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Technical Cooperation for Enhancing Infectious Healthcare Waste Management

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Abstract

Appropriate healthcare waste (HCW) management is crucial for preventing the spread of infectious diseases and ensuring public health. However, in many economically developing countries, HCW is often insufficiently segregated at sources and the hazardous infectious components are mixed with municipal solid waste, and directly disposed without any treatment, which poses great risk factors for healthcare institutes, waste management service providers, and the public. According to statistical cross-country analysis, the amount of HCW generation is expected to increase sharply in near future in developing countries. What can we do to improve the status of HCW management in developing countries and prevent the spread of infection? It is necessary to establish an effective HCW management system and strengthen its implementation capacity, especially in developing countries. When conducting international technical assistance for them to support the establishment of the HCW management system and capacity development, it is required to set the targets for technical assistance through conducting an assessment survey, analyzing problems, evaluating risks, supporting to formulate management plans, and provision of equipment. A diagnosis method for existing capacity and challenges is proposed for planning technical assistance. Experiences of technical assistance on HCW management in Palestine are presented as a case study.

Keywords: healthcare waste management, developing countries, diagnosis of healthcare waste management system, technical assistance

1. Introduction

Healthcare waste (HCW), which is defined as all the waste generated within healthcare institutes, research institutes, laboratories related to medical procedures, and healthcare activities in the home [1], contains infectious hazardous waste components and must be properly sorted, collected, and treated to prevent infection [2, 3].

Over the last decades, the need for safety management of HCW has significantly increased due to the rapid population growth and increase in medical institutes, without which potential risks are very high to human health and the environment. Approximately five million people were reported to die every year due to HCW-related diseases [4]. The risk comes from accidental injuries during the handling of

infectious waste components of HCW, which can cause diseases like hepatitis B, hepatitis C, and HIV infection [5]. Moreover, numerous other diseases can be transmitted by contact with infectious HCW.

The importance of HCW management is once again drawing attention in today's COVID-19 pandemic [6]. As the virus stays longer on plastic, metal, and cardboard materials in HCW generated from the treatment of COVID-19 infected patients can be one of the potential routes for transmission of infection [7, 8].

However, in economically developing countries, which was defined by United Nations [9], HCW management systems are often unestablished or not fully functional, where infectious HCW that are not properly segregated and/or treated turn into new sources of infection and the waste streams become as a path to spread the infection. According to WHO, just over half (58%) of the sampled facilities from 24 countries (as of 2015) had adequate systems in place for the safe disposal of HCW generated [10]. Many papers have been reported that the implementation system and capacity of HCW management are often inadequate [4, 5, 11–18].

What can we do to improve the status of HCW management in developing countries and prevent the spread of infection? Especially in low-income developing countries where funds are insufficient, capacities at organizational, institutional, and societal levels are weak, some technical assistance for enhancing HCW management will be required through international cooperation [10]. In order to make effective use of the limited resources of donor agencies and provide appropriate technical assistance, it is essential to understand the current situation, evaluate risks, diagnose existing systems, and provide necessary technical supports.

The main theme of this chapter is to consider the challenges of international technical assistance for improving the management of hazardous infectious HCW in developing countries. The author first analyzes the trends in medical waste generation around the world and predicts the needs for medical waste management in developing countries in the near future. Next, we will examine the problems of HCW management in developing countries and the risks arising from them, and review the solutions to the problems, the system design, and an effective HCW management plan for avoiding the risks. It also proposes diagnostic methods and necessary supports for implementing effective international technical assistance. Finally, a case study of the international technical assistance on HCW management in Palestine is described.

2. HCW generation in developing countries

2.1 Definition of HCW

First, the term HCW used in this chapter will be clarified in detail based on the WHO definition [1]. HCW is a broad concept and can be classified into 2 main categories, hazardous and non-hazardous HCW. According to the definition by WHO [1], the hazardous HCW can be subdivided into 6 subcategories, as follows (**Figure 1**).

1. Sharps waste: It is defined as used or unused sharps, such as hypodermic, intravenous, or other needles; auto-disable syringes; syringes with attached needles; infusion sets; scalpels; pipettes; knives; blades; broken glass.
2. Infectious waste (narrow sense): It is suspected to contain pathogens and that poses a risk of disease transmission, for example, waste contaminated with

Figure 1.
Classification of healthcare waste (HCW) based on the definition of [1]. About 15% of HCW generated is hazardous while the remaining 85% is the same as general municipal waste (MSW).

blood and other body fluids; dressings, bandages, swabs, gloves, masks, gowns, drapes and other material contaminated with blood or other body fluids; laboratory cultures and microbiological stocks; and waste including excreta.

- 3. Pathological waste: This is consist of human tissues, organs, or fluids; body parts; fetuses; unused blood products.
- 4. Pharmaceutical/cytotoxic wastes: These are any waste that contains medical drugs that are expired, unused, or no longer needed.
- 5. Chemical waste: It is regulated as hazardous waste if it exhibits one of four characteristics: ignitability, corrosive, reactivity, or ability to produce toxic leachate in a landfill.
- 6. Radioactive materials: This has proven to be valuable tools in medicine, while eventually becoming low-level radioactive waste.

Among these 6 subcategories, (1) sharps, (2) infectious, and (3) pathological wastes are at risk of disease transmission, which are often collectively referred to as ‘infectious waste’ in the broad sense of the term. In general, around 10% of HCW is infectious waste in the broad sense, 85% of HCW is non-hazardous general waste, and 5% are the other hazardous ones ((4) pharmaceutical, (5) chemical, and (6) radioactive) those must be distinguished from other HCW and properly treated and disposed based on the national regulation and standard.

2.2 Increase of HCW generation according to economic growth

The characteristics of HCW generation depend on economic and social conditions, public health conditions, healthcare service systems, and solid waste management systems in each country.

According to the World Bank [19], the global average of HCW generation is 0.25 kg/capita/day, which is a very small part of the total special waste generated. **Figure 2** shows the relationship between the level of economic growth (GDP (USD)/capita) and the HCW generation rate (kg/capita/year), using the data given by the World Bank [19] and JICA.

Figure 2. Correlation between economic growth (GDP/capita) and HCW generation rate (kg/capita/year). Each plot indicates country averaged data (2011–2017), and the dashed line is the trend. Both horizontal and vertical axes are on a logarithmic scale.

HCW generation data in 105 countries/regions are available and are plotted in the diagram as a cross-country analysis (**Figure 2**). As is clear from this diagram, the level of economic growth (GDP/capita) and HCW generation rate (kg/capita/year) show a weak positive power correlation ($r^2 = 0.3705$). In relatively low income countries (GDP/capita <10,000 USD), HCW generations are often less than 1.0 kg/capita/year.

A similar correlation can be observed for the relationship between the total amount of municipal solid waste (MSW) generated in each country/region and the total amount of HCW generated, as shown in **Figure 3**, in which the data set used was the same as **Figure 2**.

The total amount of MSW generated and the total amount of HCW generated are in a positive power correlation ($r^2 = 0.5277$), which is stronger than

Figure 3. Correlation between HCW and municipal waste (MSW) generations. Each plot indicates country averaged data (tons/year; 2011–2017), and the dashed line is the trend. Both horizontal and vertical axes are on logarithmic scale.

the above-mentioned correlation with economic growth. The diagram indicates that the generation status of MSW has a strong influence on the generation status of HCW.

It has been reported that the amount of MSW generated increases year by year due to factors such as economic growth, diversification of life, urbanization, and population growth, in which the rate of increase in developing countries is higher than that in developed countries [19]. This indicates that enhancing HCW management capacity is a strong need in developing countries.

2.3 HCW and waste management capacity

Recognizing the necessity of HCW management by government authorities means understanding its risks and considering the need for proper collection, treatment, and disposal. In that sense, it can be said that the increase in official reporting of the amount of HCW is related to the improvement of authorities' concerns on HCW management.

Figure 4 shows the MSW collection service coverage rate (%; based on the target population or the total amount of waste generated) and the amount of HCW generation (kg/capita/year) that is officially recognized by each government authority. The MSW service coverage rate can be used as an index for the quality of MSW management services.

As is clear from this figure, the HCW generation rate is generally very low, if the MSW service coverage rate is less than 83%. In other words, it shows that government authority and given administration system cannot properly respond to HCW generation unless the services for MSW management are in place to some extent. Conversely, in countries/regions where the service coverage rate is more than 83%, the necessity of enhancing HCW management is emphasized as the high priority issue for relevant authorities.

As we have seen earlier, the amount of HCW generated is closely related to the degree of economic development and also to the state of the MSW management services. It shows that socially recognizing HCW as hazardous waste and implementing necessary treatment and disposal will gradually develop in accordance with the enhancement of the capacity of MSW management service as well as economic development.

Figure 4.
Correlation between MSW collection service coverage (% in population or total waste basis) and HCW generation rate (kg/capita/year).

3. Risk, problem, and capacity in HCW management

3.1 General concept of HCW management

The purposes of solid waste management (SWM) are similar, whether addressing hazardous, infectious, or even general municipal waste; three themes are prominent; management, treatment, and waste minimization [20]. The management of HCW requires analysis and active control from generation to final disposal. Hazardous or infectious HCW should be appropriately treated before disposal to eliminate its hazard risks. Waste minimization or reduction is undoubtedly the most desirable goal of solid waste management, which is the same in HCW management, where 3Rs (Reduce, Reuse, Recycle) are key approaches after segregation at source and appropriate treatment of hazardous infectious components (**Figure 5**).

3.2 Risks caused by HCW

It is crucial that decision-makers and administrators have a complete understanding of the risks of hazardous HCW since they are responsible for setting the HCW management system with a safe workplace and preventing environmental pollution. Inappropriate HCW management poses five major occupational, health, and environmental risks; A, B, C, D, and E, as shown in **Figure 6**.

A. Risks of infection by HCW within the healthcare institutes

The most common and most investigated cause of the microbiological risks associated with HCW are injuries due to needles of sharps waste [21]. For example, according to the results of a questionnaire survey of HCW workers engaged in Palestine, 32% in-hospital workers and 27% SWM workers experienced some kind of infectious waste accident when the HCW management system had not been established and the staff training had not been given [22]. According to the CDC guideline [23], a leak-resistant biohazard bag is usually adequate for containment of infectious wastes, and puncture-resistant

Figure 5. HCW management and the concept of 3Rs (Reduce, Reuse, recycle).

Figure 6.
Causal linkage of problems and risks in hazardous HCW management often observed in developing countries. White boxes show a series of problems in HCW management and the colored boxes indicate the risks.

containers located at the point of use are set as containment for discarded tubes with small amounts of blood, scalpel blades, needles & syringes, and other sharps.

B. Occupational risks for waste management workers

The impact of hazardous HCW in developing countries is very likely to pose a great occupational risk to general SWM workers and the public outside healthcare institutes due to inadequate practices of SWM and personal protection for workers themselves. In addition, the hazards posed by HCW may be more significant due to the limited availability of immunization against infectious diseases. The distribution of personal protective equipment (PPE) such as gloves, goggles, facemask, and disinfectant, is effective to prevent accidental infections together with periodical guidance and training.

C. Risks of infection for informal waste pickers

In countries where the HCW management system is not established nor functional, HCW is directly dumped at dumpsites without any treatment. These include infectious waste and sharps, and when waste pickers collect recyclables from the sites, they can cause injury and eventually infection. The existence of informal waste pickers is due to socio-economic problems and is not directly related to the HCW management issue. However, recognizing the existence of such risks, even if the only way is direct disposal of infectious HCW, the dumping site should be off-limits or immediately covered with soil for avoiding direct exposure.

D. Risks of infection to the public

Analysis of the microbiological content of MSW and HCW has shown similar concentrations of microorganisms in both types of wastes. According to the microbiological study of HCW and MSW, 2% of blood-stained waste was positive for

hepatitis viruses, and poliovirus and echovirus were recovered from soiled diapers in MSW [24]. Some infectious waste can stay infectious for many years if disposed without being sterilized. For example, anthrax-infected cattle contain spores that are known for many decades in dry soil [20, 25]. Therefore, dumping site management is required if infectious HCW must be directly disposed without any treatment.

E. Risks of hazardous substances for the ecosystem

If pharmaceutical or chemical pollutants are released into the environment, they can easily diffuse through groundwater, surface water, and eventually leach into drinking water. Pharmaceuticals are discarded and renewed in healthcare facilities when they expire. In time of conflicts or natural disasters, large quantities of pharmaceuticals are often donated as a part of humanitarian assistance [26]. However, such donated pharmaceuticals are sometimes stocked and often mismanaged when the pharmaceutical management system is not well functioned. Disposal of these unwanted or expired drugs may disturb the ecosystem. WHO guidelines [1, 27] recommended pharmaceutical waste to reverse distributors.

Problems	Description	Challenges
1. A lack of laws and/or regulations for HCW management	Due to the unclear definition and management responsibilities of HCW, some HCWs are not processed or not properly managed. Duplication and fragmentation impede system efficiency	Establishment of the legal system on HCW. Definition of HCW and clarification of management responsibilities in line with the current situation. Establishment of HCW treatment standards
2. A lack of HCW management system and its knowledge	HCW management system has not yet been established, where no HCW management plan and unclear implementation body are determined. Plan-Do-Check-Act (PDCA) management cycle is not developed. Inefficiencies occur due to unplanned waste treatment activities	Establishment of HCW management system with implementation body and HCW management plan
3. A lack of training for medical workers	Due to inadequate training for medical workers, they have insufficient knowledge on the dangers of hazardous HCW and the precautions to be taken when handling HCW. As a result, an infection accident occurs within the medical institute	Create manuals, textbooks, and teaching materials for staff training. Train staff training instructors. Organize regular staff training
4. Inappropriate HCW management practice including a lack of source segregation	Insufficient source separation increases infectious HCW and increases the loads for the treatment system. This is because if non-infectious waste is discharged without being separated from infectious waste, all becomes infectious waste. This results in the overloading of hazardous HCW to the existing treatment system, where the incoming waste amount to the treatment system exceeds its planned capacity	Training for staff in the medical institute, preparation of manual and posters for source separation. Inspection system for the situation of source separation and container management
5. Increase of hazardous HCW		Encouraging the source separation practice
6. Insufficient/inappropriate capacity of hazardous HCW treatment facility		Enhancing the treatment system

Problems	Description	Challenges
7. Insufficient human resource, technical capacity, and financial capacity for the hazardous HCW treatment facility	There is a lack of human resources, technology, and financial base to establish a proper treatment system of hazardous HCW	Provision of equipment technology transfer, and training Financial support for establishing the treatment system
8. Insufficient cooperation between public, medical, and private sectors about hazardous HCW issue	The best available technology is required for proper treatment of hazardous HCW in given country conditions, and the private sector plays a large role in introducing it. It is expected that the suppliers of pharmaceuticals handle unused/wasted them, but it cannot be dealt without sound cooperation between the public, medical, and private sectors	Networking between public, medical, and private sectors. Defining a rule for treatment of pharmaceutical waste in HCW.
9. Weak reverse logistics of pharmaceuticals and/or treatment		Establishing a reverse logistic system for pharmaceuticals. Establishing a treatment facility for pharmaceuticals and chemicals
10. Overflow and migration of hazardous HCW into municipal SWM stream	As a result of the increase in the amount of hazardous HCW results in the overflow of HCW containing hazardous components, which poses a risk of spreading infection and other negative impacts through the waste stream	Monitoring of the treatment system
11. A lack of monitoring of hazardous HCW stream	Despite the inclusion of hazardous waste, general waste treatment and disposal is carried out without this in mind. This deteriorates the occupational health and safety conditions of SWM workers	Monitoring of storing, transportation, and final disposal of hazardous HCW, using a manifest system
12. A lack of emergency shielded landfill	If the necessary sterilization or treatments are not possible, the untreated hazardous HCW will be directly landfilled as an emergency measure. In that case, the disposal site must be shielded, otherwise, infection and/or contamination can spread throughout the environment	Constructing shielded landfill Landfill operation and management
13. A lack of training on infectious HCW for SWM workers	As mentioned above, there are various possibilities that hazardous HCW will migrate into the general waste stream, and especially in the COVID-19 pandemic, the general waste management flow itself can also be a path of infection. It is necessary to train workers engaged in SWM service to prevent infection and to use PPE	Training for SWM workers about health and safety conditions. Distribution of personal protective equipment (PPE) for SWM workers
14. A lack of awareness on waste management and hazardous HCW issues	Behind all the above issues lies the issue of awareness of the HCW issue. This includes not only the general public but also workers and decision-makers at various levels of society	Public awareness-raising on HCW and its risks Awareness-raising for decision-makers

Table 1.
Problems recognized in HCW management and challenges for solving them.

3.3 Problems and challenges in HCW management

The above-mentioned five risks are caused by 14 problems in HCW management, and the relationship between the risks and problems is depicted as a causal linkage diagram as shown in **Figure 6**. The description of each problem and the challenges

for enhancing HCW management, which indicate the goal of technical assistance, are summarized in **Table 1**. If HCW waste is not properly segregated at the source (Problems No. 1–4), it creates many risks associated with various technical and management factors in the HCW management process (No. 5–14).

4. Establishing effective HCW management

4.1 Institutional development for HCW management

In designing a system for HCW management, it is important to consider three layers institutions levels; namely, global, national, and local levels. The institution at the global level is given by the internationally-accepted guidelines published by WHO [1] and other international organizations.

In any country, a national policy is the first step in creating a successful and sustainable HCW management system. The policy should be the blueprint to drive decision-making at a political level, for the allocation of resources, and mobilize government efforts to create the conditions to implement an HCW management system [28]. Based on the international guidelines, national-level legal systems and institutions for conducting proper HCW management will be formulated according to the given conditions of the country. Specific and comprehensive legislation and policy documents on HCW management with a clear designation of responsibilities to various stakeholders are required [18].

The following five basic principles are important in formulating an effective HCW management system, which was originally specified by the Global Healthcare Waste Project conducted by the United Nations Development Programme (UNDP) in cooperation with the Global Environment Facility (GEF) and WHO [29]:

- i. Polluter pays principle: All waste generators are legally and financially responsible for safe handling of waste and environmentally sound disposal of waste.
- ii. Precautionary principle: In order to protect the environment, the precautionary approach [30] shall be applied according to their capabilities.
- iii. Duty of care principle: Stipulates that any person handling or managing hazardous HCW is ethically responsible for applying the utmost care.
- iv. Proximity principle: Treatment and disposal of hazardous HCW take place as near as possible to the generation point for minimizing potential risks during transportation.
- v. Prior informed consent principle: Prior informed consent is required for the siting and operation of HCW treatment facilities.

4.2 Planning HCW management

There are basically two types of HCW management; a national level HCW management and a local level (individual healthcare institute or service provider) HCW management. In some cases, regional (provincial, prefectural) level HCW management is set between the national and local levels.

4.2.1 National/regional HCW management plan and strategy

The purpose of planning a national/regional HCW management is to improve HCW management at the national and regional (e.g., provincial) levels, where strong political commitment is required. In the planning process, it is required to involve relevant ministries and professional organizations including academics in the HCW management field.

The goals of the national/regional HCW management plan are: to declare the government's intentions to improve HCW management, to define overall national/regional strategies and plan for improving HCW management, to specify activities and timeline for implementation, and to define the roles and responsibilities of authorities concerned & other stakeholders.

1. Assessment study

The first step for formulating a national HCW management plan is to conduct a national assessment study on HCW management, where the following four points have to be clarified: (i) an inventory of existing healthcare institutes (waste generators) and HCW treatment facilities; (ii) analysis of existing legislation, regulations, and rules; (iii) existing HCW stream and its management practices if any; and (iv) implementation agency and human resource on HCW management.

The inventory of HCW generation sources and GIS (geographical information system) map are crucial for planning HCW management, which covers all healthcare institutes including hospitals, clinics, and primary healthcare (PHC) institutions. A regression model will be applied to estimate the amount of HCW generated by them using the outpatient, inpatient, and bed numbers.

2. Planning

Specific objectives toward developing a national HCW management plan should include the following five key objectives: (1) to understand the present situation and setting the purpose of the plan, (2) to develop the legal and regulatory framework, (3) to develop financial investments and resources for HCW management, (4) to develop capacity building program, and (5) to set up a monitoring plan. The expected general contents of the national HCW management plan are as shown in **Table 2**.

4.2.2 Local HCW management plan

When planning a local HCW management, the first thing that must be done is to clarify the executing agency based on the legal system, and that agency will make the plan. The local HCW management plan is created by each healthcare institute and/or service provider based on the above-mentioned national/regional plan. It is required to be specific and practical depending on given local conditions.

Specific objectives toward developing a local HCW management plan needs to include the following six key components based on the direction of the national/regional HCW management plan: (1) designing HCW management system, (2) segregation of HCW at source, (3) HCW handling, storage, and transport, (4) treatment technologies, (5) waste disposal, (6) staff training, and (7) monitoring:

Categories	Contents
(1) To understand the background and setting the purpose of the plan	<ul style="list-style-type: none">• Summary of the results of Assessment Study (see 4.2.1 (1))• Issue and challenges on HCW management• Setting the purpose and goals of the HCW management plan
(2) To develop the legal and regulatory framework	<ul style="list-style-type: none">• Present state of HCW management, issues and challenges• Legal framework, laws, regulations, standards on HCW• Establishment of implementing agency• Coordination with other laws such as public health, SWM, and environmental protection• Guideline(s) for proper HCW management• Method of enforcement• Licensing system for healthcare institutes, treatment facilities, and service providers
(3) To develop financial investments and resources for HCW management	<ul style="list-style-type: none">• Specific budget lines, subsidies, and funds for developing HCW management• Cost recovery mechanisms to sustain HCW management• Public-private partnership• Investment plan
(4) To plan capacity building program	<ul style="list-style-type: none">• Training programs including training of trainers (ToT)• National awareness-raising campaigns for target groups• Partnership with healthcare-related professional societies, educational institutes, and universities
(5) To set up a monitoring plan and information strategy	<ul style="list-style-type: none">• Define indicators of achievement or performance• Monitoring and inspection of healthcare institutes and service provider• HCW tracking (manifest) system• Database system and information disclosure

Table 2.
General contents of the national HCW management plan.

1. Designing HCW management system

Regarding the treatment and/or sterilization of infectious HCW, there are basically two types of HCW management systems; distributed (on-site) and centralized (off-site) systems. The distributed one is a system in which a healthcare institute has its own (relatively small-scale) treatment facility and processes infectious HCW by itself. On the other hand, the centralized system is a system in which a private or public service provider collects infectious HCW and transports it from each healthcare institute based on a contract and centrally processes it in the service provider-owned treatment facility.

The advantages of the distributed system are: complete control of infectious HCW by the generator, mitigating the risk of exposure during waste collection & transportation, and reducing unknown risks in the treatment by a service provider. However the distributed system has the following disadvantages: the healthcare institute has to get a relatively high financial burden for a treatment facility, and also become responsible for meeting all regulatory requirements on infectious HCW treatment, which needs additional resources.

On the other hand, the advantages of a centralized system are minimization of cost and responsibility for the treatment of infectious HCW. Each healthcare institute can concentrate only on source separation and appropriate waste discharging. The HCW generators, in particular small-scale healthcare institutes, benefit from the quality of service and the economies of scale. The disadvantages are indirect control of infectious HCW management due to outsourcing.

In the case of a centralized system, two management plans, on-site and off-site plans, are required, and coordination and cooperation between the two actors are indispensable.

These distributed and centralized systems are often combined in a country/region to act as a hybrid system for actual HCW management (**Figure 7**). As shown in the **Figure 7**, the generated HCW is first separated into non-infectious HCW and infectious HCW (sharps and infectious) at the source. Non-infectious HCW is treated in the MSW management flow, while infectious HCW is sent for on-site or off-site treatment. If there is no treatment facility or in the case of the treatment capacity is insufficient, an emergency controlled cell is installed at the landfill site for direct disposal as an emergency measure.

2. Segregation at source

Segregation at source (source separation) is one of the most important steps to successfully manage HCW. As shown in **Figure 1**, only about 15% of the HCW is hazardous, treatment and disposal costs could be greatly reduced if proper segregation were performed. Segregating hazardous from nonhazardous waste reduces also greatly the risks of infecting SWM workers.

Segregation consists in separating the different waste streams based on the hazardous properties of the waste, the type of treatment and disposal practices that are applied. A recommended way of identifying HCW categories is by sorting the waste into color-coded and well-labeled bags or containers.

Figure 7. Outline and options for HCW management in developing countries. Dashed parts are emergency measures under limited conditions, which is an example in Palestine.

3. Handling, storage, and transport

HCW workers have the greatest occupational risk (the Risk A in **Figure 3**), where the hazard is from direct contact with sharps and infectious waste. Sharps can cause puncture wounds, scratches, and scrapes, where infectious agents can penetrate the skin. The use of special containers for sharps is absolutely necessary. In the HCW handling process, there is also potential for exposure through inhalation of pathogen-containing aerosols or particulates [20].

The best way to minimize the risk of exposure is to ensure that the infectious waste is properly isolated. Some basic principles [20] are: packaging the infectious HCW properly; avoiding physical contact with the infectious HCW; using personal protective equipment (PPE); and handling the infectious HCW as little as possible.

Another factor to be considered is public health including informal waste pickers if the hazardous infectious waste is directly disposed without any treatment as an emergent measure under limited conditions. In that case, no one has easy access to discarded needles and syringes, so that waste sharps' containers need the following features: puncture resistance, impermeability, rigidity, tamper resistance, and proper marking [31].

4. Treatment technologies

The purpose of treatment is to change the biological character of infectious HCW to eliminate, or at least to significantly reduce, its potential for causing negative impacts. The three most common techniques used to treat infectious HCW are incineration (various types are available), steam sterilization (autoclaving), and microwaving (**Table 3**). Other currently available techniques include irradiation, chemical disinfection, and so on.

5. Disposal

When infectious HCW waste has been properly treated, the waste is no longer infectious. The treated HCW can be handled in the same way as normal municipal waste. However there are two exceptional cases [18]: for sharps and pathological wastes, additional processing before disposal is necessary; if other hazardous substances such as pharmaceutical, chemical, or radioactive waste are contained, there must be additional treatment before disposal.

In the case of sharps waste treated by steam sterilization, intact sharps are possibly sent to a landfill where workers are at risk for injury; therefore, they should be shredded or destroyed when be treated. Pathological waste treated by steam sterilization also requires additional processing since body parts or organs can be recognizable, which should not be directly disposed in the landfill.

In developing countries, sometimes no suitable HCW treatment facility is available and the only option is direct landfilling. In such a case, it is necessary to avoid using an open dumpsite and dispose a landfill having a shielded structure. It is necessary to immediately cover the soil at the time of waste disposal to prevent the dissipation of HCW and protect the environment.

6. Staff training

HCW management training is an effective intervention for preventing infections and improving the occupational safety of the HCWs through building awareness,

Treatment technology	Waste type	Operation & maintenance	Residues after the treatment	Environmental consideration
Incineration	<ul style="list-style-type: none"> • Applicable for almost all infectious HCW 	<ul style="list-style-type: none"> • Relatively complex operation • It is necessary to segregate the highly flammable waste to avoid an explosion accident. • Requires skilled operators • Additional fuel is required for complete combustion 	<ul style="list-style-type: none"> • Large volume reduction (approx. 90%) 	<ul style="list-style-type: none"> • Smoke and gas emission with toxic substances are concerned when operated improperly • Relatively low to moderate cost
Autoclave (Steam sterilization)	<ul style="list-style-type: none"> • Applicable for most infectious HCW • Not applicable to pharmaceuticals 	<ul style="list-style-type: none"> • Relatively simple operation • No additional fuel is required 	<ul style="list-style-type: none"> • No volume reduction 	<ul style="list-style-type: none"> • No emission when operated properly • Relatively moderate cost
Microwave	<ul style="list-style-type: none"> • Applicable for most infectious HCW • Not applicable for pharmaceuticals 	<ul style="list-style-type: none"> • Moderately simple operation • Requires skilled operators • No additional fuel is required. 	<ul style="list-style-type: none"> • Some volume reduction (max. 30%) 	<ul style="list-style-type: none"> • No emission when operated properly • Relatively high cost
Direct Landfilling	<ul style="list-style-type: none"> • Applicable for almost all infectious HCW 	<ul style="list-style-type: none"> • Simple operation • Landfill having shielded structure and daily covering soil are required. 	<ul style="list-style-type: none"> • No volume reduction 	<ul style="list-style-type: none"> • Possible migration of pollutants into the environment • Not suitable for long-term use

Table 3.
Comparison of most common HCW treatment technologies and landfilling [14, 20, 32–35].

changing attitudes and practices [36]. Training has two functions. One is to get a good understanding of the HCW management system so that the actual work can be implemented smoothly and without fail. The other is the meaning of risk communication. In other words, it is necessary for each worker to understand various risks involved in executing HCW management work and to give due consideration to safety. Training programs are planned for each job type, and manuals and posters are created as needed so that everyone can understand them. The staff training should be done continuously every year. Donor agencies are required to plan a training of trainer (ToT) for realizing a sustainable training program.

7. Monitoring

The monitoring system needs to be able to monitor the sorting status at the source, the amount and composition of the generation, the amount of treatment, and the amount of final disposal. In particular, it is necessary to track whether all infectious HCW has been properly collected and processed from the source.

5. Diagnosis of HCW management

In developing countries, depending on the conditions, the appearance of the problem in HCW management will differ, and some of the 14 problems mentioned in **Figure 6** and **Table 2**, combine to cause significant difficulties as a whole. Therefore, it is necessary to grasp the current situation of HCW, clarify the problems, and analyze the problems specifically.

A flowchart for diagnosing HCW management is shown in **Figure 8**. By answering 10 basic questions in the flowchart, required issues and challenges for capacity development in the HCW management are derived as follows:

1. Question 1 is 'Have the legal system and authority regarding HCW management been established?' A legal system on HCW must be in place that include definitions, treatment responsibilities, regulations, standards, and guidelines for HCW and its management. In addition, it is necessary to clarify the regulatory authority at the government level and the implementing body for HCW management at the national and local levels in accordance with the legal system. If the answer to this Question 1 is negative, then the challenge for capacity development is to establish a legal system, standards, and guidelines for HCW management and to determine regulatory agency at the government level.
2. Question 2 is 'Present state of HCW has been studied?' It is not possible to make an effective HCW management plan without an accurate understanding of the current state of HCW, in particular, the generation sources, generation amount, its composition, treatment, and disposal. If the answer to this Question 2 is negative, then the challenge for capacity development is to clarify the current waste stream of HCW if any, including the inventory of healthcare institutes, waste generation amount & composition, and treatment & disposal methods, through conducting a survey.
3. Question 3 is 'In-house HCW management system has been established?' In this question, the current state of HCW management at the individual healthcare

institute level is assessed based on the law and regulation, which includes the availability of HCW plan and also its practice including segregation of HCW at source, collection, storing, and treatment. If the answer to this Question 3 is negative, then the challenge for capacity development is to formulate an HCW management plan at each level, and establish an HCW management system and strengthen the capacity of the implementing organization. This question corresponds to Problem No.2.

Figure 8.
A flowchart for diagnosing an HCW management system and for identifying challenges in capacity development, which are the targets of technical assistance.

4. Question 4 is 'Staff training program available?' Training and capacity building of staff responsible for the HCW management work is essential for effective HCW management. It is necessary that some kind of training function is set at each level of national, local, and healthcare institutes. If the answer to this Question 4 is negative, then the challenge for capacity development is to plan and organize periodical training courses for HCW management workers, and to conduct training of trainers for that purpose.
5. Question 5 is 'Distributed system or centralized system for HCW treatment?' It is a two-choice question. As mentioned above, the infectious HCW treatment system is either a distributed type that can be used in each healthcare facility or infectious HCW is separately discharged from each healthcare facility and treated at an external treatment facility, a centralized type. It is necessary to clarify which system the target country, area, or individual facility, is adopting or intending to adopt.
6. Question 6 is 'Is there monitoring system for HCW?' This question is for the case of centralized system. The monitoring system referred to here is to monitor whether infectious HCW is properly segregated, collected, and treated in the off-site facility. If the answer to this Question 6 is negative, then the challenge for capacity development is to formulate a monitoring plan and introduce a manifest system, which is designed to track infectious HCW from the time it leaves the generation source until it reaches the off-site facility by regulatory/monitoring agency.
7. Question 7 is 'Who is HCW service provider? Public or Private?' It is a two-choice question. Since infectious HCW treatment requires specialized technology, private specialized companies are often entrusted with treatment by healthcare institutions and perform the treatment as an off-site centralized system. On the other hand, public institutions also sometimes carry out the treatment in an off-site centralized system, which differs depending on each country and area. This question is important in particular for aid agencies because public intervention should not disrupt existing systems based on private enterprises' businesses, if private enterprises have a large share of the outsourced processing. For example, in an area where private services are predominant, if support such as the establishment of centralized treatment facilities is provided to public institutions as a grant aid project, it will clearly hinder competitiveness and create conflicts between public and private. Therefore, if the answer to the Question 7 is the 'private company', consider whether equipment provision (grant aid/donation) to the public will hinder the private sector. If the private sector services are existing, it is necessary to consider that the public conducts only licensing and monitoring to these private activities.
8. Question 8 is 'Waste collection service is well established?' This question is for a public SWM agency that employs a centralized system for collecting and treating infectious HCW. In such cases, it is important to consider whether public agencies are properly conducting SWM services. This is because the centralized system has a similar management structure to that of SWM; waste collection, transportation, treatment, and disposal. If the answer to this Question 8 is negative, then the challenge for capacity development is to improve implementing capacity of public agencies in SWM as well as HCW management.

9. Question 9 is 'Environmental Assessment has been done for the facility?' When installing an infectious HCW treatment facility, it is necessary to evaluate various environmental impacts such as gas emissions, wastewater, and solid waste in the treatment process. In addition, when installing a large centralized treatment facility, it is necessary to reach a consensus about the siting with surrounding local communities. If the answer to this Question 9 is negative, then the challenge for capacity development is to implement environmental impact assessment (EIA), planning measures to prevent environmental pollution, and building a consensus with local communities.
10. Question 10 is 'The capacity of treatment facility is sufficient?' Often, donor agencies ask this question first and precede the provision of facility and equipment, but as shown in the flowchart, the system only works with various technical soft components. If these soft components meet the requirements, government, or donor agencies can equip the facility and equipment, otherwise, sustainability cannot be ensured. To enhance the treatment capacity of HCW, it is also necessary to improve the operation and maintenance capacity.

6. Development of HCW management system in Palestine: a case study

Over the past decades of experience in Palestine is a typical example of inadequate HCW management [35], where one of the major threats came from that much of hazardous infectious HCW had mixed with MSW [37] and flowed into dumpsites without any treatment and safety measure [38, 39].

In 2010, the Palestinian National Authority (PNA) compiled a report on the development of a National Master Plan for Hazardous Waste Management in the West Bank and Gaza [40]. According to the report, only one-third of the healthcare facilities used special bags for HCW collection, whereas all other facilities consequently collected all types of HCW together with MSW, except for sharps that were being collected in special boxes. The report also stated that 80% of healthcare facilities in Gaza had no way to securely store HCW generated. MSW was generally collected by local government units (LGUs) without any discrimination between HCW and MSW, and eventually, all types of solid waste were mixed and disposed.

In 2012, PNA enacted Palestinian Authority Cabinet Decision No. (10) of 2012, "Medical Waste Management System, and its Uses". The bylaw allowed both distributed (on-site) and centralized (off-site) systems of HCW treatment. As a practice based on the bylaw, the first systematic HCW collection & treatment service has been started in the southern area of West Bank (Hebron and Bethlehem governorates), where an HCW treatment (microwave) facility was equipped under the support of the EU. It is a typical "centralized system" and its operation and maintenance (O/M), as well as HCW collection, transportation, and disposal, were conducted by the Hebron-Bethlehem Higher Joint Service Council for Solid Waste Management (H-B JSC). However, in the remaining middle and northern part of West Bank and over the Gaza Strip, most of the HCW generated was still mixed and disposed without any treatment. The required local HCW management plan was little formulated at each healthcare institution and authority.

Under the circumstances described above, international technical cooperation projects for the capacity development of Palestinian authorities on HCW management were organized in the Gaza Strip from 2015 [22, 39, 41, 42], those are composed of five

components: (1) assessment study to grasp the current state of HCW; (2) formulation of a strategy and preparation of HCW management plan; (3) capacity building activities such as seminars, workshops, and staff training courses; (4) Pilot projects on on-site and off-site HCW management to verify the effectiveness, efficiency, and feasibility of the HCW management plan; and (5) Provision of equipment by international donors.

As of 2015, there were 2245 inpatient beds in public hospitals and 619 inpatient beds in private/NGO hospitals in the Gaza Strip. The proper on-site segregation of the infectious and sharps showed that 2.4–0.7 kg/day of HCW is generated from hospitals and clinics. The generation rate from outpatients accounts for a rate of 11.0 g–9.5 g per outpatient [41]. The estimated total HCW generation amount was around 7199 kg/day, and the estimated amount of infectious HCW was calculated around 1071 kg/day.

Healthcare institutions in the Gaza Strip are responsible for on-site management, where MOH conducts monitoring, supervision, and enforcing bylaw on all healthcare institutions for their compliance with appropriate on-site management; three categories of segregation at sources (sharps, infectious, and noninfectious), controlled storage, and separated discharge of HCW.

Regarding the responsibility for off-site HCW management in the centralized system, collection, transport, treatment by autoclave/microwave, and final disposal, the collection service have been managed by the Joint Service Council of Khan Yunisi, Rafah, and Middle Gaza (JSC-KRM) since 2017, and later JSC of North Gaza and Rafah (JSC-GNG) has started the service since 2020. An HCW management system was established over the Gaza Strip as the twin centralized systems using autoclave/microwave facilities for the infectious waste treatment (**Figure 9**). From 2017 to 2019, intensive training courses have been held for the workers in healthcare institutes and service providers (JSCs).

The costs of HCW management services are borne by the HCW generator based on the polluter-pay principle (PPP), where each healthcare institute pays a reasonable fee to JSCs. In the pilot project in the southern Gaza Strip from 2018 to 2019, the real costs for waste collection, transportation, treatment, and final disposal operations

Figure 9. Centralized HCW management systems, service providers, and supervising authorities in Gaza Strip.

were measured and aggregated, and the cost per unit weight of infectious HCW was determined. In this way, the HCW management systems in Gaza have basically been established.

HCW management is still not fully established in the West Bank area of Palestine. An international cooperation project supported by Japan (JICA) is currently conducting assessment surveys and planning, and in 2022, three centralized treatment facilities will be installed, staff training courses will be organized, and HCW management services will be started to the entire area.

More than 10-year process corresponds well with the 10-step diagnostic process described earlier (**Figure 8**), demonstrating that Palestine has gradually improved its capacity for HCW management.

In Gaza Strip, the 1st step was the enacting bylaw on HCW management in 2012, and then the 2nd step of the survey on the present state of HCW was conducted from 2010 (Master Plan) to 2016 (Gaza Local Plan). The 3rd step of the local HCW management plan and 4th step of the staff training program was conducted from 2017 to 2019. Under given conditions, public (JSCs) operating centralized treatment system was introduced as 5th and 6th steps in 2018, and autoclave and microwave facilities were equipped from 2018 (autoclave) to 2021 (microwave) as the 9th to 10th steps.

On the West Bank, it is still in the 2nd and 3rd steps, but in 2022, the treatment facility will be equipped, training will be conducted, HCW management services will be started, and 10 steps are expected to be achieved.

7. Conclusions

Proper management of HCW in developing countries is an urgent issue. It is important not only for public health and environmental protection in developing countries, but also for controlling infections throughout the world, in the time of pandemics.

According to statistical cross-country analysis, the amount of HCW generation shows a moderate positive power correlation with economic growth (GDP/capita). It also shows a positive power correlation with the amount of MSW generated. This indicates that economic growth will lead to an increase in MSW as well as a rapid increase in the amount of HCW generated. On the other hand, in countries with a high level of service coverage of MSW collection of 83% or more, a sudden increase in the amount of HCW are observed. This is considered to indicate that the recognition of HCW generation and the necessity of its proper management are formed in the public administration of HCW issues when the MSW management service reaches a certain stage.

It is necessary to establish an effective HCW management system and strengthen its implementation capacity, especially in developing countries. When conducting international technical assistance for them to support the establishment of the HCW management system and capacity development, it is required to set the targets for technical assistance through conducting an assessment survey, analyzing the problems, evaluating risks, supporting to formulate HCW management plans, and provision of equipment.

A flow chart to the 10-step diagnosis of HCW management is proposed to identify issues and challenges of HCW management in developing countries. The results can be used for setting the targets of technical assistance and cooperation for enhancing HCW management. More than 10-year process of technical assistance

and cooperation program in Gaza Strip, Palestine corresponds well with the 10-step diagnostic process, demonstrating that Palestine has gradually improved its capacity for HCW management.

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