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Implementation of a multi-variable regression analysis in the assessment of the generation rate and composition of hospital solid waste for the design of a sustainable management system in developing countries

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Abstract

Forecasting of hospital solid waste generation is a critical challenge for future planning. The composition and generation rate of hospital solid waste in hospital units was the field where the proposed methodology of the present article was applied in order to validate the results and secure the outcomes of the management plan in national hospitals. A set of three multiple-variable regression models has been derived for estimating the daily total hospital waste, general hospital waste, and total hazardous waste as a function of number of inpatients, number of total patients, and number of beds. The application of several key indicators and validation procedures indicates the high significance and reliability of the developed models in predicting the hospital solid waste of any hospital. Methodology data were drawn from existent scientific literature. Also, useful raw data were retrieved from international organisations and the investigated hospitals' personnel. The primal generation outcomes are compared with other local hospitals and also with hospitals from other countries. The main outcome, which is the developed model results, are presented and analysed thoroughly. The goal is this model to act as leverage in the discussions among governmental authorities on the implementation of a national plan for safe hospital waste management in Palestine.

Keywords

Hospital solid waste, hazardous waste, general waste, generation rates, regression, model

Introduction

The rapid growth of the medical sector over the past decade in most parts of the world, combined with an increase in the use of disposable medical products, have contributed to the large amount of medical waste being generated (Coker et al., 2009; Karamouz et al., 2007; Patwary et al., 2009; Silva et al., 2005). The World Health Organization (WHO) specifically described hazardous medical waste categories since the early 1990s.

In developed countries, good practice guidelines and legislation define medical waste and state the various possible ways for handling treatment and final disposal of such waste (Blenkharn, 2006; Mohee, 2005; Tudor et al., 2005). In many developing countries, little information is available regarding generation, handling, and disposal of HSW. Most hospitals in Developing Countries (DCs) dispose of their waste, along with general domestic waste, in an open dumping site outside of the city, constituting great risk for the environment owing to the high toxicity (Muhlich et al., 2003) and posing significant public health problems (Diaz et al., 2005; Idowu et al., 2013; Silva et al., 2005) owing to pathogenic organisms causing infectious diseases (Birpinar et al., 2009; Chintis et al., 2004; Sabour et al., 2007; Silva et al., 2005).

When the suitable waste management project is scheduled (or re-scheduled) in any country (developed or developing), primal criteria are economics, social, technical, and environmental. In developing countries where the national legislation and introduced framework is weak or non-existent, the basic criterion is

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the acquisition of specific data related to waste quality and quantity of the waste, as well as the necessary preparatory steps towards the implementation of any project. Rapid increase in the number of healthcare centres, as well as hospital solid waste (HSW) generation growth, lack of information, effect of variable, and out of control factors on HSW generation cause the forecasting to be a complex health problem, especially in the developing countries (Jahandideh, 2009; Oweis et al., 2005; Patil and Shekdar, 2001). Forecasting of solid waste generation is the major important and initial step in planning and operation of solid management system (Abbasi et al., 2013; Chang and Lin, 1997; Denafas et al., 2014a; Rimaitytė et al., 2012; Thanh and Matsui, 2011).

Many researches have been conducted worldwide to determine the quantities of the waste streams generated from healthcare services, e.g. in accordance with the outpatient number in order to give more appropriate results than the evaluation methods are capable of (Eker and Sinan Bilgili, 2011), to establish patterns based on seasonal variation (Katoch and Kumar, 2008) or even to monitor and determine the requirements for the improvement of the handling practices and the implementation of off-site centralisation (Ruoyan et al., 2010). Summarising, all conducted researches aimed to determine the generation rates and physical properties of healthcare waste and/or to forecast them. The location where they were performed (i.e. developed or developing countries worldwide) determined the complexity of them. In developing countries, the retrieval of raw data is the main aim of the researches. The present article comes to bridge the gap between basic research and advanced raw data processing in developing countries.

Another field research will not solve the problem of sustainable HSW treatment in DC. So the research performed is backed up with the development of an advanced methodology that can assess the HSW components and quantities generated by a source via the application of a model that is using the obtained data sets to predict the daily quantity of HSW generated.

The calculated generation rates can serve as a reference for hospitals and controlling authorities, primarily in Palestine and secondly to other developing countries, given that the research base factors are similarly or suitably modified. The information provided may be used for resource planning and optimisation in any hospital unit. The modelling results of this research will be used to raise the hospital's head-capacity planning of the waste management system to satisfy the hospital's increasing waste treatment/disposal demands. Their further dissemination aims to be the starting point for organisation of a national HSW management plan. Thus, this study, for the first time in Palestine, provides information on the hazardous waste generation, allowing benchmarking between hospitals and possibly between countries.

Research methodology

Principle of multivariable multiple regression analysis

Several investigators established linear models using multiple linear regressions for HSW prediction (Bdour et al., 2007; Cheng et al., 2009; Denafas et al., 2014b). Regression models can assist waste management planners to make existing waste management systems function at their best or most effective, to set regulations and guidelines, and to evaluate current strategies for the management of waste (Katoch and Kumar, 2008).

In this regard, only a few models are available, some focus on integrated sustainable waste management systems (Berger et al., 1999; Costi et al., 2004) and others are optimisation models (Berger et al., 1999; Costi et al., 2004; Gottinger, 1988; MacDonald, 1996). Most of these models can help in multi-criteria decision-making, environmental impact assessment, cost-benefit analysis or risk assessment applicable mainly to municipal waste handling (Morrissey and Browne, 2004; Woolridge et al., 2005).

In the frame of the present article, the multi-variable regression analysis applied determines a linear regression function expression through comparison between dependent and independent variables and it includes the following steps; based on a set of data, establish quantitative relations among several variables. The influence of each variable is tested and only the significant are variables introduced into the model, whereas those with no significant influence are eliminated. The solid waste components and quantities generated are monitored and assessed using the derived relations from the model.

Case study analysis

The case study targeted hospital units in Nablus city located in the northern part of the West Bank, Palestine, which provided their services to the local population amounting 364,333 persons in 2013 (Palestinian Central Bureau of Statistics, 2007). In total, there are six active hospitals (being governmental, charitable and private); four of them were selected to participate in the survey and their characteristics are presented in Table 1. The number of beds ranged between 50 beds in Al-Ittehad hospital, to 204 beds in Rafidia hospital. The largest hospital in terms of number of employees (561) was Rafidia hospital, while Al-Ittehad hospital was the smallest one with 140 employees. A surgery department exists in all hospitals except of the Al-Watani hospital. Paediatrics, Maternity and Orthopaedic departments were available in three out of four hospitals. The kidney dialysis department was available only in Al-Watani hospital and the Burn Unit department was available only in Rafidia hospital. Support departments and units were available in the four hospitals. Department variation contributes the most in waste generation as well as other factors, such as patient or bed number, seasonality, etc., all of which are documented in international scientific literature.

The conducted research took into consideration basic parameters affecting waste generation.

- The bed occupancy is 85.2% and 84.4% in Rafidia and Al-Watani hospitals, respectively.
- The hospital days recorded are 62,174 and 16,938 in Rafidia and Al-Watani hospitals, respectively, in 2013.

Table 1. Characteristics of Nablus city hospitals.

Characteristics of hospitals	Hospital name			
	Rafidia (Public)	Al-Watani (Public)	Al-Ittehad (Charitable)	Al-Arabi (Private)
Number of beds, 2013	204	110	50	100
Number of employees, 2013	561	258	140	242
Departments				
Surgery	A	NA	A	A
Paediatrics	NA	A[a]	A	A
Emergency	A	A	A	NA
Intensive care unit	A	A	A	A
Kidney dialysis	NA	A	NA	NA
Maternity	A	NA	A	A
Orthopaedic	A	NA	A	A
Burn unit	A	NA	NA	NA
Support departments and units				
Pharmacy; Laundry; Physiotherapy; X-ray unit; Laboratory; Maintenance; Kitchen	A	A	A	A

A: available NA: not available.
[a]It is an exclusively medical/cardiac intensive care unit.

- The number of admissions was 9280 and 4010 in Al-Arabi and Al-Ittehad hospitals, respectively (Palestinian Health Information Center, 2014).

The waste originating from each hospital presents significant differences; treatments provided by each clinic are responsible for that. Bloody gauzes may be existent in all clinic types, but waste such as human tissue is resulting in high quantities from surgery and maternity clinics' waste. Emergency and intensive care unit clinics are the ones that follow the aforementioned in terms of the generation of infectious waste quantity. On the other hand, orthopaedic clinics are not expected to generate a high quantity of infectious waste. To provide such information and facilitate researchers to discriminate the waste types generated by each clinic in each hospital investigated, the head of each hospital was asked to support this research; site visits were conducted to all selected hospitals to assess working conditions and the procedures followed regarding HSW. Since personnel cooperation was required for the collection of data, they were requested to attend a basic training course to better understand the purpose of the survey, the occupational safety associated with working with HSW, and the particular procedures for sorting and weighing HSW. The researchers provided them with the necessary protective measures, such as gloves, masks, aprons, overalls, and special boots, as described by the International Organizations (WHO, US Environmental Protection Agency (EPA), etc.). HSW was classified in each hospital as general (non-hazardous) waste (GW) and hazardous waste (HW).

GW comes mainly from the kitchen waste and administrative offices. Weighing scales were used to quantify the amount of HSW generated. The HW consists of all types of hazardous solid hospital wastes, such as infectious waste, pathological waste, sharps, pharmaceutical waste, chemical waste, etc. Every kind of waste that came in contact with patients' body fluids was considered as infectious. Other waste, i.e. pressurised containers, broken glass, and syringes, which were not used in patient treatment were not included in infectious waste category, but they are included in HW. The hazardousness of the recorded waste originates from their sharpness, their potential flammability or explosiveness, and the bearing of infectious agents owing to patients' treatment.

Waste was collected and measured daily for 14 consecutive days (between July and September 2013) to estimate the amount of waste generated. HSW was separated and deposited into two different coloured and labelled puncture-proof plastic containers. Yellow colours were used for HW containers, while black colours were used for GW containers. The containers were first weighed with weights recorded using a data format sheet every day at 8:00 am, and the containers were then emptied in the usual disposal place used by the hospital. One day means 24 working hours. The data was entered into the software SPSS version 17 for analysis. Descriptive indicators, such as range of values (minimum–maximum), mean and standard deviation for HSW data were determined. The generation rates and percentages of GH and HW generated at the four different hospitals were compared with each other and with data from other countries' hospitals.

Results and discussion

HSW quantity and generation rate

Planning and management for handling and disposal of HSW is a function of the quality and quantity of HSW. A summary of range of values, mean, and standard deviation (SD) of quantities and generation rates of both GW and HW at the four hospitals (Rafidia, Al-Watani, Al-Ittehad, and Al-Arabi) are shown in Table 2. The mean value of the HW in the four hospitals is 0.76 kg patient^{-1} day^{-1} (17.03%).

The generation ratio differs from one country to another; in Addis Ababa, Ethiopia, the HW generation rate was found to be varied from 0.361 to 0.669 kg patient^{-1} day^{-1}, comprised of 58.69% non-hazardous and 41.31% HW (Debere et al., 2013).

Table 2. Daily quantities of HSW generation rates in the surveyed hospitals in Nabluscity, Palestine, 2013.

Name of hospital	Generation rate	General waste			Hazardous waste			Total hospital solid waste		
		Range of values	Mean	SD	Range of values	Mean	SD	Range of values	Mean	SD
Rafidia (Public)	kg day^{-1}	520–770	676.36	75.79	129–143	137.07	4.58	650–906	813.43	76.13
	kg bed^{-1a} day^{-1}	2.55–3.77	3.32	0.37	0.63–0.70	0.67	0.02	3.19–4.44	3.99	0.37
	kg in-patient^{-1b} day^{-1}	3.88–13.50	8.22	2.98	0.97–2.91	1.67	0.62	4.85–16.15	9.88	3.57
	kg total patient^{-1c} day^{-1}	0.63–2.37	1.20	0.56	0.15–0.49	0.25	0.12	0.78–2.83	1.45	0.67
Al-Watani (Public)	kg day^{-1}	313–546	453.43	70.00	85–105	93.71	6.96	400–649	547.14	75.12
	kg bed^{-1} day^{-1}	2.85–4.96	4.12	0.64	0.77–0.95	0.85	0.06	3.64–5.90	4.97	0.68
	kg in-patients^{-1} day^{-1}	14.23–36.45	25.09	6.87	3.63–7.73	5.16	1.20	18.13–44.18	30.25	8.00
	kg total patient^{-1} day^{-1}	0.96–5.03	2.03	1.21	0.23–0.99	0.42	0.25	1.20–6.02	2.45	1.46
Al-Ittehad (Charitable)	kg day^{-1}	174–217	189.57	13.15	34–43	38.57	2.50	209 – 258	228.14	15.09
	kg bed^{-1} day^{-1}	3.48–4.34	3.79	0.26	0.68–0.86	0.77	0.05	4.18–5.16	4.56	0.30
	kg in-patients^{-1} day^{-1}	6.03–13.56	9.01	2.67	1.17–2.56	1.83	0.54	7.21–16.13	10.85	3.21
	kg total patient^{-1} day^{-1}	1.04–5.86	3.93	1.25	0.21–1.19	0.80	0.25	1.24–6.97	4.73	1.50
Al-Arabi (Private)	kg day^{-1}	317–429	377.79	31.49	68–85	76.36	5.29	394–510	454.14	34.51
	kg bed^{-1} day^{-1}	3.17–4.29	3.78	0.31	0.68–0.85	0.76	0.05	3.94–5.10	4.54	0.35
	kg in-patients^{-1} day^{-1}	11.03–28.60	17.29	4.96	1.97–5.40	3.52	1.04	13–34	20.81	5.97
	kg total patient^{-1} day^{-1}	2.89–11.10	6.52	2.66	0.61–2.27	1.32	0.54	3.51–13.37	7.85	3.20

[a]Bed means both occupied or unoccupied.
[b]In-patient means a patient who stays in a hospital while receiving medical care or treatment.
[c]Total patients means the sum of in-patients and out-patients (those who attend to the hospital but do not stay in a hospital).

Table 3. Comparison of generation rate of HSW in different countries.

Country	Generation rate (kg bed^{-1} day^{-1})	References
Brazil	3.2–4.5	Silva et al. (2005)
China	0.5	Shen et al. (2003)
Greece	0.00124–1.9	Tsakona et al. (2007); Komilis et al. (2012)
Iran	2.75–4.58	Taghipour and Mosaferi (2009); Farzadkia et al. (2009); Bazrafshan and Mostafapoor (2011)
Jordan	0.83–4.3	Awad et al. (2004); Abdulla et al. (2008)
Kuwait	3.6–4.7	Hamoda et al. (2005)
Libya	1.3	Sawalem et al. (2009)
Nigeria	0.01–3.98	Idowu et al. (2013)
Norway	3.9	Bdour et al. (2007)
Palestine	1.86–5.90	Al-Khatib et al. (2009); Eleyan et al. (2013); Present study
Portugal	3.9	Diaz et al. (2008)
Saudi Arabia	1.1	Al-Zahrani et al. (2000)
Taiwan	2.6–4.14	Cheng et al. (2009)
Vietnam	1.42	Diaz et al. (2008)

Another study conducted in hospitals in Iran reported the amounts of HW and GW were 29.89% and 70.1%, respectively (Taghipour and Mosaferi, 2009). A generation rate of 0.85 kg occupied bed^{-1} day^{-1} in Central Macedonia in Greece was reported by Sanida et al. (2010). According to Pruss et al. (1999), the WHO has estimated that 75%–90% of the HSW generated from hospitals in developed countries is GW, and that the remaining 10%–25% is hazardous. The WHO estimations for infectious HSW generation rate in the Middle East Region is between 0.75 and 0.33 kg bed^{-1} day^{-1}. So far, the present article as well as a Lebanese study has proved that the infectious waste generation is a bit higher; 0.76 kg bed^{-1} day^{-1} and 0.77 kg bed^{-1} day^{-1} (Maamari et al., 2015), respectively.

HSW generation depends on numerous factors.

- Level of activity (number of beds; number of outpatients per day, total number of patients per day, and/or number of staff).
- Type of department (e.g. general ward, surgical theatre, office).
- Type or level of facility (e.g. clinic, provincial hospital) or type of clinics per facility.
- Location (rural or urban).
- Regulations or policies on waste classification.
- Segregation practices.
- Temporal variations (week day versus weekend, seasonal).
- Level of development of country.

The present research results were compared with the generation rates determined in other studies from different countries, as shown in Table 3.

It is clear that the total generation rates in other developing countries (e.g. Brazil, Jordan, Taiwan, Nigeria) and some developed ones (e.g. Norway) are of the same level as in the current research, since healthcare treatment processes do not present great differences. The comparison with other research outcomes was crucial in order to verify the current research results and proceed with the raw data processing and the development of the model. To achieve that, credible data were searched and compared. This resulted in future potential application of the proposed methodology in other countries' hospitals, given that the necessary adjustments are made by the researchers.

The waste generated at the medical establishments consisted of infectious and general medical wastes. Table 2 shows that the annual average amount of infectious waste generated yearly was the highest at large public medical centres, accounting for 39.64% (137.07 kg day^{-1}) of all medical wastes. Given the great number of beds in those centres, the index kg bed^{-1} day^{-1} is the lowest of all four investigated (0.67 kg bed^{-1} day^{-1}), followed by local medium-sized public hospitals (0.85 kg bed^{-1} day^{-1}), small medical centres (charitable clinic; 0.77 kg bed^{-1} day^{-1}) and private hospitals (0.76 kg bed^{-1} day^{-1}). In fact, only16.8% of all wastes generated from the charitable clinic were infectious.

The generation rate indicates the types of services offered at Al-Arabi and Rafidia hospitals and suggest a difference; the higher total HSW generation rates at the Al-Arabi hospital are probably owing to the fact that it is a private hospital and, thus, serving a larger number of high class patients in comparison with other hospitals. The hospitals that have capacity to provide infectious disease care are those who generate the more HW.

Emphasis is given to the clinics of each hospital, which certainly constitute a significant parameter; according to bibliography the following are recorded.

- Surgery: 1.023 kg bed^{-1} day^{-1} (Cheng et al., 2009).
- Emergency: 0.411 kg bed^{-1} day^{-1} (Cheng et al., 2009).
- Intensive care unit: 0.467 kg bed^{-1} day^{-1} (Cheng et al., 2009).
- Dialysis: 0.739 kg bed^{-1} day^{-1} (Cheng et al., 2009).
- Maternity: 2.6 kg bed^{-1} day^{-1} (Komilis et al., 2012).
- Paediatrics: 0.27 kg bed^{-1} day^{-1} (Komilis et al., 2012).

The dialysis clinic disposes the largest amount of infectious waste compared with those of the emergency clinic. This is probably the reason why the medium-sized public hospital (Al-Watani) generates a high amount of HW even though the number of treated patients is low compare with those of the other medical establishments. The large hospital (Rafidia) may not have a dialysis clinic, but the existence of a surgery clinic, which generates almost 38% more HW, increases the amount of total generated HW. In that case, the existence of surgery in charitable and private hospitals constitutes a parameter seriously affecting the overall HW generation. The maternity clinic also contributes largely to the HW generation; its existence in the charitable medical establishment of Al-Ittehad increases the overall HW generation that researchers expected to find in this type of medical establishment. Clinics such as paediatrics are low in the rank, and their existence does not contribute largely to the overall HW generation. The medium-sized clinics, in terms of HW generation, are those of the emergency and intensive care unit; they exist in almost all medical establishments and they significantly contribute in the HW generation.

Last but not least, the different proportions of HW and GW can be explained also by the application of HSW management systems (e.g. segregation programmes utilising containers or colour-coded plastic bags) and adds the GW to the stream of municipal waste. With the lack of a suitable segregation programme in the hospitals, all generated HW (100%) can be considered as being infectious as well. This warrants a significant cost for the disposal and treatment of hospital HW in each country around the world (Taghipour and Mosaferi, 2009).

Multiple-variable regression HSW prediction models

Generalised multiple-variable regression models have been derived to predict each of three experimentally measured HSW components in kg day^{-1}; general solid hospital waste generation (W_G), hazardous solid hospital waste (W_H), and total solid hospital waste (W_T) as a function of three parameters. The first parameter is the number of inpatients (T_{in}). The two other parameters are the number of total patients (T_p) and number of beds (T_{bed}). The prediction models are exponential in form as indicated by:

$$LnW_G = 6.606 - \frac{162290181.527}{(T_{in})^8} - \frac{137.174}{(T_p)^{1.9}} + 0.0000117556\left[(T_{bed})^{1.9}\right] + \frac{10935.454}{(T_{in})^4} - \frac{45.797}{(T_{bed})^{0.9}} \quad (1)$$

$$LnW_H = 5.272 - \frac{70207020.690}{(T_{in})^8} - \frac{130.07}{(T_p)^{1.9}} + 0.00001076\left[(T_{bed})^{1.9}\right] - \frac{25.771}{(bed)^{0.7}} + \frac{37.307}{(T_{in})^{1.9}} \quad (2)$$

$$LnW_T = 7.036 - \frac{70563103.998}{(T_{in})^8} - \frac{126.619}{(T_p)^{1.9}} + 0.000011\left[(T_{bed})^{1.9}\right] - \frac{25.496}{(bed)^{0.7}} + \frac{35.353}{(T_{in})^{1.9}} \quad (3)$$

where Ln is the natural logarithm function. Based on these equations, a multiple-variable predictive model is derived for W_G, W_H, and W_T, resulting in three different regression models. Therefore, the raw data collected were pooled together for the purpose of developing individual multiple-variable regression models for each HSW component. Although, the relationships between the dependent variable and independent variables in equations (1)–(3) are non-linear ones, linear regression techniques have been used to estimate the regression coefficients associated with the three multiple-variable regression models after performing the necessary linear transformation, which are mainly dependent on the minimisation of the sum of squared errors. Following that, optimisation of five main regression indicators was attempted in order to reach the highest possible estimated regression equation. The estimated values of the five deployed indicators are provided in Table 4.

The empirical prediction models for W_G, W_H, and W_T are significant at a confidence level of 99.99%, as the model F-indicator is equal to the value of 186.081 for W_G, 602.838 for W_H, and 242.238 for W_T. The corresponding variable coefficient t-indicator values are generally high, ranging from −11.712 to 64.740 for W_G, from −20.046 to 62.661 for W_H, and from −12.611 to 53.174 for W_T, which mostly results in a confidence level of 99.99%. The predictive models have a determination coefficient (R-square) of 0.949 for W_G, 0.984 for W_H, and 0.960 for W_T. The fourth indicator used is the standard error of estimate, which is generally small compared with the predicted W_G, W_H, and W_T values, with its value of 0.11260 for W_G, 0.06282 for W_H, and 0.09880 for W_T. The fifth indicator used is the variance inflation factor (VIF), which measures the impact of collinearity among the independent variables in a regression model on the precision of estimation. It expresses the degree to which collinearity, among the predictors, degrades the precision of an estimate. Typically, a VIF value of greater than 10 is of concern. In the W_G model (equation (1)), none of the VIF values exceeded the critical VIF value of 10. Considering the W_H and W_T models (equations (2) and (3)), all VIF values were less than 10, which is acceptable.

In addition to the above five main indicators, a normal probability plot (Figure 1) and the histogram of standardised residuals for the one dependent variable (lnW_G) have been obtained as an example for one multiple-regression model, as shown in Figure2. The normal probability plots and standardised residual histograms show that there were no substantial deviations from the assumptions of normality for the error terms associated with the derived predictive models. Figure 3 provides scatter plots of the standardised residuals for the dependent variable (lnW_G) indicating that the standardised residuals are highly independent. Therefore, the performed residual analysis provided a good validation of the developed multi-variable regression models to be used in predicting W_G, W_H, and W_T. Hence, it can be concluded that the regression models developed for W_G, W_H, and W_T fit the data very well.

Finally, the generated regression models were validated using a holdout sample of about 40% of the total sample size to verify the model's predictive strength. The corresponding

Table 4. Summary of multiple regression predictive models indicators.

Predictive model	Model R-square	Model standard error	Model F-indicator	Model coefficients	Coefficient t-indicator	Confidence level	Coefficient VIF
Equation (1)	0.949	0.11260	186.081	6.606	64.740	99.9%	–
				−162,290,181.527	−2.456	98.2%	7.374
				−137.174	−2.542	98.6%	1.999
				0.0000117556	3.343	99.8%	4.061
				10,935.454	2.541	98.6%	8.642
				−45.797	−11.712	99.9%	4.059
Equation (2)	0.984	0.06282	602.838	5.272	62.661	99.9%	–
				−70,207,020.690	−3.446	99.8%	2.252
				−130.047	−4.396	99.9%	1.930
				0.00001076	4.340	99.9%	6.491
				−25.771	−20.046	99.9%	5.032
				37.307	4.519	99.9%	4.263
Equation (3)	0.960	0.09880	242.238	7.036	53.174	99.9%	–
				−70,563,103.998	−2.202	96.8%	2.252
				−126.619	−2.722	99.1%	1.930
				0.000011	2.827	99.3%	6.491
				−25.496	−12.611	99.9%	5.032
				35.353	2.723	99.1%	4.263

VIF: variance inflation factor.

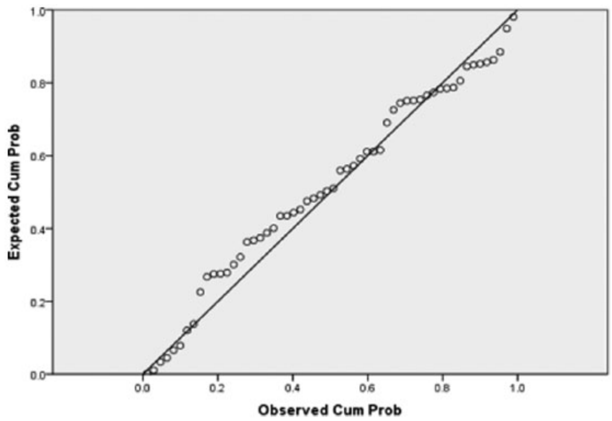

Figure 1. Normal p–p plot of expected versus observed cumulative probabilities of residuals of *Ln* (W_G).

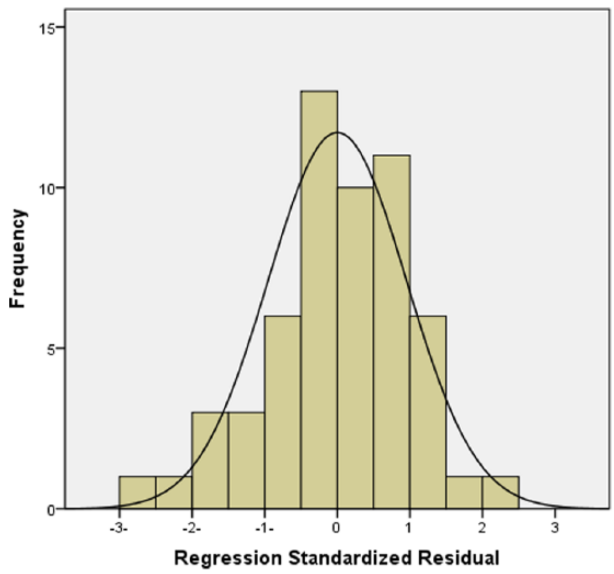

Figure 2. Histogram of standardised residuals for the dependent variable *ln* (W_G).

mean of the squared prediction errors (MSPR) was calculated for W_G, W_H, and W_T with the results provided in Table 5. It is clear from Table 5 that the MSPR values associated with both sets of models are close to their corresponding mean squared errors (MSE). This means that the MSE indicator was not seriously biased and it provided an appropriate indication of the predictive ability of the derived multiple-variable regression models.

All the obtained indicators have indicated that the derived predictive regression models for W_G, *WH*, and W_T fit the data very well and that they have a very high predictive ability. Therefore, the derived general models presented in equation (1) for W_G, equation (2) for W_H, and equation (3) for W_T are reliable and effective models to be used in estimating W_G, W_H, and W_T generated from hospitals.

HSW prediction

In the *HSW* relationship (equations (1)–(3)) for given (T_{in}), (T_p), and (T_{bed}), the *HSW* can be predicted with high accuracy by plugging the known values of (T_{in}), (T_p), and (T_{bed}) into equations (1)–(3) for a given hospital. The overall error in the prediction of the *HSW* (Error (%)) can be estimated as:

$$Error(\%) = \left[\frac{HSW_m - HSW_p}{HSW_m}\right] * 100 \quad (4)$$

Numerical example. Following is a numerical example for Al-Arabi hospital. In Table 6, in a row, the measured general, hazardous, and total wastes $(W_G)_m$, $(W_H)_m$, $(W_T)_m$, the predicted general, hazardous, and total wastes $(W_G)_p$, $(W_H)_p$, $(W_T)_p$, respectively by using equations (1)–(3), in addition to the overall errors (equation (4)) in the measured general, hazardous, and total wastes $(W_G)_{Error}$, $(W_H)_{Error}$, and $(W_T)_{Error}$ (%) are presented. From Table 6 it has been found that the mean errors for W_G, W_H, and W_T are 6.26%, 4.64%, and 5.77%, respectively.

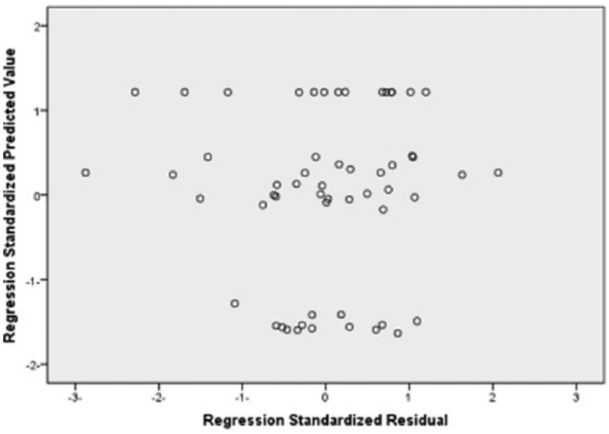

Figure 3. Scatter plot of standardised residuals for the dependent variable ($ln\ W_G$).

Table 5. MSE and MSPR associated with the multiple-variable regression models.

Dependent variable	MSE	MSPR
$Ln\ W_G$	0.013	0.011
$Ln\ W_H$	0.004	0.003
$Ln\ W_T$	0.010	0.012

MSE: mean squared errors; MSPR: mean of the squared prediction errors.

Conclusions and recommendations

Based on the preliminary results obtained in this study, the average generation rates of hospital GW, HW, and total HSW in Nablus city are 3.752, 0.765, and 4.517 kg bed^{-1} day^{-1}, respectively (82.97% GW and 17.03% HW). The generation source (public or private hospital) also constituted a research parameter; the research outcomes proved that no great differences in the HSW generation rate index was recorded owing to the source parameter.

The indepth analysis concerning the daily generation of HSW was pooled together for the purpose of generating a multiple-variable regression model for each mean of the three components of HSW. The result is three distinct multiple-variable predictive models, which are functions of three dependent parameters; the number of inpatients (T_{in}), number of total patients (T_p), and number of beds (T_{bed}). The five main indicators indicated the high reliability and significance of the derived multi-variable predictive models. The model validation included the normal probability plots, residual plots, and MSPR and proved the appropriateness of the derived models in predicting a daily generation rate in the case of HSW; W_G, W_H, and W_T.

The methodology applied in this case can be adapted in any other national hospital unit in Palestine. Indicator and/or parameters adjustments may be required to adapt this methodology internationally prior to the organisation of HSW management plans in developing countries, such as Palestine. Developed countries may also follow the methodology proposed in the present article but the adjustments required will be extended.

The results of the present research will be used for the develpment of a handbook addressing the corresponding hospitals' heads regarding the in-situ management of the generated HSW. This handbook will act as leverage in the discussions among hospital authorities and governmental authorities (health ministry, environment ministry, etc.) on the implementation of a national plan for safe HSW management.

For future studies, it is recommended to repeat this analysis throughout the year so that there can be allowance for seasonal

Table 6. Numerical example for HSW prediction for Al-Arabi hospital.

$(W_G)_m$ (kg day^{-1})	$(W_H)_m$ (kg day^{-1})	$(W_T)_m$ (kg day^{-1})	$(W_G)_p$ (kg day^{-1})	$(W_H)_p$ (kg day^{-1})	$(W_T)_p$ (kg day^{-1})	Absolute $(W_G)_{Error}$ (%)	Absolute $(W_H)_{Error}$ (%)	Absolute $(W_T)_{Error}$ (%)
376.00	71.00	447.00	374.87	76.69	452.00	0.30	7.71	1.11
382.00	78.00	460.00	353.57	73.30	432.17	7.73	6.21	6.24
429.00	81.00	510.00	394.28	79.91	468.28	8.44	1.36	8.53
386.00	69.00	455.00	373.95	75.34	444.60	3.17	8.79	2.31
333.00	68.00	401.00	362.48	73.79	433.32	8.48	8.17	7.75
382.00	78.00	460.00	384.72	77.94	459.40	0.71	0.07	0.13
408.00	77.00	485.00	385.82	79.63	468.43	5.59	3.36	3.48
426.00	82.00	508.00	377.89	76.35	450.33	11.98	7.14	12.05
357.00	76.00	433.00	382.86	79.19	465.50	6.99	4.12	7.24
317.00	77.00	394.00	375.50	77.71	457.33	16.94	0.92	14.90
355.00	69.00	424.00	379.70	77.13	454.70	6.73	11.14	6.99
391.00	85.00	476.00	406.75	83.46	489.41	3.95	1.82	2.78
379.00	81.00	460.00	404.82	83.51	490.38	6.59	3.05	6.40
368.00	77.00	445.00	367.70	76.18	448.55	0.08	1.07	0.80

variation in the predictive data to be provided, as the seasonal variation in waste output is well known to be linked to seasonal disorders and thus overall patient diagnosis, as well as disease type that includes, for example, the increased vomit and diarrhoeal output, together with soiled limit, incontinence pads, and other contaminated paper waste associated with seasonal Norovirus infection in temperate regions. In addition, for future studies, a specific equation for public, charitable, and private hospitals may be more meaningful in waste management.

Importantly, others may have different successes if using this approach to modelling HSW components.

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