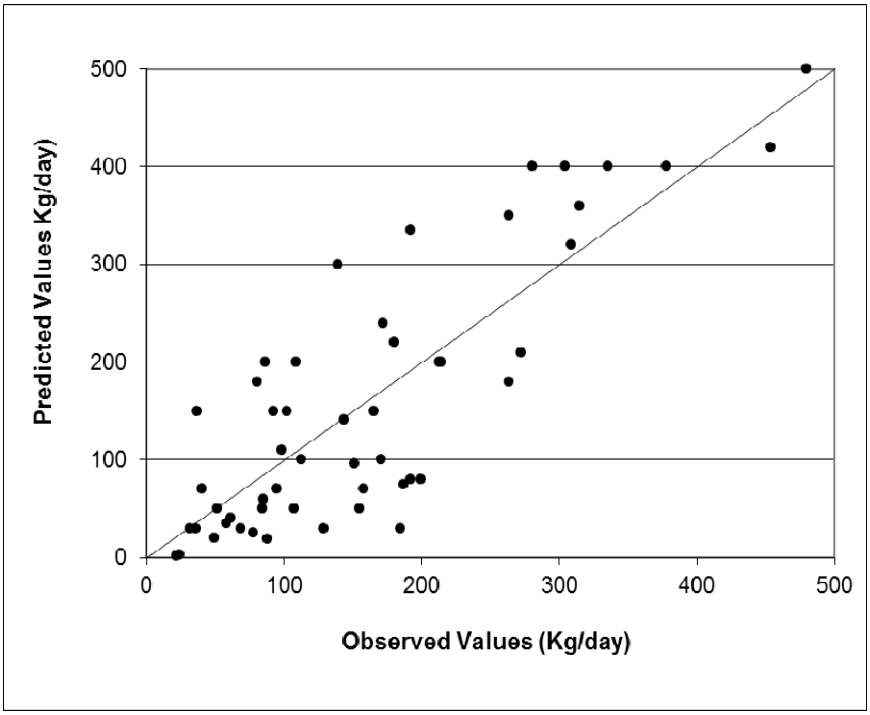

Fig. 10. Observed vs. predicted general (non-hazardous) waste generation

Other researchers have established correlation between medical waste generation rates and a number of factors. For example, Cheng et al. [3] used multiple variable regression analysis for collected data on medical waste generation at 150 healthcare establishments in Taiwan to establish correlation between general medical waste and infectious waste production at these establishments vs. factors including the type of hospital and clinic, reimbursement payment by national health insurance, total number of beds, bed occupancy, number of infectious disease beds and outpatients per day. The results indicated that only insurance reimbursement and number of beds were significant prediction factors. In another study, Komilis and Katsafaros [21] developed linear equations to describe and predict medical waste generation rates in a 40-bed general hospital in Greece as a function of key hospital parameters including the number of examinees, the number of patients that occupied beds, and the number of tests performed daily at the clinical bio-pathology laboratory. The strongest correlation obtained by these researchers was for hazardous medical waste daily generation rates at the clinical bio-pathology laboratory vs. number of examinees per day or the number of tests performed daily with a coefficient of determination R^2 equal to 0.75, which is much lower than R^2 values obtained and reported in this research.

4. CONCLUSION

- The results indicated that the percentage of non-hazardous (general) waste generated was lower compared to the range reported in the literature due to inefficient separation of wastes at source and the lack of any waste minimization plan.
- Although almost all facilities implemented source separation of the wastes, the separately collected wastes were mixed and comingled during the collection and transport phase. This is one of the main existing drawbacks of the healthcare waste management system.
- Significant percentage (close to 50%) of healthcare facilities did not have standard storage rooms.
- Majority of healthcare facilities were not equipped with autoclave or incinerator, or the equipment was not functional. This is another existing drawback of the healthcare waste management system.
- Although the majority of collected healthcare wastes were landfilled separately from the municipal solid wastes of the region, there was some room for improvement.
- There was a good correlation between the generated quantities of total and general wastes and the number of active beds and the number of employees of facilities and these two parameters can be used to estimate the quantity of waste generation.

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