HEALTH CARE WASTE MANAGEMENT TOWARDS THE CIRCULAR ECONOMY A CASE STUDY AT TRIBHUVAN UNIVERSITY TEACHING HOSPITAL IN NEPAL

IETC Technology for Environment

IGES Institute for Global Environmental Strategies

CCET IGES Centre Collaborating with UNEP on Environmental Technologies

Health Care Without Harm

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This case study reports on the development of a healthcare waste management (HCWM) system at Tribhuvan University Teaching Hospital (TUTH) in Nepal where the intervention began in 2014 with support from HECAF 360, a local NGO, and Health Care Without Harm (HCWH), an international NGO, and WHO Nepal. It describes the approach and path followed by TUTH in the area of HCWM and the circular economy. It also describes factors that acted as barriers to or assisted in the changes by analysing the past data and information collected as well as interview with the key stakeholders.

By enhancing waste separation at source and needle cutters in the hospital, installing a biodigester to treat organic waste and autoclaves to treat infectious waste, levels of hygiene have risen and risk of exposure to infectious disease and injuries associated with waste handling have been reduced. In addition, the risk of emission of air pollutants and greenhouse gases caused by the use of incinerators without air pollution control has been minimized through non-burning treatment technology. The hospital offsets some of the costs of the system by selling recyclables from general waste and treated infectious waste.

Several recommendations for future activities and scale-up can be drawn from this case study, as follows:

- National and regional governments should: follow the National Health Care Waste Management Standards and Operating Procedures 2020; facilitate the implementation of HCWM to meet the standards of the Standard Operating Procedures set under the policy and strategy by allocating sufficient budget and personnel; perform monitoring and evaluation with data collection and analysis; disseminate relevant information; provide training and develop a curriculum to enable ongoing improvements in the skills and knowledge of individuals responsible for HCWM.

- Healthcare facilities (HCFs) must have a HCWM plan with sufficient budget and human resources for implementation. For tasks outsourced, contracts should include conditions ensuring appropriate handling and treatment of all waste generated at HCFs based on the HCWM plan. As well as expenses associated with waste management, hygiene conditions at HCFs and working environments for the staff should be carefully monitored for future improvements. Above all, determined leadership from top management is vital to implement of waste management plan.

1 INTRODUCTION

1.1 Healthcare Waste Management (HCWM) in Nepal

Healthcare, like almost all other human activities, generates waste. The majority derives from everyday activities such as hospital administration and the provision of food for staff and patients, but a significant fraction resulting from the provision of care is hazardous because it may be infectious, may contain hazardous chemicals, or could cause physical injury. If such waste is not treated properly it can harm patients, caregivers, the community and the environment. It has been estimated that improper HCWM places half of the world's population at risk (Harhay *et al.* 2009) and infringes human rights, including the right to a clean environment, the right to safe working conditions and the rights to life and health (Georgescu, 2011, Stringer *et al,* 2011).

Different countries have slightly different approaches to classifying and treating waste, but hazardous healthcare waste (HCW) is broadly categorised as infectious, sharp, chemical / pharmaceutical or radioactive waste (WHO, 2014). Direct threats to health care occur at the healthcare facility, through exposure to patients and hospital staff during medical treatments or waste handling, or offsite, to individuals in the waste treatment chain, and people who may come into contact with waste which has been illegally dumped. Pharmaceutical, chemical and radioactive waste can cause burns or toxicity, and infectious waste can act as a medium to transmit disease, particularly HIV and hepatitis (Mondal, 2013, WHO, 2014, Attaullah *et al*, 2011). Globally, needle-stick injures cause healthcare workers an estimated 66,000 cases of hepatitis B, 16,000 cases of hepatitis C, and 1,000 cases of HIV every year (Pruss-Ustin *et al,* 2005), with up to 22% of such injuries occurring during or after disposal (Cooke and Stephens, 2017). Healthcare workers in the Southeast Asian region suffer the highest rates of annual needle-stick injuries, with 58% of workers suffering an injury each year (Bouya *et al,* 2020). Most research pertains to healthcare workers (Mondal, 2013, Karki *et al*, 2020), but formal and informal waste workers can be among the most vulnerable as they handle waste daily and are often poorly educated, of low status and untrained, and subject to gaps in occupational health and safety. Documented examples include needle-stick injuries suffered by HCW handlers (Deresss *et al*, 2019), municipal workers (Mol *et al*, 2016, Thompson *et al,* 2010) and rag-pickers, including some who deliberately seek out discarded medical devices, which may be illicitly repackaged and resold (Cook *et al*, 2020).

Indirect threats range from contracting diseases from persons involved in HCWM to pollution resulting from HCW disposal. Open burning and low quality incineration of HCW are commonly practiced in Nepal (Pathak *et al,* 2021). These practices are major sources of dioxins and furans (Batterman, 2004) which are classified as human carcinogens. Due to their persistence in the environment these can contaminate foodstuffs. High levels have been found in chicken eggs, close to HCW incinerators (IPEN and Arnika, 2021).

To address environmental and safety issues related to HCWM, international agreements have been made. Among the legal instruments most directly pertaining to HCWM are the Minamata Convention on mercury and the UNECE Agreement concerning the International Carriage of Dangerous Goods by Road (UNECE, 2021). In an important step to eliminating hazardous HCW, the Nepali government has ceased the import, purchase and use of mercury based equipment in line with the guidance of the Minamata Convention (WHO, 2015). Nepal is also a party to the Basel Convention on the transboundary movement of hazardous wastes, and the Stockholm Convention on persistent organic pollutants (POPs) (UNEP, 2021-a, 2021-b). Incineration is used globally to treat HCW, even though HCWM priorities follow the same waste management hierarchy as other types of waste, and the preferred strategy is prevention, followed by reduction, reuse, recycling, incineration with energy recovery, and finally disposal as the option of last resort (see Figure 1). According to the Secretariats of the Basel (SBC, 2003) and Stockholm Conventions (SSC, 2008) which provided recommendations on HCWM and best available technologies and best environmental practices (BAT/BEP) for incineration, incinerators should be equipped with highly effective air pollution controls, or preferably be substituted with alternatives including steam based technologies (UNEP, 2007), which do not emit POPs, including dioxins and furans which are unintentionally produced by incineration (SSC, 2008). Incinerators which do meet the Stockholm Convention should be monitored for dioxins continuously as quarterly or annual sampling does not capture episodes of high releases during transient conditions in the incinerator (Idczak *et al,* 2011). The World Health Organization (WHO) also recommends that such low-tech incineration of HCW be phased out (WHO, 2004). Moreover, WHO regards waste as harmless after disinfection in vacuum autoclaves (WHO, 2019), and envisages recycling of used syringes after disinfection (Agnenu *et al,* 2014). Accordingly, the Nepali Ministry of Health, in its 2020 National Health Care Waste Management Standards and Operating Procedures, promotes recycling of waste for environmental reasons and further recommends that disinfection technologies avoid the use of internal shredders, which make recycling impossible. Similarly, in India, policy on disposal of immunization waste specifically allows recycling of autoclaved or chemically disinfected waste (India CPCB, 2021). All such measures should be considered in a comprehensive waste management strategy.

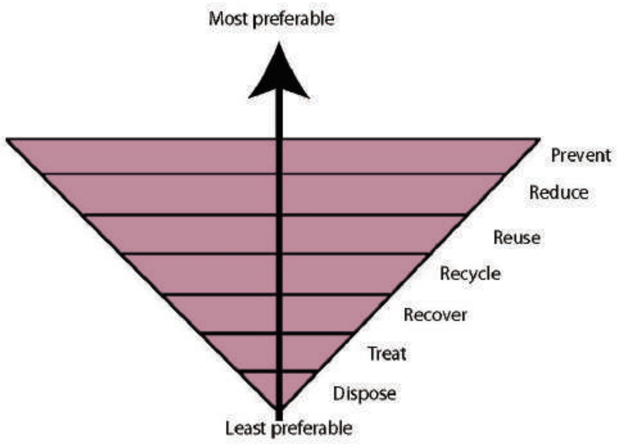


Figure 1: Waste management hierarchy (WHO, 2014)

WHO and UNICEF include waste management as one element of "WASH", or water, sanitation and hygiene, for healthcare facilities (WHO and UNICEF, 2019). Improving WASH in healthcare contributes to meeting Sustainable Development Goal 6, covering clean water and sanitation. According to the WHO and UNICEF Joint Monitoring Programme in 2019, only 1% of HCFs in Nepal meet the basic standards for HCW, which are segregation into at least three categories and safe treatment and disposal of infectious waste and sharps. Some research shows that 60% of facilities above 25 beds have an autoclave for waste disinfection but overall compliance with the waste guidelines was poor (Joshi *et al*, 2013). Most hospitals in Nepal still dispose of HCW by burying it in their back yards, open burning, or by incineration with little or no air pollution control. Non-incineration technologies were recommended in the Nepali national healthcare waste management guideline (Nepal MoHP, 2014) at the time the project commenced, and remains in the 2020 National Health Care Waste Management Standards and Operating Procedures.

The amount of waste produced by hospitals varies with the type and facility. The average (for hospitals over 25 beds) was 3 kg/patient/day, of which 1 kg (33%) was infectious (Joshi *et al*, 2013). In Province 1, the easternmost province of Nepal, the average waste generation rate was 2.3 kg/bed/day, of which 0.8 kg (28%) was infectious (Nepal, Ministry of Social Development, 2020). A similar ratio, 32% infectious and 68% non-infectious, was found in the south-eastern city of Nepalgunj, but this was calculated after the researchers separated the waste. Poor segregation at hospitals meant that in its collected state, waste was 73% infectious (Pathak *et al*, 2021). A similar situation is found in other countries in the region, in terms of amounts of waste generated, and that most of it is mixed and so must be treated as hazardous (Khan *et al,* 2019). Under such circumstances, separating HCW at source is considered a fundamental key to reducing risk as well as environmental pollution.

1.2 Objective

The objective of the case study is to demonstrate good practices in HCWM at Tribhuvan University Teaching Hospital, the biggest hospital in Nepal. This case study has been conducted through literature review, collection of existing data and interview with key stakeholders. No field survey was carried out for the purpose of monitoring of the past project in a quantitative manner. At the end, it draws recommendations based on an analysis of policy, technology, finance, and institutional setting. It is expected that the case study will help other practitioners to streamline HCWM nationally as well as internationally.

1.3 Project Partnership

IGES Centre Collaborating with UNEP on Environmental Technologies (CCET) in collaboration with IETC has developed this case study. Below are the project partners who contributed to the project implementation at Tribhuvan University Teaching Hospital.

Tribhuvan University Teaching Hospital (TUTH)

Tribhuvan University Teaching Hospital (TUTH) (Figure 2) is located in the northern part of the capital city of Nepal, Kathmandu and is the site and instigator requesting the project covered in this report. TUTH was established in 1982 and currently has 15 outpatient departments, 30 indoor units and 22 laboratory units, which conduct research and education as well as provide medical services. Japan International Cooperation Agency (JICA) supported in the construction of TUTH, nursing college and dormitory between 1980's and 90's, and improved medical equipment. It has 700 patient beds and treats 2,000 outpatients per day. The hospital set the broad parameters for the project, allocated the necessary human and financial resources, led the construction of the necessary infrastructure and procured the required equipment. Its senior management worked closely with WHO Nepal and HECAF 360 to create an appropriate plan and ensure that the steps needed to implement it were carried out as smoothly as possible.

WHO Nepal

At the request of the Executive Director of TUTH, WHO Nepal agreed to provide technical assistance in implementation of safe HCWM and assigned Dr. Sudan Panthi, National Program Officer and senior WASH expert as their representative. WHO's role was to provide professional technical input to the project and evaluate the progress of the waste management system through active participation in committee meetings and other activities.

HECAF 360

The Health, Environment and Climate Action Foundation (HECAF 360), a Nepali NGO, was built on Health Care Foundation Nepal (HECAF) which was founded in 1994 with a mission to create a non-profit

Figure 2: Tribhuvan University Teaching Hospital
(Source: https://www.flickr.com/photos/usaid_images/17910340946)

hospital – the National Kidney Centre – to address the gap in care provided by national hospitals. When the hospital began providing dialysis, it began also to generate infectious waste. Seeking a solution to treating and disposing of such waste safely, the hospital became the first to deploy this technology for HCW disinfection in Nepal. The project's success created recognition of the method, and led to the HECAF team helping other hospitals. This team works directly with hospitals or in partnership with Health Care Without Harm (HCWH), WHO, The Global Fund, GiZ and other agencies.

In 2020, the HECAF 360 team set up as a separate entity from the Health Care Foundation Nepal (HECAF) under a new name, Health Environment and Climate Action Foundation (HECAF 360)[1]. Since becoming involved in HCWM the team has conducted 108 detailed diagnostic assessments on healthcare operations at HCFs and transformed the waste management systems of 10 large HCFs and 40 small HCFs. This case study focuses on one of these, Tribhuvan University Teaching Hospital.

Health Care Without Harm (HCWH)

Health Care Without Harm (HCWH)[2] is an international NGO which has focused on transforming the global healthcare sector via promotion of environmental health and justice since its founding in 1996 (HCWH, 2021). HCWH has offices in the USA, Europe and the Philippines and strategic partners in India, Brazil, South Africa, Australia, China and Nepal.

HCWH created the Global Green and Healthy Hospitals (GGHH), an international network of hospitals, HCFs, health systems and health organizations dedicated to reducing their respective environmental footprints and promoting public and environmental health. The framework and roadmap to achieving this goal are provided by the GGHH Agenda and its 10 interconnected sustainability goals for hospitals and health systems to work towards at their facilities. The GGHH community has over 1,500 members in 75 countries who represent the interests of more than 43,000 hospitals and health centres, with the aim of involving the health sector in the climate movement and expanding their healing mission beyond their facilities. Of GGHH's ten sustainability goals, improving HCW is a goal espoused by the most GGHH members. In 2011, HECAF 360 became a strategic partner of HCWH and member of GGHH. HCWH has collaborated with HECAF 360 on HCWM and in co-developing strategies, tools and methodologies for over ten years (Stringer, 2010, 2015, 2020).

2 INTERVENTION

The initiative was instigated by Professor Dr. Deepak Mahara, then director of TUTH. A primary motivation was to cut the pollution and risk to public health that resulted from waste disposal practices of the time. Commenting on this, Prof. Mahara said "*Safe Health Care Waste Management is the most important part along with the diagnostic care of patients which contributes to improve the health of the hospital.*"

Prof. Mahara's initiative was supported and joined by his deputy directors Prof. Dr. Prem Khadga (former executive director), Prof. Dr. Dinesh Kafle (present executive director) and the nursing directors: at the time of the project initiation, Mrs. Dharma Lakshmi Shrestha, who was followed in the post by Mrs. Kopila Palikhe, then Mrs. Kabita Devkota, who is the present Nursing Director.

Due to the absence of a proper waste management system on the wards, patients and hospital staff were exposed to risk of infection and needle-stick injury. Infectious wastes were collected in open sites within the hospital compound (Figure 3), where it degraded and polluted the hospital environment. Informal recycling was conducted on-site, and rag pickers visited daily in search of waste to sell. Among the materials collected for recycling were water bottles, plastic gallon containers, saline bottles, paper and cardboard. Such gallon containers may be sold for reuse, rather than recycled. This increased the possibility for infectious disease to spread.

1 www.hecaf360.org (visited in July 2021)
2 www.noharm.org (visited in July 2021)

Figure 3: Informally collected recyclables during the assessment in 2014 (Source: HECAF 360)

The hospital's only method of treating infectious waste was incineration (Figure 4). The incinerator was a diesel-fuelled single chamber unit without air pollution control, located in close proximity to the paediatric department, birthing centre and respiratory ward. Smoke from the incinerator (Figure 5) contains carcinogens such as dioxin and furans and other pollutants which may cause respiratory illness, cancer and other diseases. The smoke also caused a nuisance when it entered the windows of nearby wards.

2.1 Timeline

The project started with the assessment in November 2014 and the contract to implement an improved HCWM system was awarded in March 2017. Next, the necessary infrastructure was built and once it was complete and ready to receive waste, training and rollout of segregation and waste handling systems to the wards commenced in January 2018. Once the new practices were established on these first wards- dubbed model wards- they were replicated step by step through the hospital.

At the time of writing, the ongoing rollout of the project, including establishment of a training centre for HCWM to enhance its mission to further medical education and protect public health, has been paused due to the COVID-19 pandemic.

The hospital has focused all its resources on protecting public health, and lockdowns have prevented the support team from visiting for updates and further training. HECAF 360 were themselves involved in the emergency response, including managing waste from the evacuation of Nepali students from Wuhan in February 2020, arranging donations of equipment to fight the pandemic[3] and providing waste management support to hospitals dealing with COVID-19 treatment and vaccination.

The timeline of the project up to the start of the pandemic is given below. Table 1 lists the wards in which the new system had been implemented at that time, and which still await roll-out.

Project timeline:

- November 2014: Assessment (report completed December 2014)
- March 2017: Contract signed
- 2017: Building started/completed
- 2017: Autoclave installation
- 2017: Biodigester constructed
- January 2018: waste systems set up in first wards ("model wards")
- 2019: continued implementation- new practices replicated to 23 wards
- 2020: Replication paused due to COVID-19

Figure 4: The incinerator formerly used (Source: HECAF 360)

Figure 5: Smoke emitted by the incinerator (Source: HECAF 360)

3 https://www.hecaf.info/covid-199

Table 1: Wards with waste management system implemented and awaiting implementation at the start of the COVID-19 pandemic

Wards with waste management system implemented	Wards awaiting implementation
Annex I	Maternity
Annex II	Neonate
Annex III	Labour room
Burn	CSSD
Eye	Observation
Female surgical ward	Emergency
Haemodialysis	D. Addiction
HDU	Pediatric I
ICU	Pediatric II
Liver Transplant Unit	Pediatric Emergency
Male surgical ward	PICU
MICU	NICU
Nephrology	Birthing
Neuro	ENT
Neuro surgery	ENT OT
Ortho A	Blood Bank
Ortho B	Lab
Ortho Cabin	Administration
Ortho OT	Emergency Lab
Ortho Recovery	Outpatient departments
Post Op	
Psychiatric	

2.2 First Step: Initial Assessment

The initial assessment was conducted from 7–16 November 2014 with the aims of understanding the existing waste handling practices, assessing the occupational health and safety status of the staff, and quantifying the waste generated (Figure 6).

The data collection methods were as follows:

- Waste quantification: Waste from every unit was recorded for seven working days in a standard format designed by HECAF 360.
- Practice observation: The team observed segregation, collection, transportation, final disposal and occupational health and safety practices of the staff working in the hospital. Most of the observation data were recorded in a standard format, as well as using photographs and videos.

Figure 6: Waste sorting carried out during the assessment in 2014 (Source: HECAF 360)

- Individual interviews: The team conducted interviews with various individuals from the hospital, such as the hospital director, nursing director, person in charge of support staff, support staff and nurses to understand current practices involved in HCWM.
- Questionnaire survey: The team conducted a survey with nurses, doctors, support staff and housekeeping staff to ascertain their knowledge, attitudes and practices relating to HCWM, needle-stick injuries and other blood and body fluid exposure during their service period.
- Document review: Existing documents relating to waste management were reviewed.

Hospital staff were trained on waste audit procedures, provided with appropriate PPE and assigned teams to audit waste from each ward and hospital area over the course of one week. In each location, waste was weighed and volumes were measured according to collection category. It was then segregated and re-measured. This provides information on amounts of infectious and other categories of waste under the pre-initiative procedures and what they would be if waste was fully segregated. This data was used to predict the ideal number and size of waste bins for each area, the volume of autoclave capacity needed to treat the infectious waste and the potential amounts and values of recyclable waste. The characterization of the waste generated is shown below in Figure 7.

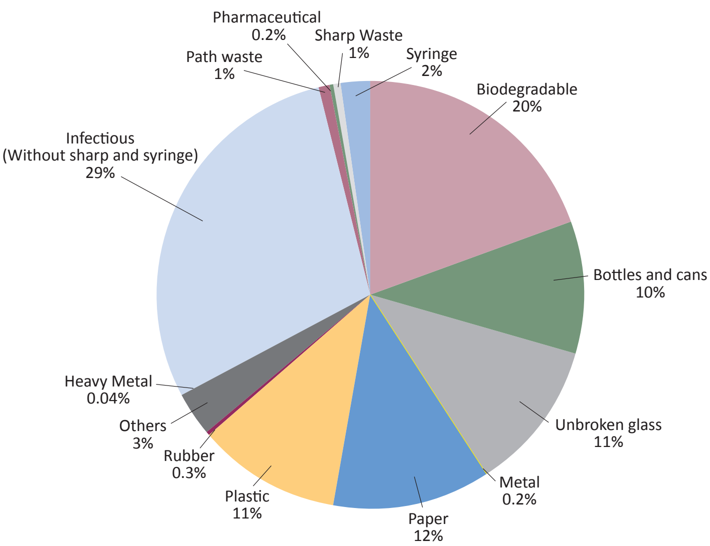


Figure 7: Waste composition (based on 2014 assessment)

2.3 Second Step: Development of Intervention Plan

With technical support of HECAF 360, TUTH prepared an intervention plan and the project was conducted with financial support from the Ministry of Health. The overall budget for the autoclave, biodigester and other equipment was approximately 10 million Nepali rupees (NPR) (about 90,000 USD).

HECAF 360 was awarded an initial contract for technical support for two years. They were responsible for implementation of a waste management system in all wards, provision of HCWM training for all staff levels of the hospital, solving existing problems in waste management, preparing logistics lists for requirements, monitoring for proper waste segregation and management in wards and the treatment centre, and recording and managing waste-related data.

The programme was intended to enable TUTH to maintain the system over the long term. In particular, a waste management committee has been established and a HCW supervisor appointed. The committee members have been trained in HCWM, including monitoring, and provided with the same excel-based monitoring tools. Training was provided for management, medical staff and waste management staff. With the support from WHO Nepal, TUTH conducted a national workshop on HCWM in presence of Vice-Chancellor. It was decided that TUTH should develop a national level training centre to guarantee capacity for ongoing training and maintain knowledge and performance standards.

2.4 Third Step: Selection of Technology and Tools

The pollution created by the incinerator had been one of the motivating factors spurring the project, and poor segregation was revealed during the assessment. Safe sharps disposal is also one of the key elements to a safe waste disposal system (WHO and UNICEF, 2019), so selecting the most appropriate means to deal with this problem was vital to the success of the project. This section describes the technologies chosen for each stage of the waste management process for this project, which were put into practice in the fourth step: implementation and capacity building.

Waste Segregation and Handling

Segregation Trolleys

Segregation and handling of waste are critical to safe and sustainable HCWM. Reatment trolleys are equipped with bins, colour coded in line with the Nepali national guidelines, and help nurses manage waste as they can be brought to the bedside or wherever needed (Figure 8). Waste can be transferred to the main bins later on.

Figure 8: Segregation trolley (Source: HECAF 360)

Needle Cutters

Needle cutting significantly reduces the volume of sharps waste and enables recycling of the plastics in syringes (Agbenu *et al*, 2014). Research shows that needle cutters are broadly accepted by medical staff and do not increase the number of needle-stick injuries suffered (Agbenu *et al*, 2014, WHO, 2010) and reduce the chance of injuries to waste handlers. There are many types of needle cutters, pullers and destroyers, the simplest being a "puller", which is a sharps container with slots allowing the user to insert the needle and pull it off, so that the needle drops into the container and the syringe is disposed of elsewhere. Needle destroyers use an electrical charge to destroy the needle. Needle cutters, also known as hub cutters, cut the needle off, often along with the tip or "hub" of the syringe, so that another needle cannot be attached to it. Needle/hub cutters are advantageous as they

Figure 9: Demonstration of needle cutters (Source: HECAF 360)

prevent reuse of syringes, which is a problem in some parts of the world (Mujeeb *et al*, 2003). Needle destroyers are dependent on electricity or batteries, so they are less flexible than manual cutters. Cutters which rely on the hand strength of the operator, are less easy to use than types which employ the strength of the whole arm (Figure 9).

Waste Transportation Trolleys

Hazardous (risk) waste and general waste must be collected and transported separately. Use of trolleys, as shown in Figure 10 allows different types of waste, segregated at source in the wards, to be kept separate during transport. Waste is collected at least once a day and transportation routes are designed to avoid public and sensitive areas, such as food preparation areas, to the extent possible.

Waste Disinfection Technology

When installing waste management technologies, TUTH is trying to maintain the highest possible environmental criteria. There is a range of different technologies for HCWM on the market. Table 1 below compares their advantages and disadvantages (UNDP, 2017). Details

Figure 10: General waste trolley with blue bins (left) and risk waste trolley with red bins (right). (Source: HECAF 360)

Table 2: Advantages and disadvantages of non-incineration waste treatment technologies

Treatment Method	Advantages	Disadvantages
Pressure pulse autoclaves	Environmentally sound Higher steam penetration than gravity autoclaves Relatively low operating costs Available in a wide range of sizes Widely used and accepted	Not designed for anatomical, pharmaceutical, and chemical waste and waste that is not readily steam-permeable Reduces waste by about 50%
Pre-vacuum autoclaves	Environmentally sound Higher steam penetration than gravity-fed autoclaves Relatively low investment and operating costs Available in a wide range of sizes	Not designed for anatomical, pharmaceutical, and chemical waste and waste that is not readily steam-permeable Sealed, heat-resistant containers may not be fully disinfected if treatment parameters are inadequate Minimal reduction in waste volume without a shredder
Dry heat treatment	Environmentally sound Compact size	Not designed for anatomical, pharmaceutical, chemical, and some infectious waste Available only for small-scale use
Microwave treatment	Environmentally sound High microbial inactivation efficacy with internal shredding High volume reduction with shredding	Not designed for pharmaceutical or chemical waste Relatively high investment and operating cost Units with shredders require intensive maintenance
Rotary kiln incineration	Adequate for all infectious waste, most chemical waste, and pharmaceutical waste Very high microbial inactivation efficacy High volume and mass reduction	Very high investment and operating costs Requires air pollution control Maintenance intensive
Multiple chamber (excess air) high temperature incineration	Adequate for all infectious waste including anatomical waste Very high microbial inactivation efficacy High volume and mass reduction	Relatively high investment and operating costs Requires air pollution control Maintenance intensive
Co-incineration	Combustion at high temperatures (>1,200°C) Pre-equipped with flue gas treatment – no additional costs	Cost for modifying incinerator to handle co-incineration of HCW Requires air pollution control Maintenance intensive Problems with heavy metals

Source: UNDP (2017) modified

of how different technologies operate, including their costing, are described by WHO (2014) and UNEP (2012). Of the technologies available, autoclaving is the most common and has been used to sterilise medical instruments and supplies for around a century[4], so it is widely understood and accepted by the medical profession. A very small number of other steam-based technologies (e.g., microwave) are in place.

A pre-vacuum autoclave (also called a vacuum autoclave) designed for HCW was recommended for TUTH to treat all infectious waste except pathological waste. This technology was selected owing to its established adoption, proven efficacy, low costs, and option to recycle waste after disinfection. One of the strengths of vacuum autoclaves is that they extract the air within the waste, ensuring good steam penetration and hence efficient destruction of pathogens. A similar effect can be achieved with pressure pulses in non-vacuum autoclaves, but based on previous experience these require more energy per cycle. Moreover, non-vacuum autoclaves are usually intended for general purposes, whereas models designed for HCWM are generally of the vacuum type because waste, which is an unpredictable mixture of plastics and other materials, requires the best possible steam penetration technology.

Further, HECAF 360 and HCWH established a successful method of collecting syringes in large metal drums for disinfection, which would not be possible with other technologies (Stringer, 2015).

4 https://brnskll.com/shares/a-brief-history-of-sterilization/ (visited in July 2021)

2.5 Biodigestion of Pathological and Organic Waste

The assessment found that TUTH was producing 189 kg of biodegradable waste and 10 kg of pathological waste each day, which represent over 72 metric tonnes of waste per year. At the time of the assessment, the hospital was at 87% occupancy; if beds were 100% occupied, the projected amounts would be: biodegradable waste 217 kg/day and pathological waste 11.5 kg/day, adding up to 83 tonnes of waste per year.

The biodegradable waste was predominantly food related, being mostly inedible materials like fruit peel and uneaten remains of patient meals. The pathological waste almost exclusively comprised placentas from the maternity department.

Both types of waste quickly decompose, especially in the warmer seasons, creating a nuisance and attracting flies, rats and other pests which can act as disease vectors. HECAF 360 and HCWH had been developing the concept of biological treatment for biodegradable waste and had successfully installed biodigesters at other Kathmandu hospitals, including the 460-bed Bir Hospital and Kathmandu Medical College. Biodigesters are common in Nepal's agricultural sector and consist of brick or concrete domes, and are seeded with cow dung, which contains methanogenic bacteria. These bacteria break down the waste and generate biogas, consisting mostly of methane and carbon dioxide, which is used as cooking gas. On farms, a biodigester will usually have one dome and be used to treat animal dung and vegetable waste. The digestate from these systems is used as fertiliser.

The situation in HCFs differs slightly owing to the inclusion of pathological waste, which as well as being potentially infectious has a much higher nitrogen content than vegetable matter. The biodigester expert working with HECAF 360 consequently redesigned a system to compensate for such differences. Blood-borne pathogens that might be present in pathological can only survive a few days to a few weeks outside the human body, and cannot adapt to or survive the long residence time of up to several months in the aquatic environment in the biodigester, hence retaining waste in the system leads to its natural destruction (Farzadegan *et al*, 1996, Pirtle and Beran, 1991).

The average length of time that waste stays in the digester is known as the retention time and is based on the volume of the chamber and the volume of waste entered. Since the amounts of waste were known, the chambers were designed to be large enough to hold the waste for the required time. Maximising the retention time for pathological waste and balancing out the high level of nitrogen contained are both achieved by building a digester with two chambers, in series (Figure 11). The first chamber has a retention time of at least 90 days, and the second, at least 30 days, during which time the blood-borne pathogens that might be

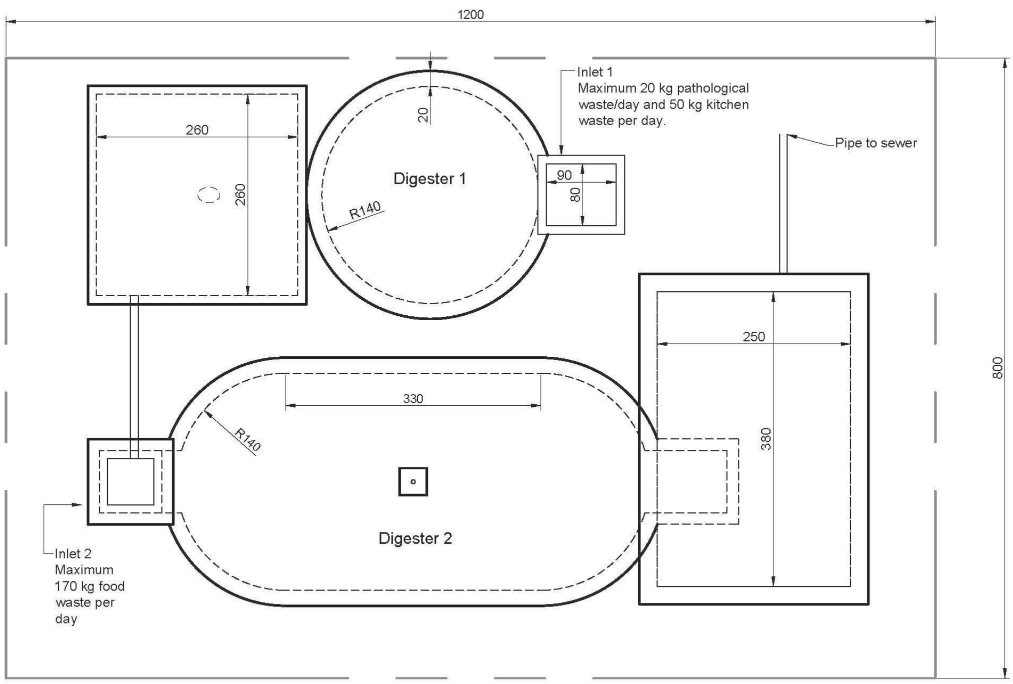


Figure 11: Layout of biodigester at TUTH (Source: HECAF 360)

found in pathological waste will die off. As an extra level of safety, the digestate is directed into the sewer without further handling.

2.6 Fourth Step: Implementation and Capacity Building

At the initiation of the project HECAF 360 worked closely with senior hospital management, and some awareness raising was conducted. Training for most medical and waste treatment staff took place only after the infrastructure was in place, to ensure staff could put the training to direct use without delay. If new procedures are not put into practice quickly enough after training, they may be forgotten. Initially, two autoclave operation staff received on-the-job training at two different hospitals. Later, in line with the increase in daily amounts of waste being collected and treated, these staff passed on their expertise to new staff under supervision from the HECAF 360 team.

Ward staff were trained incrementally (Figure 12). First, a model ward was selected in consultation with HCF staff – in this case the nephrology ward. Simple general wards were preferred, especially those where supervisors expressed interest in the project. After one day of training, including consultation on the best configuration of equipment for each ward, the system was implemented. Model wards were monitored and staff mentored until the new practices were established, and a post implementation review was conducted.

Medical staff and support staff received a one-day training on the new waste handling segregation system. The training package included a theory session, a half-day field visit and a practical session on waste segregation. The training packages for nursing staff and support staff differ according to knowledge level. Newcomers were trained by the waste coordinator or HECAF 360. The hospital provides new staff with either a one-day training or one hour on HCWM in the regular orientation programme.

Figure 12: Training underway on a ward (Source: HECAF 360)

To date, HECAF 360 has trained 647 medical staff, including nursing and technical staff and 346 supporting staff since 2018, of the total hospital staff of 1,900. However, as of the time of writing, implementation, including training, had been suspended by the hospital due to the COVID pandemic.

Waste Treatment Centre

The waste treatment centre was built in accordance with HECAF 360's design (Figure 14). It has separate Green and Red areas, each with its own entrance. General waste enters the Green area directly, where it is stored in storage compartments and segregated according to categories favoured by recyclers. Risk waste, including infectious waste, enters the Red area via a separate entrance, where the autoclaves are housed. After autoclaving, waste is transferred to the Green area and sorted, and either directed into the storage compartments for recycling or dispatched for disposal

Figure 13: The waste treatment centre (top) and Storage for recyclable wastes (bottom) (Source: HECAF 360)

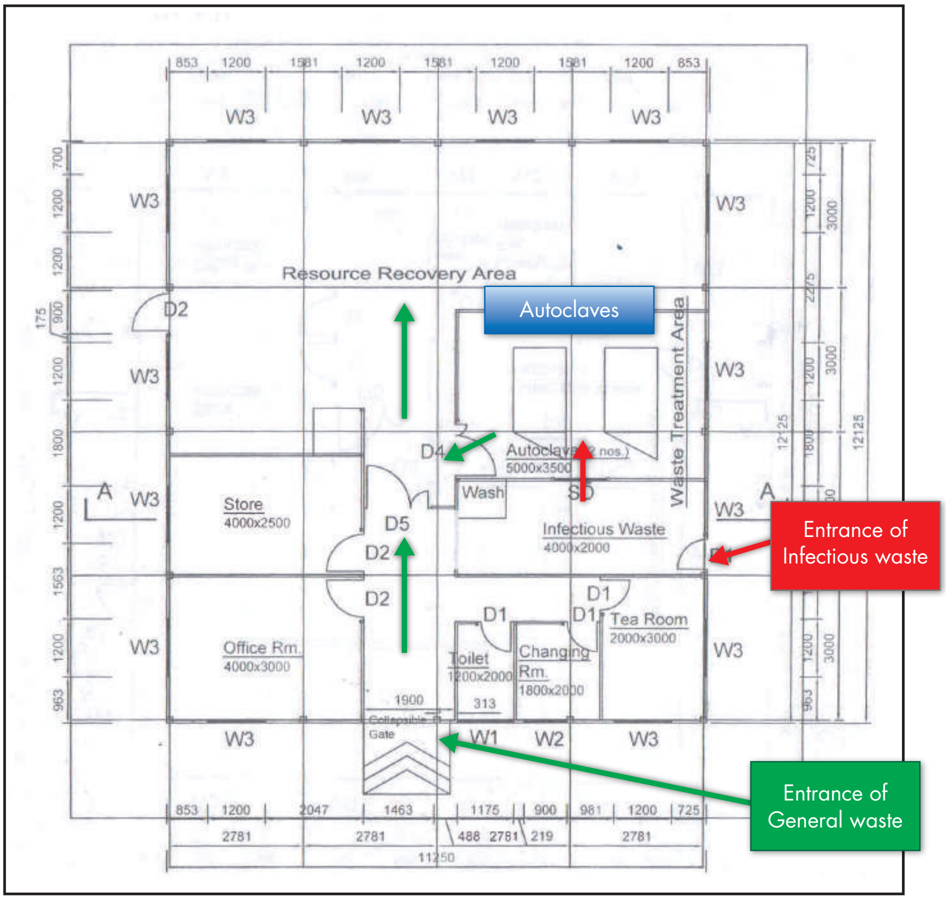


Figure 14: Layout of the waste treatment centre (source: HECAF 360)

by municipal authorities (see Figure 13). Uneaten food from wards is sent to the biodigester.

Operation And Maintenance of Autoclaves

One 227 litre Natt Steel pre-vacuum autoclave was procured by the hospital through their standard bidding process. It was rigorously tested to ensure safety in handling processed waste. All preventive maintenance, issues occurring during operations, repairs made, and disinfection tests are documented (Figure 15).
Modern waste treatment autoclaves of the type installed at TUTH have treatment programmes designed to disinfect waste effectively, but always require validation before use. Such tests are conducted with dummy waste and success in disinfection is checked using two test methods: "integrators" and self-contained biological indicators (SCBIs). Integrators are test strips which change colour gradually during exposure to high temperatures and give immediate indication of success/failure of the disinfection cycle (Figure 16, left). On the other hand, SCBIs, which contain heat resistant bacterial spores, are incubated for 24 hours after autoclaving, and success/failure is judged based on a colour change of the liquid medium, with a change in colour


Figure 15: Waste autoclaves in operation (left), and monitoring (right) (Source: HECAF 360)

Figure 16: Steam integrators (top) and self-contained biological indicators (SCBIs) (bottom) (Source: Stringer, HECAF 360)

indicating spore survival and growth and therefore test failure (Figure 16, right).

Once in service, autoclaves should be tested with chemical integrators every day. The initial frequency of biological spore testing was once a week. If all spore tests were passed for four consecutive weeks, the frequency of testing was decreased to once in two weeks (UNDP, 2010). Records of all tests must be maintained.

Another test to be carried out regularly is the Bowie-Dick test, which demonstrates proper air removal from the chamber of the autoclave. A test pack, consisting of porous materials with a thermo-chromatic paper sandwiched inside it, is placed inside an otherwise empty autoclave chamber and a disinfection cycle is run. After the cycle completes, the thermo-chromatic paper is taken out and checked against the manufacturer's example. A change in colour signifies the autoclave has passed the test; slight or no colour change indicates failure of disinfection and the need for immediate attention to ensure that all stages of the treatment process are being carried out properly.

Leak tests are carried out to check that the autoclave remains fully pressurised. They should be one of the pre-programmed cycles on an autoclave. The autoclave should be run with an empty chamber over about 15 minutes. After the cycle, results are printed out. Pressure drops of 1 mm Hg/min or less signify success; and if higher signify failure and the need for immediate maintenance.

Basic maintenance, such as cleaning or replacing a door seal (a common cause of test failure), can be performed by hospital biomedical engineers. More complex tasks may require the intervention of manufacturers. HCWM autoclaves sold in Nepal are generally manufactured in India, so obtaining spare parts is comparatively simple. Local agents may also employ qualified engineers. Hospitals should choose pre-vacuum autoclaves from manufacturers with local agents and engineers, and to ensure maintenance contracts are included in the purchase order, due to the variable level of service provided locally by manufacturers.

Operation of Biodigester

Once constructed, the biodigester was filled with cow dung and water to introduce bacteria to break down the waste. After this mixture had acclimatised and started to generate biogas, waste was introduced. Pathological waste was fed into the digester every day, along with three times the same weight in food waste, and sufficient water to keep the slurry flowing (Figure 17). The remainder of the food waste and more

Figure 17: The biodigester under construction in 2017 (top); Food waste being fed into the biodigester (bottom) (Source: HECAF 360)

water were added to the second chamber. As material from the first digester flows into the second chamber, the pathological waste undergoes a second digestion before finally being discharged into the sewer. Biogas, a by-product of the reaction, was piped to the kitchen for use as cooking gas.

2.7 Fifth Step: Sustainable Operation

Organizational Structure

Before the initiation of this project, there was no focal person or committee responsible for HCWM. A two-tier waste management committee was constituted to oversee and implement the project.

Management Committee

The management committee was formed according the national guidelines (Nepal MoHP, 2014) and the WHO guidelines (2014) (Table 3). It is chaired by the hospital director and contains all the department heads to handle higher-level issues including plan approval and troubleshooting. Members were initiated in HCWM and subsequently updated on progress to help them learn more as the programme unfolded. The waste coordinator received the same initial one-day training as the ward staff and was trained on waste data collection. Committee members were subsequently trained on the job. New staff joining management received the same training.

Hospital staff responsible for executing the waste management system were trained according to their roles. They also attend meetings of the waste management committee and meet with the director and other senior staff (chief administrator, store chief, hospital waste management coordinator) for updates and troubleshooting. Post-implementation meetings are held to resolve any problems arising.

Working Committee

The working committee shown in Table 4 includes some of the participants mentioned above, and in particular the hospital waste management coordinator, who acts as the working committee chair. The role of this group is to implement the system as set out by the oversight committee and report back to them.

Table 3: Membership of the waste management committee, 2019

Chair	Executive Director
Co-Chair	Former Executive Director
Member-Secretary	Waste Management Coordinator
Member	National Program Officer & Representative from WHO Nepal
	Executive Director, HECAF360
	Nursing Director
	Heads of Department of Emergency and General Practice, Department of ENT, ICU Committee, Member, Medicine Department, Orthopaedic Department, Pathology Department, Pharmacy Unit, Plastic Surgery Department, Psychiatry Department, Radiology Department, Surgery Department, Out Patient Department, Finance Administration, Hospital Administration, Housekeeping Unit, Department of Technical Support, Transportation Unit, Security, and

Table 4: membership of the HCWM working committee

Chair	Waste Management Coordinator
Member Secretary	Head of Housekeeping
Member	Head of General Administration, Senior Nursing Supervisor, Head of Technical Support, HECAF 360

Staffing

There are seven full time HCWM staff, as listed below. They are supported by the biomedical engineer and biomedical technicians in maintenance of the autoclave, needle cutters and transportation trolleys.

- Coordinator
- Waste treatment centre supervisor
- 2 autoclave operators
- 2 transporter/sorters
- 1 assistant

Procedures

The new system is governed by the Nepali national guidelines and informed by the best international environmental practices. Standard operating procedures (SOPs) provided to TUTH set out clear procedures for staff to help fulfil their roles in upholding the systems. The SOPs include:

- o Waste handling and disposal for general wards
- o Waste handling and disposal for specialist wards (e.g., haemodialysis, psychiatric ward)
- o Waste handling and disposal for operating theatres
- o Using needle cutters
- o Waste transportation
- o Sorting waste for recycling
- o Waste autoclave operation
- o Waste sales
- o Using the biodigester

Monitoring

Since the implementation of HCWM in the model ward, HECAF 360 has monitored waste segregation, placement of buckets, and cleanliness on the wards. Supervision and support for issues faced in the wards improves waste management at the ward level.

During previous collaborations, HECAF 360 and HCWH developed a waste tracking system that includes a monitoring checklist for waste handling on the wards, and trackers for waste generation, autoclave operation and maintenance, and waste sales. These are excel-based tools, each of which collate and provide analysis of daily data for a period of one year. Each tool contains a simple, printable data collection form. The outputs are summary tables and charts which are designed for printing in a format that is clear and easy to understand for persons responsible for the HCWM system. HECAF 360 analyses the data regularly to assess progress and identify issues requiring action. In the longer term, TUTH will use these same tools to monitor the waste management system themselves, allowing the waste management committee to make decisions in an informed manner.

Development of Training Centre

Of the aims set out for TUTH, one was to enable training on HCWM with practical learning for internal staff as well as external healthcare workers. A training centre was established and equipped for this purpose. However, since the onset of the COVID pandemic in early 2020, TUTH has set aside the space in the centre for the treatment of COVID patients. While this means the centre cannot currently be utilised as a training centre, it has already provided various trainings, as given below:

- Dissemination workshop

The objective of this high-level workshop was to raise awareness of the HCWM system at TUTH. It covered the importance of its mission and the need to inform stakeholders of plans to initiate development of a training centre on HCWM at TUTH. Since learning about the system, the National Health Training Centre has identified TUTH as a candidate for development as a national HCWM training centre.

The vice-chancellor of the Tribhuvan University was the chief guest at this workshop. The audience comprised officials from Tribhuvan University, the Dean of the Institute of Medicine, representatives from Kathmandu Municipality, the Ministry of Health, Ministry of Local Development and other related stakeholders including private and government hospitals.

- Training for small clinics

The objectives of this training for small clinics, conducted as a pilot with support from WHO Nepal, were to increase awareness of HCWM at various levels within the health sector, build the leadership role of TUTH in the sector and present it as an exemplary model for waste management. Participants were representatives from private clinics and small health centres. HECAF 360 provided the training and TUTH hosted the training session. TUTH and other model sites offered observation visits to their sites.

3 OUTPUTS AND IMPACTS

3.1 Reduction of Risk Through Segregation

One of the most important benefits of the new system is enhanced health and safety protection for the staff of TUTH. A survey of 267 staff conducted during the assessment in 2014 found that 62% had suffered a sharps injury during the previous year. Of the injuries, 68% (42% of the staff surveyed) involved hollow needles. Because these often contain blood, they are a likely vehicle of infection. 28% of injuries occurred during waste disposal, such as while recapping a syringe, or through contact with one protruding from a sharps container.

Owing to the low rate of segregation prior to the intervention, approximately 92% of the waste was classified as risk waste and only 8% as non-risk waste not contaminated with infectious, toxic or other hazardous material at the time of the assessment in 2014. The assessment team estimated that with proper segregation TUTH could potentially reduce amounts of risk waste to 33%. This figure is higher than general estimates from WHO (2014) stating 10–25% of waste from HCFs is hazardous but is within the range of HCFs assessed by HECAF 360[5] and may reflect the lower level of general waste in lower income countries.

Figure 18 shows that 34% of the waste collected in 2019 was classified as infectious. This was almost exactly the figure predicted in the assessment in 2014. This means that wards sending waste to the treatment centre practice very high quality segregation.

Together with the segregation activity, using needle cutters also contributed to alleviation of disposal-related injuries. Workplaces have improved because of the new system; waste handlers have been trained and vaccinated, are provided with PPE and work in safer and more hygienic conditions. The waste treatment team collects most types of waste daily from the participating zones. Exceptions are sharps containers, which are collected when they are 75% full, and placentas, which are taken directly to the biodigester by the support staff of the birthing centre. As the system expanded through the hospital, the number of wards covered gradually increased, and with it the number of beds covered and amounts of waste handled (Figure 19).

Before the system was put in place no records of waste flows existed, but it was known that the majority of waste was directed for municipal disposal and that smaller amounts were incinerated on-site or recycled via unofficial channels. By the end of 2019 the system had been implemented throughout most of the hospital, excluding the canteen. The canteen produces more waste than any other individual section of the hospital – over 90 kg of mostly biodegradable waste each

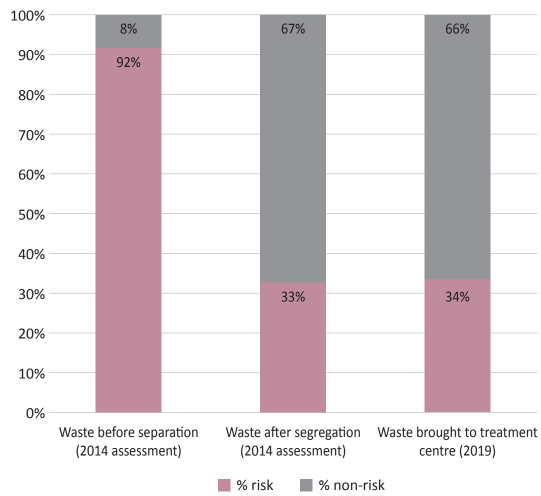
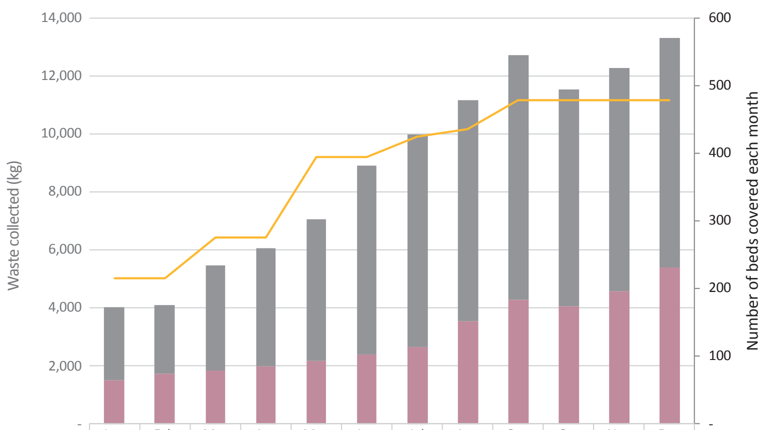


Figure 18: Percentage of risk and non-risk waste in 2014 and 2019



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
General	2,529	2,357	3,639	4,069	4,903	6,518	7,340	7,625	8,431	7,483	7,703	8,030
Risk	1,511	1,749	1,835	1,991	2,180	2,393	2,646	3,555	4,298	4,061	4,573	5,380
Beds	216	216	276	276	395	395	425	436	478	478	478	478

Figure 19: Weight of waste collected in 2019

5 HECAF 360 Unpublished data

> *"The survey found that 60% of the staff have encountered needle-stick injury. After implementation of this system needle-stick injury was reduced to zero."*
> – Ms. Dharma Laxmi Shrestha (Hospital waste management) coordinator)

> *"Now all the waste in wards is segregated well and transported separately using waste transportation trollies. Risk waste is first autoclaved and only then do we start to separate. Now we feel safe from risk of healthcare waste."*
> – Suresh Nepali, autoclave operator and waste separator at the waste treatment centre

day. The data given below relate to the wards and the facilities of the hospital for which the system was implemented.

At the time of assessment in 2014, the hospital generated 968 kg of waste per day under 87% bed occupancy. The total projected waste generation at 100% occupancy was 1,118 kg/day, of which about 45% was classified as recyclable and 21% as biodegradable waste. This category includes food waste and pathological waste, such as placentas from the maternity ward, and can be biodigested.

Waste generated was recorded daily, to create totals for every month (Figure 20). During the first half of 2019, the amount of waste sent for municipal disposal was reduced to 22–28% of the total generated. A further 34–44% was biodigested and 30–40% recycled. This performance started to dip later in the year, largely due to issues related to feeding the biodigester and using the gas generated, but improved toward the end of the year. Despite this, over the course of the year, 40% of waste had been recycled, 28% biodigested and only one third (32%) sent to the landfill. This result shows that proper waste separation was taking place and that the projected target had for the most part been achieved, except for the treatment of organic waste.

Disposal Of Organic Waste

During 2019, the daily input of waste to the biodigester was 72.3 kg, which represents only 36% of the total organic waste that was expected based on the measurements by the 2014 assessment. There are two reasons for this shortfall. First, not all wards are incorporated into the system, therefore some food

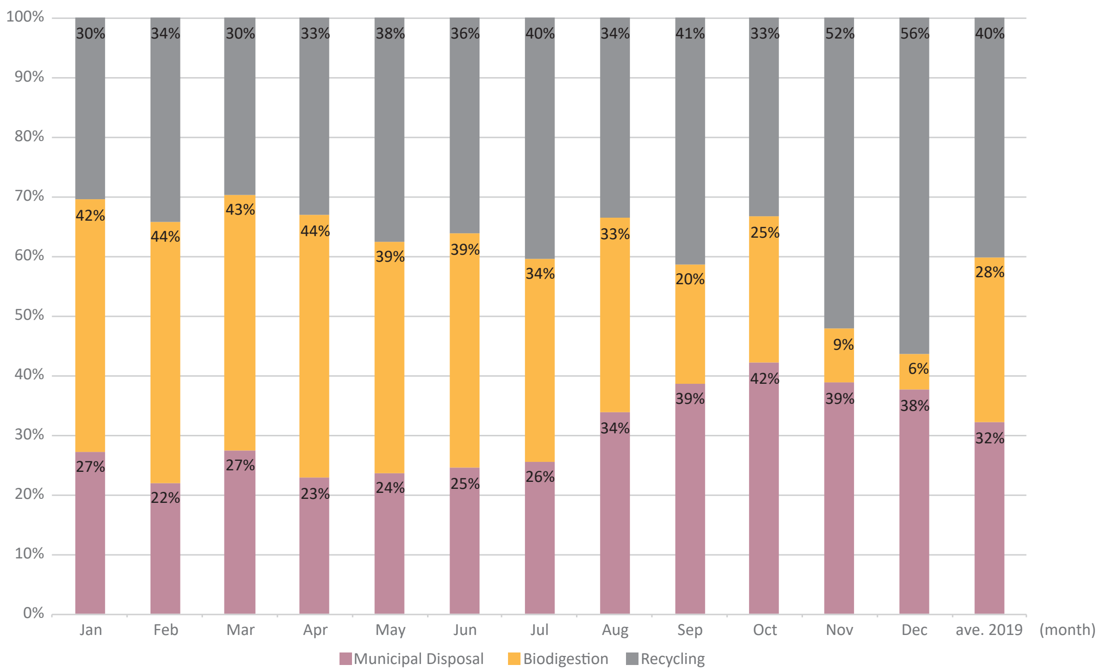
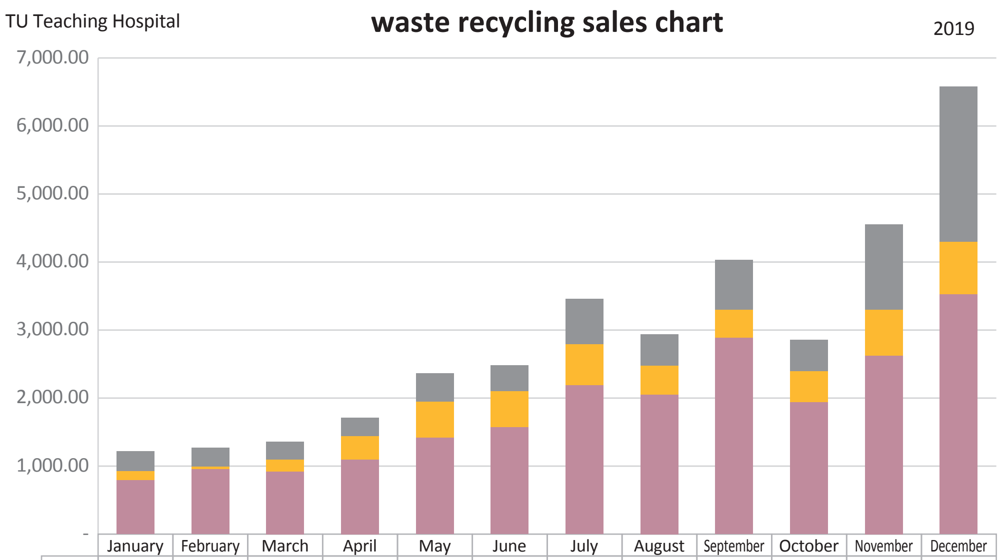


Figure 20: Percentage of waste recycled, biodigested or sent for municipal disposal in 2019



	January	February	March	April	May	June	July	August	September	October	November	December
Other	-	-	-	-	-	-	-	-	-	-	-	-
Metal	2.48	8.61	11.21	9.30	21.27	16.68	30.72	20.43	26.19	10.92	28.98	26.33
Paper	273.00	265.26	244.76	268.62	385.40	396.85	651.71	455.59	697.37	448.76	1,232.68	2,276.00
Glass	117.86	30.00	168.61	350.88	532.11	504.07	586.65	427.80	426.00	454.78	669.63	762.10
Plastic	830.12	989.33	948.24	1,103.90	1,445.56	1,603.56	2,230.39	2,075.85	2,911.61	1,980.49	2,667.84	3,563.90

Figure 21: Weight of waste recycled per month in 2019 (kg)

waste is still sent to the municipal landfill. Second, and more significantly, the hospital kitchens are operated by an external company on a contract basis, and this company sells the food waste for animal feed production – still a common practice in Nepal – so sending the waste to the biodigester would deprive them of this income.

INCREASE IN RECYCLING

During the assessment it was estimated that a maximum of 432 kg/day (45% of the total waste) was potentially recyclable. However, this figure is an estimate of maximum potential amount assuming all potentially recyclable materials are sold. In reality, a certain portion is rejected due to contamination or condition of separated waste. A more reasonable target is therefore 70–90% of the estimated maximum potential amount, or 302–389 kg/day to be recycled.

In December 2019, 6.6 tonnes of waste (213 kg/day) was sold to recyclers. Though the result did not achieve the target in 2019, mainly due to lack of all-ward system coverage, based on the continued rise in recycling amount during the course of 2019 (Figure 21), the hospital can be expected to achieve this target once all wards are participating.

3.2 Environmental Benefit

Hygiene Improvement

The new system with proper waste segregation at source has significantly improved the cleanliness of the whole site, both indoors and outside.

> *"Flies and nuisance smells have been significantly reduced and the whole hospital environment cleanliness has been improved. Also, patients and visitors are motivated and aware of the hygiene practice to be implemented at their household level."*
> – Dharma Laxmi Shrestha, the hospital waste management coordinator

> *"Prior to the project, we placed 3-4 buckets but all the wastes were thrown into one large bin which attracted many rodents and flies. Now, these rodents, flies and nuisance smells have been controlled and we feel like there is no waste in our ward."*
> – Niri Maya Jirel, responsible for the nephrology ward

Figure 22: Bins on the wards before the intervention (left), and afterwards (right) (Source: HECAF 360)

Improving the hygiene of the hospital increased public confidence in the hospital and made the hospital more resilient to disasters which affect public health. After the 7.8 magnitude Gorkha earthquake in 2015, hospitals with this type of waste management system were able to continue treating waste, despite the enormous disruption. For example, Bir Hospital, Kathmandu's largest trauma centre, had to treat victims in the street owing to fears that the building might collapse, which resulted in a three-fold increase in infectious waste in the days following the earthquake. The staff, who were well trained and aware of the importance of their role, continued to work and as a result managed to handle the excess amounts of waste (Stringer, 2016).

A similar situation occurred at the onset of the COVID-19 pandemic, when many HCFs and healthcare systems had to deal with up to 500% more waste than normal (UNEP and IGES, 2020). Based on interviews, TUTH has been able to continue treating its waste without disruption, unlike other some hospitals in Kathmandu, which have been overwhelmed by the amounts of COVID-19 waste.

Reduction of Greenhouse Gas (GHG) Emissions and Air Pollution

Avoiding burning waste through autoclaving and recycling contributes to reduction of the carbon footprint of the hospital. Over 12.6 metric tonnes of waste were autoclaved during 2019, including 1.3 metric tonnes of waste in December alone (Figure 23). Previously this infectious waste was incinerated, so autoclaving has significantly reduced local air pollution and carbon emissions. Most infectious HCW comprises paper and plastic. Based on the amount of carbon in these materials, it can be estimated that each tonne of

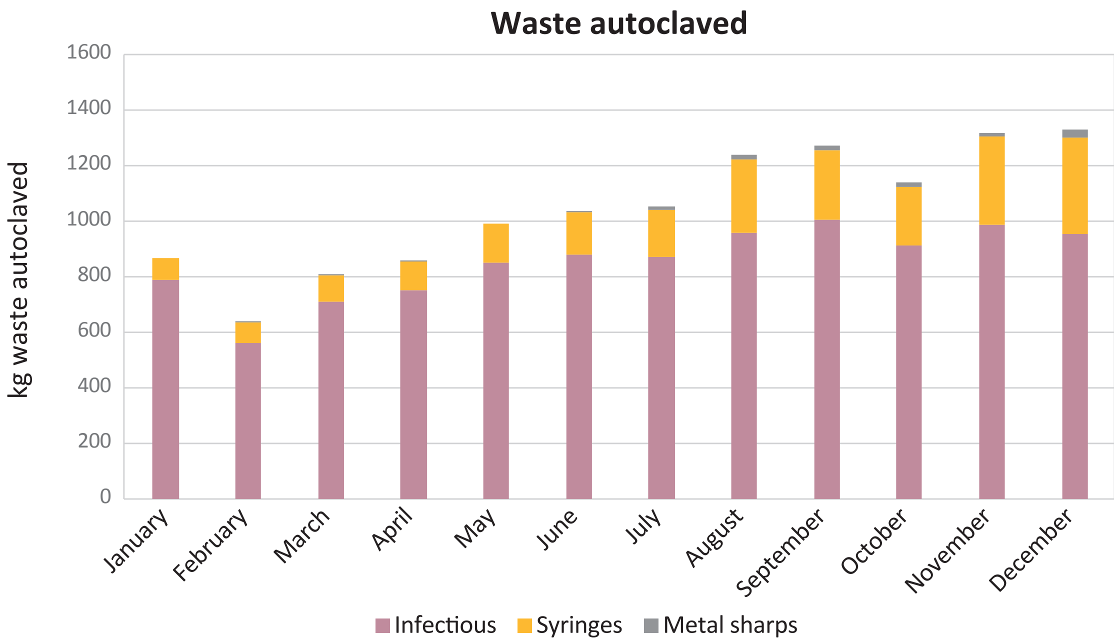


Figure 23: Weight of waste autoclaved in 2019

plastic and paper burned releases approximately 3 tonnes and 1.6 tonnes of carbon dioxide, respectively. Emissions from the diesel fuel powering the incinerator further would be in addition to this. No data is available on the quantities of paper and plastic burned prior to system installation, but if the paper and plastic which were recycled in 2019 had been burned instead, it would have resulted in 82 tonnes of carbon dioxide emissions[6].

A climate-related co-benefit of the biodigester is combustion of the methane in the biogas, which converts it to carbon dioxide. The high climate forcing potential of methane means that there is an overall reduction in the carbon footprint of this disposal route compared to the previous practice of landfilling and incineration. As the climate crisis proceeds, having a low carbon waste management system will help TUTH play its part in reducing CO_2 emissions as well as enhancing resilience in dealing with climate-related emergencies.

3.3 Financial Benefit

Improving waste management naturally incurs costs, both over the short and long terms. WHO and UNICEF estimate that for least developed countries (LDCs), costs related to investment in basic water sanitation and hygiene, including HCWM should approximate 1% of the overall healthcare budget, and costs for maintenance should be 2% (WHO & UNICEF, 2020).

For example, costs for a central treatment facility in Nepalgunj, one of sub-metropolitan cities in Nepal, which was projected to treat 680 kg of infectious waste each day were as follows: investment 255,000 USD; annual operating costs 63,300 USD, resulting in an average cost for treating waste of 0.255 USD/kg/day (Pathak *et al*, 2021), which is lower than 0.62 USD/kg, the cost of treating infectious waste at full utilisation of a system in Africa (Ghana and Madagascar: UNDP, WHO and HCWH, 2020). The Nepali facility includes economies of scale, and the African estimate includes depreciation.
The budget for waste management prior to and during the project was managed by the hospital, with some financial support provided by the Ministry of Education for system installation. The hospital is able to fund continued system operations either with the support from Ministry of Health or based on its own budgets. Expansion of recycling would attract some income to offset costs, and expenditure for municipal waste services and on-site incineration would be reduced.

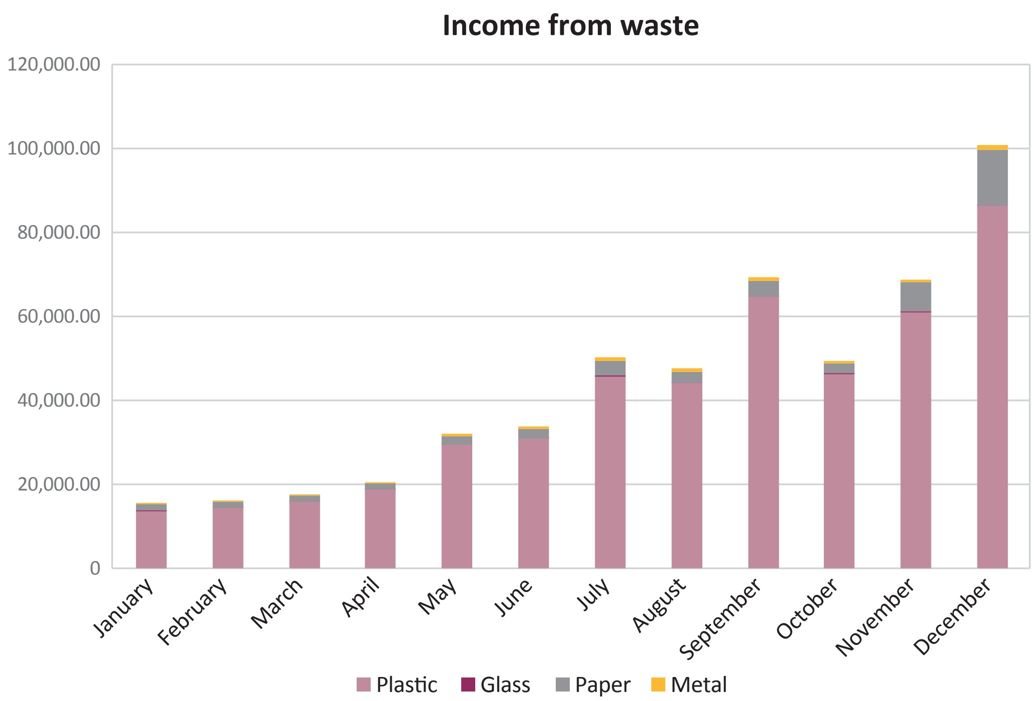


Figure 24: Income from recyclables sold in 2019

6 The CO_2 emissions avoided are estimated on the basis of the amount of carbon in each tonne of a material, and the weight of carbon dioxide that would be generated from it.

> *"The health care waste management system in TUTH is sustainable due to the income from waste sales and the trained manpower"*
> – Prof. Dr. Deepak Prakash Mahara

Value of Recyclables

In the assessment carried out in 2014, it was estimated that 432 kg/day (45% of the total waste) was potentially recyclable, with a maximum potential sale value of 240,000 NPR (about 2,450 USD) per month based on the exchange rate at the time of assessment[7].

The monthly income from waste in 2019 is illustrated in Figure 24. The total annual income from sales exceeded 500,00 NPR, including more than 100,000 NPR in December alone. At the exchange rate for December 2019, the sales for the year had a value in excess of US$4,500, including US$890 for December. Though sales in 2019 were lower than the maximum potential sale value (240,000 NPR), overall income from recyclables can be expected to rise when system coverage includes the rest of the hospital.

In December, for example, 6.6 tonnes of waste (213 kg/day) was sold to recyclers, who visited the waste treatment centre to collect it. This amounted to 50% of the waste collected (13,332 kg) for the month. While a lag may exist between collection and sale, since some of the waste sold in December may have been collected in earlier months, the proportion of waste that

Table 5: Prices for recyclable materials from HCFs in Kathmandu in 2019

Product or material	Price per tonne (NPR)		Price per tonne (USD)	
	min	max	min	max
Aluminium	115,000	125,000	1,022	1,111
X-Ray	80,000	102,000	711	907
Plastic Guddiya	61,000	61,000	542	542
Plastic Saline Bottle	51,000	61,000	453	542
Syringe	30,000	31,000	267	276
Gallon	30,000	31,000	267	276
Aluminium foil	27,000	30,000	240	267
Plastic (Mix)	20,000	22,000	178	196
Plastic mix (Polythene, PPM, HM)	20,000	20,000	178	178
Plastic Water Bottle	14,000	20,000	124	178
Carton	6,000	9,000	53	80
Plastic Kachara	8,000	9,000	71	80
Thin Paper	5,000	8,000	44	71
Thick paper	4,000	7,000	36	62
Gloves	5,000	6,000	44	53
Tin (can)	4,000	6,000	36	53
Glass saline bottles	500	1,000	4.4	8.9
Aluminium (Cans)	1,000	1,000	8.9	8.9
Other glass	200	200	1.8	1.8
Vials	200	200	1.8	1.8
Ampoule (Broken glass)	200	200	1.8	1.8

7 UN operational rates of exchange https://treasury.un.org/operationalrates/OperationalRates.php#N

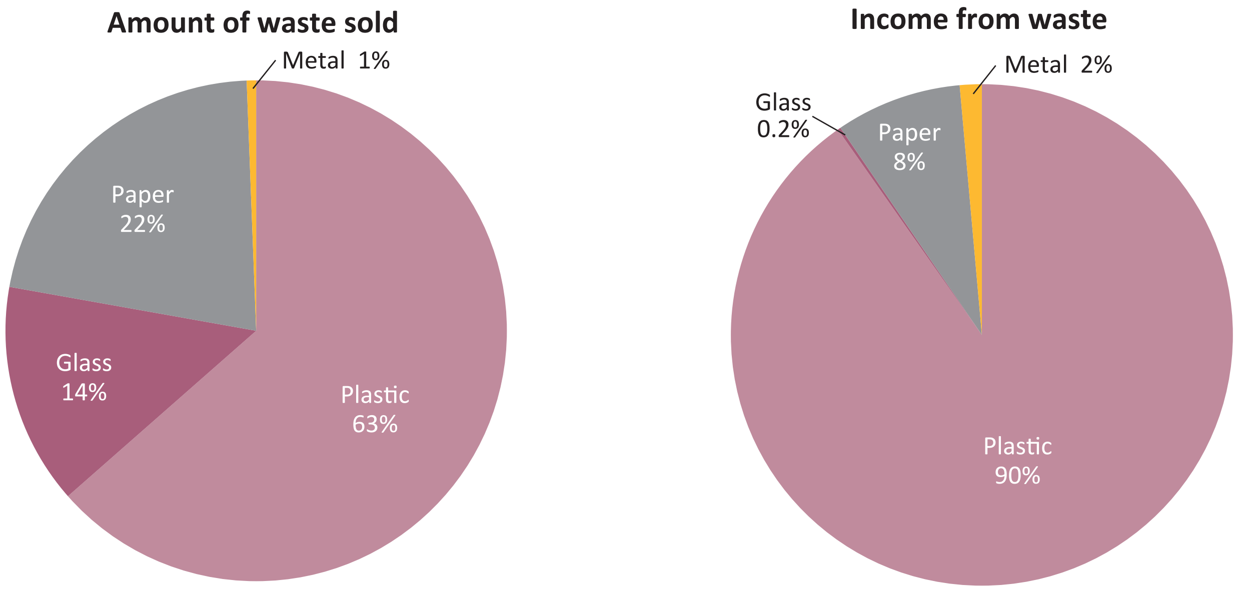


Figure 25: Contribution of different materials to waste sold and income earned

could be sold compares favourably with the estimate (45%) arrived at through the assessment.

It must be noted that variations in income are to be expected due to fluctuations in commodity values, with further variations in USD figures resulting from exchange rate fluctuations. Maximum and minimum prices obtained for recyclables by hospitals in Kathmandu in 2019 are given in Table 5.

Although aluminium and X-rays (from which silver can be recovered) have the highest per-kg value, only small amounts are produced. The largest and most valuable waste stream is plastics. The most valuable polymers overall are high density polyethylene and polypropylene, which are used to make items like saline bottles and syringes, and can attract prices from 250–500 USD (30,000–60,000 NPR) per metric tonne. Water bottles, made of polyethylene terephthalate (PET) are valued at 14,000–20,000 NPR per tonne, or around 124–178 USD. During 2019, almost 5,000 kg of syringes and saline bottles were recycled, bringing in an income of 250,000 NPR, or almost 2,400 USD. In comparison, 6,200 kg of water bottles made of PET were sold, bringing in an income of 100,000 NPR or 950 USD.

Figure 25 shows that plastics represented 63% of the recyclables sold but 90% of income. Paper, 22% of the waste stream by weight, represented 8% of the income, and glass, 14% by weight, represented 0.2% of income.

Value of Biogas

Biogas is generated in both chambers of the biodigester and piped into the nearby kitchens to be used as cooking gas. The value of the biogas was estimated by comparison with the value of the fossil-based natural gas that it could replace. Every metric tonne of waste fed into the digester replaces gas with a value of approximately 20 USD (Stringer, 2020).

Based on the recorded inputs, over the course of 2019 the gas generated would have had a value of approximately 66,000 NPR, or 560 USD. Were inputs equal to those measured in the assessment, the value would be 180,000 NPR, or 1,500 USD. The total savings from both these sources may be sufficient to recover the construction costs within the lifetime of the digester but will not provide profits under the current situation as the canteen services which are outsourced do not take part in the project. Potential savings are, however, best viewed as a side benefit of a system whose primary purpose is the safe disposal of biodegradable and infectious waste.

3.4 Gender Consideration

Gender aspects were not included in the project but should be included in future health system. Most of the healthcare work is carried out by nurses, of whom approximately 80% are female; support staff and cleaners are also likely to be female. In general, waste treatment operatives, such as autoclave operators are male, though those tasked with sorting waste may be female. Owing to the comparative size of the cohorts, most of those exposed to waste either at the generation or treatment stage are female.

Meta-analysis indicates that waste handlers are almost twice as likely to show evidence of hepatitis infection as others (Mol *et al*, 2017). Although healthcare providers are usually vaccinated against hepatitis and other diseases, such provision is not always extended to waste workers. Future projects should therefore include more analysis of the risk factors (e.g., exposure to waste, needle-stick injuries) and protections (training, vaccination, PPE) for males and females over various roles, enabling the benefits for all to be better understood.

4 CHALLENGES AND OPPORTUNITIES

Recycling of waste is an important element of the circular economy, as the value of a material is retained within the economy even when the original product has reached the end of its life. Where waste is not properly managed it is also common for rag-pickers to visit the hospital in search of waste that can be sold. Staff may also sell waste, a phenomenon that has been recorded in other countries as well as Nepal (Patwary *et al*, 2011, Stringer *et al*, 2011). Unofficial recycling was noted at the time of assessment. Staff and rag-pickers may not be aware of the potential hazards of the waste they handle (Patwary *et al*, 2012), and put themselves and others at risk by continuing this practice.

Well-managed recycling is therefore protective both of the environment and public health while considering waste as a valuable resource. While recycling of general waste is not controversial, it is less well accepted for treated infectious waste. However, no technical or public health barriers exist that prohibit the recycling of disinfected waste.

4.1 Influencing Factors as Barriers to Change

Although Nepal first set guidelines on HCWM in 2002 (Nepal, Health Research Council, 2002), and waste management is also enshrined in the minimum service standards for HCFs (Nepal, MoHP, 2019), these are currently not strongly enforced. There is little external pressure on hospitals to invest in high quality HCWM systems.

Lengthy government procurement processes slowed progress. The budget for waste management before and during the project was managed by the hospital, with some financial support from the Ministry of Education for installation of the system. Although a budget plan was included in the original proposal, it did not include technical specifications for all the equipment required. Because the resources for the equipment came from the Ministry of Education, the procurement department required significant justification before purchasing could proceed, which slowed down completion of the waste treatment centre. Rollout on the wards was dependent on the availability of bins, segregation trolleys, needle cutters and so on, and delays in their procurement were reflected in delays in expanding the system.

Staff changes in the purchasing department meant that the process of education on equipment had to be repeated. Staff turnover is a common occurrence in any large project, requiring frequent training and education of new personnel. Changes at the management level can have significant repercussions as new leaders do not always continue projects started before the start of their tenure. Fortunately support for improving HCWM has continued at TUTH.

The vast majority of the personnel of the hospital supported the project, but the kitchen services were contracted out and the contractors expressed no interest in participating. One reason given for this was that they were selling kitchen scraps to farmers, so sending them to the biodigester would reduce their income. They also refused to use the gas, which caused some operational problems for the biodigester. Under a normal use scenario, gas builds up in the chambers overnight, which pushes the digesting slurry into a compensation chamber. The gas is then used up during the day, and the slurry flows back. This movement helps mix the waste to improve digestion, so when the gas was not used, undigested solids built up and impeded waste flow through the system. Waste feeding had to be suspended for a short time while the system waste unblocked and burners set up at the waste treatment centre to ensure the gas was fully used. Unless the contract for catering services is changed, the biodigester will not reach its full capacity. In the meantime, remains of patient meals from the wards are collected as part of waste services, and are of sufficient quantity to mix with the hospital's pathological waste to ensure digestion, fulfilling the main function of the structure.

COVID-19 has exerted enormous pressures on the global healthcare sector and all of TUTH's human and financial resources have been directed towards fighting the virus since early 2020. The hospital was obliged to use the space intended for the training centre to treat increasing numbers of COVID patients, which has prevented the hospital from offering training on HCWM so far. The various lockdowns have also prevented the HECAF 360 team from visiting the site. As a consequence, the process of rolling the system out across all areas of the hospital has been suspended until the situation improves. However, it is hoped that will resume soon.

4.2 Influencing Factors that Assisted Changes

As noted in the section on challenges, the existing waste management guidance is not rigorously enforced. However, the national government is attributing ever increasing importance to the subject and awareness of the importance of HCWM, and the potential for safe, sustainable and cost-effective solutions is much higher in Nepal than it was 10 years ago.

With policy and financial support from national government, technical support from HECAF 360 and HCWH, and external financial support from donor agencies including WHO, the system at TUTH has made much progress. Above all, leadership from the hospital directors provided not only the initial impetus for the project; their devotion to the highest possible standards played a vital role in the overall success of the project. The broad network created together with determined leadership has enabled the hospital to join the Global Green and Healthy Hospitals network, through which TUTH waste specialists can connect with colleagues in other hospitals and learn from them.

Finally, the improved working and living environments provide human benefits which incentivise staff to play their part in maintaining the current environment: reduced risks from waste, a cleaner and more pleasant working environment, contribution to reduced air pollution in Kathmandu and combatting climate change.

4.3 Recommendations for Future Implementation and Scale-Up

Based on the findings and analysis from the collected data and interviews with individuals involved in the project, recommendations for further improvement are summarized in Table 6.

The report on this project imparts an important lesson: to install a comprehensive HCWM system in a hospital of this size usually takes several years, and requires continual efforts to maintain it thereafter. Such efforts should therefore be regarded more as an ongoing process rather than a project with definite start and end points. The work carried out by the HCW committee in cooperation with all the departments in maintaining and continually improving the system must proceed unabated.

Table 6: Recommendations for further improvements and scale-up

Area	Issues	Recommendations
National and regional government		
Implementation of policy and strategy	Existing waste management guidance is not rigorously enforced	- National and regional governments should facilitate and control the implementation of HCWM to achieve or maintain the standards set under the policy and strategy, including developing a plan and budget to provide safe and sustainable HCWM for all healthcare facilities - Good practices together with the established policy and strategy should be disseminated widely, especially among HCFs to raise awareness on the importance of HCWM - Actions to improve the occupational health and safety of HCW workers should be implemented
Data management	Lack of data hinders identification of issues and their causes, which in turn hinders making adequate plans and monitoring	- Data collection as part of monitoring would assist regulatory authorities to track waste management, to ensure compliance with rules and regulations, and to set future plans - Regular inspection should be carried out and digital monitoring introduced. Waste management data should be incorporated into the health management information system. - As well as quantifying waste data, the benefits to health and environment, including climate change, should also be estimated in a quantitative manner
Finance	Lack of finance hinders implementation of policy and strategy	- Sufficient budget in line with the HCWM strategy should be allocated and secured for short and long term - Incentives for expanding the recycling market, especially concerning plastic material should be identified and utilized - Collaboration with international agencies, to obtain financial support should be investigated
Procurement	Absence of green procurement criteria will prevent taking part in circular economy	- Application of green procurement criteria to purchasing across the HCF, to reduce amounts of waste generated, its toxicity, and increase amounts of products for reuse and recycling at the end of products' useful lifetimes
At Healthcare Facility (HCF)		
Leadership of top management	Weak leadership will hinder institutional development	- Determined leadership from top management is a vital element for improvement of HCWM - Leaders should create a broader network both locally and globally as this will attract further opportunities and support for improvements
HCWM plan	Absence of plan as guidance prevents the ability to make positive changes	- Development of a solid and feasible HCWM plan, to guide work staff towards the objective - Initiation or enhancement of data collection, in support of above HCWM plan, to analyse the current situation and identify issues to be solved and targets to be achieved - Regular recording of data to track waste management, waste recycling and generated income, and to ensure compliance with rules and regulations associated with HCWM

Area	Issues	Recommendations
Budget allocation	Lack of budget hinders implementation of HCWM plan; dependency on external funds will result in difficultly in controlling implementation	- Allocation of sufficient budget in line with the HCWM plan, allotted for short and long term - Acquisition of knowledge on investment and operational costs, to assist proper budget allocation - Recording of budgets and expenditures associated with HCWM, for monitoring and future budgetary planning
Administration / procurement	Bureaucracy slows down the implementation	- Procurement should be accelerated while maintaining transparency and accountability in the process - The waste manager and the waste management committees should have some procurement authority - Creation of standards for green procurement of HCWM equipment and supplies need to be promoted under the circular economy
Outsourcing task	Kitchen waste was not used as feedstock for the biodigester due to disagreement by the canteen contractor	- Negotiation and consensus agreement from concerned stakeholders in elaborating contracts for outsourcing service; ensuring all services provided inside a hospital are in line with the HCWM plan
Incentive for working staff	Lack of incentive will demotivate staff and lead to poor HCWM	- Inclusion of aspects and roles of HCWM as part of training for all working staff including medical professionals and new incoming staff, and provision of follow-up training at least once a year; such training to ideally consist of desk learning and practical on-the-job components - Improvement of working environment such as reduced risks from waste and a cleaner and more pleasant working environment as well as service area in the hospital, to help raise the level of dedication of working staff and level of satisfaction of users, including patients - Higher recognition and remuneration for waste workers, considering their important role in protecting the community from risks associated with HCWM

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