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Environmental audits and process flow mapping to assess management of solid waste and wastewater from a healthcare facility: an Italian case study

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Abstract

In Europe, there are an increasing number of policy and legislative drivers for a more sustainable approach to the management of natural resources as well as for the mitigation of environmental health risks. However, despite significant progress in recent years, there is still some way to go to achieve circularity of process, as well as risk mitigation within organisations. Using a case study of the Gardone Val Trompia hospital in northern Italy, this manuscript offers a novel holistic examination of strategies to enhance resource efficiency and environmental health within a key sector, i.e. the healthcare sector. Through the use of environmental audits and process flow mapping, trends in waste and waste water arisings, and the associated financial and environmental costs, and risks were identified. Recommendations for developing more resource efficient approaches, as well as mitigating the environmental and public health risks are suggested. These include strategies for

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improved resource efficiency (including reduction in the hazardous waste), and reduced environmental impacts during the containment, transport and treatment of the waste.

Key words:

Healthcare waste; holistic monitoring; medical waste; resource efficiency; water saving

1. Introduction

Globally, there is an increasing need for governance strategies that enable a more sustainable management of resources (World Bank, 2016; UNEP, 2014). Organisations play a key role in the development of such governance strategies (Tudor, 2009; Jones *et al.*, 2012; Wallace and Raingold, 2012). Specifically within the healthcare sector there is a growing realisation of the need for the development and effective implementation of such approaches, in order to not only ensure environmental compliance but also costs savings (Appleby, 2013; SDU, 2014; Unger and Landis, 2016; Mutters *et al.*, 2016).

Sustainability within the healthcare sector exists on two levels (HPOE, 2014): operational sustainability and environmental sustainability. Operational sustainability focuses on redesigning facility operations to consume the fewest resources and services. Environmental sustainability aims to reduce the volume of materials discarded as waste, leading to economic benefits. A key aspect in attaining a more sustainable approach within the sector relates to the evaluation of the consumption of resources and the management of the resulting waste. While there have been a number of previous studies evaluating factors such as waste generation rates, these have generally tended to focus solely on solid waste and on the environmental sustainability (e.g. Moreira and Gunter, 2013; Maamari *et al.*, 2015; Caniato *et al.*, 2015; Ren *et al.*, 2016; He *et al.*, 2016), with limited research on operational sustainability and the combined evaluation of solid and liquid wastes.

Using the Gardone Val Trompia (GVT) Hospital, in Brescia, Italy, as a case study, this project examined approaches for the more sustainable management of waste and water at a healthcare facility (HCF).

2. Managing water and waste from healthcare activities

2.1 Water

2.1.1 Healthcare water consumption

HCFs are significant users of water and produce equally large quantities of waste water which requires treatment (Wyasu and Okerele, 2012; Carraro *et al.*, 2016; Patwary *et al.*, 2011). Water consumption depends heavily on factors such as the kind of healthcare services provided, number of beds, facility type, geographical location, climatic conditions and local water-use practices (WHO, 2011).

Hospitals that have conducted successful water use reduction programs have been able to reduce usage by approximately 20 to 30%, with a return on investment (ROI) in the range of approximately 25 - 40% (HERC, 2016). For large HCFs, this can translate to over €100,000 per year savings in water, sewer and energy costs.

2.1.2 Healthcare wastewater treatment

A proportion of the wastewater produced will pose a higher risk than domestic wastewater, as depending on the services provided, the wastewater may contain chemicals, pharmaceuticals and contagious biological agents, and might even contain radioisotopes (WHO, 2013). In high-income countries, wastewater generation in secondary- and tertiary-level hospitals is mainly measured on an inpatient ratio (litre of generated wastewater per patient treatment day), with the following typical generation rates (WHO, 2013):

- Small-medium sized hospitals: 300-500 l per inpatient per day
- Large hospitals: 400-700 l per inpatient per day
- University hospitals: 500-900 l per inpatient per day.

In primary healthcare clinics, the rate of wastewater generation is often measured as the sum of the number of inpatients and outpatients. Minimum water quantities required in the healthcare setting are:

- 40-60 l per inpatient per day
- 5 l per outpatient
- 100 l per surgical procedure

The monitoring of the wastewater system includes two key aspects: monitoring the sewerage system and the effluent quality (WHO, 2013).

2.2 Healthcare solid waste management

2.2.1 Waste generation rates

On average between 75% and 90% of the waste produced by HCFs is comparable to domestic waste and usually called “non-hazardous” or “general health-care waste” (WHO, 2013). The remaining 10–25% is regarded as “hazardous” and may pose a variety of environmental and health risks.

Healthcare waste generation is based on two key factors (Tudor, 2007; Eker and Bilgili, 2011):

- Level of activity (often measured in terms of the number of occupied beds, number of patients per day, and/or number of staff)
- Type of department (e.g. general ward, surgical theatre, office).

Various studies have reported different quantities of per capita waste arisings. For example, Serafimidou *et al.* (1992) reported a value of 4.50 kg/occupied bed/day; Tsakona *et al.* (2007) recorded values of 0.5-7 kg/occupied bed/day; Caniato *et al.* (2016) indicated 1.3 kg/occupied

bed/day. Eker and Bilgili (2011) reported the value 0.23 ± 0.62 kg/outpatient/day. The Italian Institute for Environmental Protection and Research (ISPRA, 2008), stated an average value from 1.17 to 1.28 kg/occupied bed/day.

2.2.2 Waste management

The principal Italian law regarding the management of healthcare waste is the D.P.R. 254/2003 (Decreto del Presidente della Repubblica, 2003). Under the Waste Directive 2008/98/EC (EC, 2008), hazardous waste is defined on the basis of the European Waste Catalogue (EWC).

3. The case study hospital: The Gardone Val Trompia Hospital

As shown in Fig. 1, the GVT Hospital is located in the North of the Brescia Province, some 18 km from the provincial capital, Brescia, in the valley called Val Trompia. It is considered to be a 'basic unit hospital' as the catchment area of the hospital is about 110,000 inhabitants. It covers a surface of 7,502 m². It was designed to contain 260 beds, but at the time of the study had only about 130 beds.

FIG 1 HERE

At the time of the study, the GVT Hospital was comprised of a range of departments delivering various services. Between 2011-2013, the number of patients fell from 6,003, to 4,251, while staff decreased from 455 to 420. In 2013, the number of beds was 131, while some 125,321 procedures were performed.

Services and the non-patient departments were active from Monday to Friday. The dialysis service was active also on Saturday mornings. Some 2% of the patients were hospitalised in the day hospital, while some 82% of the patients spent from 1 - 15 days in the hospital.

4. Methods

Data were collected during the period January - May 2014. The procedure consisted of two phases, namely assessment of: (1) water consumption and the efficiency of the wastewater treatment plant and (2) the solid waste generation rates from selected departments.

4.1 Water consumption

First the supply of freshwater to the hospital and then within the distribution system inside the facility was examined, in order to evaluate the flow of water from withdrawal from the municipal aqueduct, to the discharge into the surface water body. Some of the input and output of the balance were excluded from the analysis because they were considered negligible, for example, bottled water consumed by patients and hospital staff, which was considered to be captured in the waste water.

Data about the yearly total consumption of water were analysed and then compared to the number of patients, beds and days of hospitalization to estimate per capita arisings. All of the possible uses of water were evaluated and, with the help of the technicians, the uses with the highest consumption of water were identified. As a result, four departments were selected for more detailed analyses:

- Canteen
- Dialysis
- Orthopaedics and traumatology ward
- Sterilization

Using literature data about water consumption of devices (Table 1), the daily consumption (dc) and yearly consumption (yc) for each department selected was estimated. The aim was to identify where it would have been most effective to intervene to reduce the consumption of water.

TABLE 1 HERE

The water consumption rates were estimated according to the following equations:

$$uc_i = swu_i * ur_i \quad (3.1)$$

$$tc_i = uc_i * \text{number of devices} \quad (3.2)$$

$$dc = \sum tc_i \quad (3.3)$$

$$yc = dc * 365 \text{ days} \quad (3.4)$$

Note: uc_i = unitary consumption; swu_i = specific water use; ur_i = use rate; tc_i = total consumption for each type of device; dc = total daily consumption; yc = annual consumption. The annual consumption of dialysis department, which was closed on Saturday afternoon and Sunday, was estimated by multiplying total daily consumption by 287 days.

The consumption of the air conditioning system was not taken into account due to lack of data.

4.2 Waste water treatment

Data about the composition and the dimension of the plant were acquired from the site, and then, every step of the treatment was examined. Using flow-meters, daily and monthly waste water discharge rates were also determined. Starting from data about the flow-rates and monthly input and output pollutant concentration, the removal efficiency of different standard parameters (e.g. BOD₅, COD, total suspended solids, etc.), were calculated to assess the efficiency of the plant, according to the relevant Italian law (Decreto Legislativo, 2006).

The trends of the input and output yearly pollutant masses and the yearly removal efficiency of the plant were determined according to the following equations:

$$M_{in} = \sum_i (C_{in\ i} * Q_i) \quad (3.1)$$

$$M_{out} = \sum_i (C_{out\ i} * Q_i) \quad (3.2)$$

$$\eta = \frac{M_{removed}}{M_{in}} = \frac{M_{in} - M_{out}}{M_{in}} \quad (3.3)$$

Notes:

- M_{in} : yearly mass input
- M_{out} : yearly mass output
- $C_{in\ i}$: monthly concentration input
- $C_{out\ i}$: monthly concentration output
- Q_i : monthly flow rate
- η : yearly removal efficiency

4.3 Solid waste management

4.3.1 Assessment of waste arisings

The procedure to assess the unitary value of kg/person/month of waste produced by the hospital was subdivided into two main phases: First, to understand the flows of the waste inside the hospital, from their generation to their disposal before their offsite transport. Second, to evaluate the daily production of waste for a specific period of time to obtain an average value for each type of waste.

The weighing campaign took place during 08 - 21 May, 2014 (excluded the 11th May), between 8:30 - 10:30am. Some 1,564 bags and 610 waste bins were weighed. Weighing was done in the waste storage area of the hospital, using a digital balance (maximum 150 kg; accuracy 0.01 kg). The bags

were brought by an employee and all of them were weighed. Since the canteen disposed of its waste three times a day: morning, afternoon and evening, the same canteen staff was in charge at recording of the quantities of the afternoon for the first week. The types of waste surveyed were:

- Unsorted
- Organic
- Paper
- Cardboard and wood
- Plastic
- Glass and tin
- Potentially infectious

Data were recorded in a Word table during sorting, and later transferred to an Excel spread sheet. The data collected were analysed to assess the total weight and the weight for each department for each type of waste. Based on previous studies (e.g. Tudor, 2007; Eker and Bilgili, 2011), kg/person/month was the unit chosen as it gives more appropriate results than other evaluation methods. The relation between the daily variation of waste production and the daily variation of staff and patients or performance number of each department was analysed using the formula in 3.4.

$$uv_m = \frac{tw}{N_p} * 30 \text{ days} \quad (3.4)$$

Notes:

- uv_m : monthly unitary value [kg/person/month]
- tw : total waste produced [kg]
- N_p : number of staff or patients/performance [person]*

*For the potentially infectious waste the staff number was not considered because that type of waste was produced by the care of patients. To allow comparison with literature data the production per occupied bed per day was assessed using the formula 3.5. Another parameter evaluated was the production per outpatient per day (see formula 3.6).

$$uv_b = \frac{tw}{N_b} \quad (3.5)$$

Notes:

- uv_b : daily unitary value [kg/occupied bed/day]
- tw : total waste produced [kg]
- N_b : number of occupied bed [occupied bed]

$$uv_o = \frac{tw}{N_o} \quad (3.6)$$

Notes:

- uv_o : daily unitary value [kg/outpatient/day]
- tw : total waste produced [kg]
- N_o : number of outpatients [outpatients]

4.3.2 Analysis of the unsorted waste

The general composition of the unsorted waste and contamination levels were also determined. The bags analysed as a part of the total unsorted waste were subdivided according to their origin and then samples were selected at random. They were opened and emptied onto a ground cloth, having around some empty pre-labelled bags. The content was divided manually and placed into the appropriate pre-labelled bags, which were then weighed and recorded.

5. Results

5.1 Water consumption

The survey considered only freshwater, grey and black water, not rain water because it was discharged in the municipal sewage without treatment. Figure 2 shows a greater use of water in summer, generally from May - September. The highest value was 5,422 m³, while the lowest was 2,748 m³, and the specific value in 2013 was 886 l/bed day. On average, generation of waste water was 1m³/day, or 2,165m³/month. The overall quantity of water consumed between 2011 – 2013 decreased from 55,318 m³ to 42,367 m³.

FIG 2 HERE

To evaluate consumption levels a formula was used, where the value “number of user” is expressed:

$$\text{Total consumption} = \text{Unitary consumption} \times \text{number of users} \quad (4.1)$$

The two highest areas of water consumption were found to be the Orthopaedics and Traumatology ward and the canteen.

The Orthopaedics and Traumatology ward was composed of 17 rooms, 33 beds and every room had a bathroom with a WC, a hand basin and a bidet. There was one small kitchen with a dishwasher, one toilet for public use, two washing rooms with three taps (but only one was used), one bath and a bedpan washer. There were approximately 33 users of the patient rooms, four of the doctors' rooms and five of the washing rooms. The main areas of water consumption were the wash rooms and patient rooms.

The daily consumption was found to be 8.4 – 9.2m³, with a yearly consumption of 3,070 – 3,350m³.

The highest usage of water was caused by the bedpan washer and personal uses of the patients.

The canteen cooked about 500 meals per day for patients and hospital staff. The pieces of equipment having the highest water usage were the sinks, taps and dishwasher. The daily consumption was found to be $5.0 - 5.6\text{m}^3$, with a yearly consumption of $1,830 - 2,050\text{m}^3$. Electricity usage was 4.7kWh/day .

5.2 Waste water management

The treatment plant treated the wastewater before its discharge into the surface water body (the Mella river), that is 200 metres away from the hospital. As illustrated in figure 3, the plant occupied an area of 154.2 m^2 and was comprised of a primary screen, two lift pumps, an oxidation tank, a sedimentation tank, three recirculation pumps and a storage tank for the sludge. The monthly average flow rate was $3,230\text{ m}^3$ and the daily average flow rate was $106\text{ m}^3/\text{d}$.

FIG 3 HERE

Figure 4 illustrates that the monthly waste water flow rates were generally higher in the first half of the year. In January 2014, data were not available.

FIG 4 HERE

Table 2 shows the quality of the wastewater entering the treatment plant, as well as the output. All of the monitored inputs parameters increased from July.

The removal efficiencies of the treatment plant were high ($\text{BOD}_5 = 86\%$; $\text{COD} = 86\%$; $\text{NH}_4^+ = 96\%$; $\text{P} = 72\%$). The output concentrations were within the legal Italian limits, thus indicating that it was working effectively.

TABLE 2 HERE

5.3 Solid waste management

5.3.1 Non-hazardous waste

The average weight of the non-hazardous waste was 3.04 kg per bag or 366.18 kg per day. The unsorted fraction represented on average 62% of the total daily non-hazardous waste (Table 3). Paper, plastic and cardboard together represented 30-40% of the total non-hazardous waste.

TABLE 3 HERE

5.3.1.2 Waste production from selected departments

The entire hospital produced 10.58 kg/person/month of non-hazardous waste. The non-patient departments produced the highest quantity of non-hazardous waste per person per month, especially unsorted and paper waste. Services were the smallest producer of waste per person. 'Other' comprised the non-patient departments and it produced mainly unsorted and paper waste. The unsorted fraction was produced mainly by the wards and the services. 'Other', the operating theatres and wards produced the highest per capita quantity of waste (Table 4). Overall, waste arisings were 2.29 kg/occupied bed/day.

TABLE 4 HERE

5.3.2 Analysis of the unsorted waste

On 15th May 2014, the composition of the unsorted waste for each clinical department was analysed. The overall weight was 277.37 kg and the sample analysed was 78.45 kg (some 28% of the total). Paper was the main type of waste, followed by textiles and plastic. However, different departments had different compositions (Table 5). For Medicine, Surgery, Orthopaedics and the Sub-acute care unit the composition of unsorted waste was similar. Textile materials were the main type of waste,

then there were plastic and paper. The Cardiology ward had a different composition of unsorted waste. The main fraction was organic, then paper and plastic. The unsorted waste produced by the outpatient services contained especially paper, then plastic and metals. For the services of analysis laboratory and dialysis, the composition was different from the other outpatient services. The unsorted waste of the analysis laboratory contained paper and some fractions of plastic and cardboard. For the dialysis, the main fraction consisted of plastic bags containing residues for the therapy. The unsorted bags of the operating theatre contained mainly paper and composite paper/plastic.

TABLE 5 HERE

5.3.3 Overall waste production

The site produced 5.26 kg/person/month of potentially infectious waste, with an average weight of 2.91 kg/bin. Wards, operating theatres and the dialysis were the main producers of potentially infectious waste with 31%, 23% and 22% of the total respectively.

Considering together non-hazardous and potentially infectious waste, the amount was 6,537 kg and the unitary waste production was 11.52 kg/person/month. Figure 5 illustrates that the operating theatre was the main overall per capita producer of waste.

FIG. 5 HERE

In the wards, there was a ratio 3:1 of between non-hazardous and potentially infectious waste production per person per month. The services produced about the same quantity of both the wastes. The canteen and the other departments produced only non-hazardous waste with the former producing half of the waste produced by the latter.

6. Discussion

6.1 Water management

The water consumption for the hospital decreased in the three year period 2011-2013. The average water consumption for American hospitals is 315 gallons/bed day (1,192 litres/bed day) (USEPA, 2012), while in Italy the consumption is 500-1,000 litres/bed day (Paoletti, 2010). Thus, for the Gardone V.T. Hospital, the value found is in line with the national range, higher than the typical WHO (2011) small-medium sized facility, but lower than in the USA.

Water consumption was due to ‘domestic uses’ (e.g. WCs, sinks, hand basins, bidets) and ‘Non-domestic uses’ (e.g. food preparation, autoclaves, bedpan washer, osmotic treatment). The highest portion of water (85%) was consumed by non-domestic uses, while 15% was consumed for domestic uses. These values are roughly in line with international averages (WHO, 2011).

The greater consumption of water between May – September was probably because consumption also included the watering of green areas and, especially, the use of cooling water for the conditioning system. The Orthopaedics and Traumatology ward and the canteen were the highest consumers of water due to the bathrooms and bedpan washer, and food preparation, respectively.

The wastewater produced by the hospital was about 810 l/inpatient/day, which is higher than that for a small-medium sized hospital reported by WHO (2013). However, the output concentrations of the waste water treatment plant were below the legal limits imposed by the Italian law (Decreto Legislativo, 2006).

Evidently, the conservation of water should be focused around specific departments (e.g. wards and the canteen), and potentially be aimed towards the initial months of the year. The achievement of the targets of water saving depends on the development and application of two different, but complementary, factors:

- Technological practices: based on modification of plants or of supply procedures (e.g. checking for leaks, installation of flow restrictors, reclaiming or recycling water, use of dual flush or a three pipe system - cold, hot water and non-potable water reticulation)
- Behavioural practices: based on change of the staff habits of use.

It would be important to first conduct a detailed water audit to identify uses, usage patterns, and quantify potential water-saving opportunities. This should include the installation of data-logging water meters at the input and output of the utilities (wards and services) to know the total consumption of different areas of the network. This would enable identification of areas where there might be high consumption.

Given the link to the use of bathrooms and preparation of food, there should probably be the use of a combination of both technological measures (e.g. use of flow restrictors and dual flushing), as well as behaviour change measures (e.g. awareness raising for staff and patients, as well as training for staff in the canteen). Another strategy that could be employed to save money could be to use the fresh water instead of bottled water for the meals of the canteen. The cost of bottled water for the meals of the canteen is about €14,000. A micro-filtration treatment for 200 people costs €2,600. The volume of water used is about 100 m³. The cost of 1 m³ was €1.78, so the total cost would be €178.00 + €2,600 = €2,778, down from €14,000. The money saved would be about €11,200.

6.2 Waste management

The entire hospital produced 10.58 kg/person/month of non-hazardous waste and 5.26 kg/month of potentially infectious waste. The production during the working days was quite regular (400 kg/day for the non-hazardous waste and 160 kg/day for the potentially infectious waste). During the weekend the production decreased (190 kg/day for the non-hazardous waste and 70 kg/day for the potentially infectious waste). The fall in the quantity of waste at the weekend was because the outpatient services, the dialysis, the radiology and the analysis laboratory were not active.

There was a high fraction of unsorted waste (62%) that was primarily comprised of textiles (40%), paper (20%) and plastics (17%). Given the high fractions of paper and plastics, there is good potential for recovery of value, provide that these fractions could be segregated out. Putting in place separate waste collection in the common areas, such as near the food and drink distributors and into the waiting rooms, could reduce the quantity of paper and plastic and increase the recycling of these materials. For the analysis laboratory and the outpatient services, better segregation of the paper fraction could reduce the quantity of the unsorted waste and could improve the recycling, as well as for the operating theatre. For the Cardiology ward there is the potential to improve the segregation of organic fraction. At a wider level, there should be efforts made to work with medical staff to change clinical practices to use less materials including use of environmentally preferable purchasing and green procurement (WHO, 2013). For example, it was found that changing the supply of the needles to avoid the composite packaging could remove 3% of the unsorted waste.

Concerning the production of different departments, the non-patient departments produced the highest quantity of non-hazardous waste per person per month (32.50 kg/person/month), especially unsorted (60%) and paper (28%). The values found (2.29 kg/occupied bed/day and 0.57 kg/outpatient/day) were in line with those reported by others (e.g. Serafimidou *et al*, 1992 Tsakona *et al.*, 2006; Eker and Bilgili, 2011).

The daily production of potentially infectious waste per outpatient was 0.17 kg/outpatient/day. This rate is in line with Eker and Bilgili (2011). The value 0.80 kg/occupied bed/day was slightly lower than the value reported by ISPRA (2008), but between those reported by Serafimidou *et al.* (1992) and Tsakona *et al.* (2006) and lower than the Italian Institute for Environmental Protection and Research (ISPRA, 2008).

7. Conclusions

The activities within HCFs can lead to significant impacts on the environment. There is a need therefore for the development and implementation of systems that enable evaluation and enhanced practice within the sector. As the study examined waste in its totality (i.e. solid and liquid waste), it was better able to suggest key departments and processes for targeting to improve the sustainability of practice. The recommendations also take account of a more holistic approach encompassing technological and behavioural factors. It is only in this targeted, yet holistic manner, that more sustainable approaches can most effectively be developed and implemented.

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Authoring

Mentore Vaccari set up the research and with Terry Tudor carried out the literature survey, data analysis, results discussion and paper drafting. Waleed Montasser contributed to data analysis. Luigi Leone provided data and revised their analysis.

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