*Muhammed Alamgir, S.M. Tariqul Islam, Mahmudul Hasan, N.J. Pollen (Eds.)*
*ISBN: 978-984-35-7297-4*

*Full Paper of the WasteSafe 2025 – 9th International Conference on*
*Sustainable Solutions for Waste Management in Developing Countries*
*22-23 February 2025, Dhaka, Bangladesh*

# MEDICAL WASTE MANAGEMENT AS A PILLAR FOR SAFE URBAN DEVELOPMENT: CASE STUDIES FROM SATKHIRA, KHULNA, AND JASHORE, BANGLADESH

**Shantonu Das[1], Tahmid Rahman[2], Nibir Adhikary[3], Arpon Roy[4] and Aditi Chakma[5]**

*[1,2,3,4,5]Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Bangladesh*

## ABSTRACT

*Medical waste management (MWM) is crucial for healthcare, involving the proper handling, treatment, and disposal of waste from healthcare facilities. This includes contaminated items like needles and bandages, which pose health risks. In Satkhira, 3.5 tons/day of medical waste is collected, 3 tons/day in Jashore, and 316.41 kg/day in Khulna. Most healthcare establishments dump their waste in municipal yards, lacking proper collection, segregation, and disposal methods. Developed countries now favor treating only infectious waste using environmentally friendly methods like autoclaving over incineration. Substituting medical equipment to avoid dioxin or mercury release and avoiding PVCs can protect biodiversity. Government regulations on medical waste disposal are essential for urban development and achieving the goal of becoming a developed nation. There is a significant research gap in MWM, highlighting the need for more studies to improve management practices.*

## INTRODUCTION

Any form of waste considers it as a contagious or non-contagious is burden to the environment and society. The authority preserving human health and relations, World Health Organization (WHO) characterizes medical waste as any refuse or by-products generated by hospitals and healthcare institutions related to the diagnosis, treatment, or immunization of humans and animals. This includes items such as used syringes, needles, sharp metal objects, dressings, blood specimens, anatomical parts, pharmaceuticals, chemicals, radioactive substances, and medical devices (Prem Ananth et al., 2010). Poor management of medical waste presents serious dangers to both public health and the environment. The problems that stem from insufficient waste handling include injuries caused by sharp objects, the spread of diseases in humans due to infectious agents, and environmental pollution from harmful and toxic materials (Ghanimeh et al., 2019). As the foremost producer of medical waste in the world, the United States is responsible for the generation of over 3.5 million tonnes of medical waste each year. The average cost associated with the disposal of this waste amounts to $790 per tonne, highlighting the significant financial implications of managing medical waste effectively (B.-K. Lee et al., 2004). The creation of a separate category for medical waste in the municipal waste management system dates back to the late 1970s, when items like syringes and bandages started showing up along the eastern coast of the United States. This led to a public outcry, which in turn resulted in the establishment of the US Medical Waste Tracking Act (MWTA), officially put into effect on November 1, 1988 (Akter, 2000). The initial measures implemented to address this issue involved the installation of 6,500 small, unregulated medical waste incinerators at healthcare facilities. It became apparent that these small incinerators not only generated greater pollution than the medical waste itself but also encouraged the production of increasing amounts of waste, a significant portion of which consisted of disposable plastics. In developing countries like Bangladesh there is no proper collection, segregation and disposal methods can be discovered in any of the medical facilities. As the literacy rate in developing countries is low, like in Bangladesh it's as low as 76.36% [Macrotrends, 2021]. The possibility of proper disposal remains uncertain. This review examines the waste collection, segregation, disposal, and recycling methods in areas like Satkhira, Khulna, and Jashore, and compares them to developed regions such as the US, Canada, and Germany. The waste management process remains significantly underdeveloped in parts of Bangladesh. Additional studies indicate the need for proper waste disposal methods and the role the government should play in addressing waste-related issues.

## MEDICAL WASTE CLASSIFICATION

The WHO estimates that around 15 to 20% of medical waste is actually hazardous because of its potential to be infectious, toxic, and in some cases, radioactive (Tsai, 2021). Bangladesh currently does not have a hygienic or standardized modern system for disposal of medical waste. Medical waste management is one of the most important parts of health, but it appears the Ministry of Health or the Department of Health is not concerned about it; the 2008 legislation on safe disposal of medical waste is very weak and not up-to-date (Shanta, 2023). Medical waste refers to waste that is considered infectious, toxic, or otherwise hazardous, as illustrated in Figure 1.

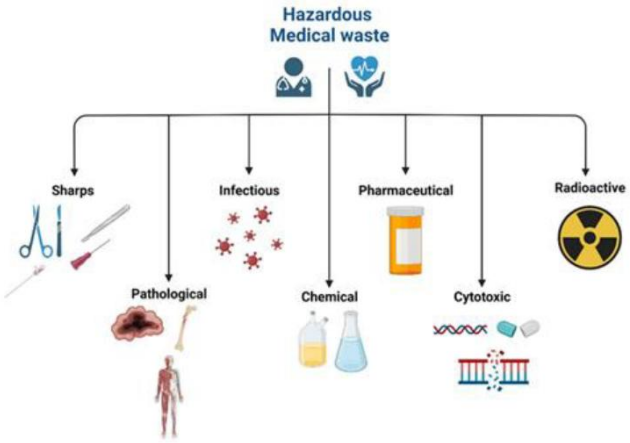


Figure 1 Distinct types of hazardous medical waste

## MEDICAL WASTE MANAGEMENT STEPS

Medical waste management is a sequence of actions that handle MW from the time of generation until it can be securely disposed of. Figure 2 shows the processes in the MW management process. The efficacy of the waste management process is proved by reducing waste disposal and achieving a circular economy, in which the resources used inside the medical system are maximized, resulting in nearly nil waste.

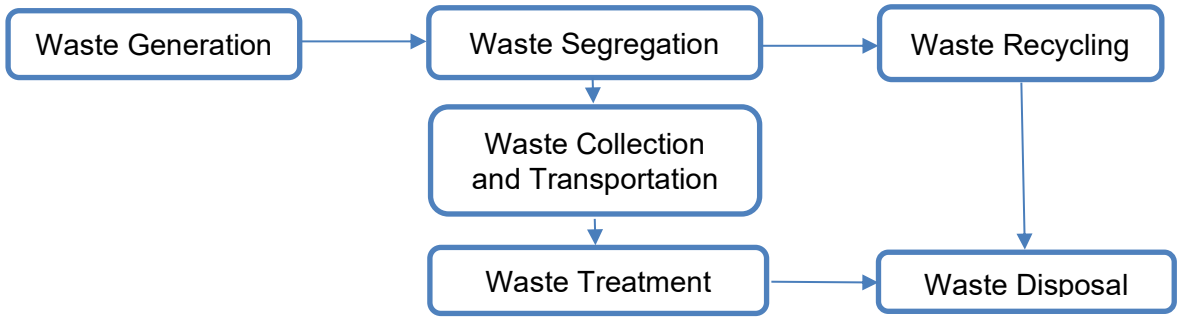


Figure 2 Flow Diagram for Medical Waste Management

## MEDICAL WASTE GENERATION

The volume of medical waste produced by various medical institutions is a critical issue that has spurred considerable investigation in this area. The quantity and composition of medical waste are influenced by a multitude of factors (Windfeld & Brooks, 2015). To limit trash accumulation, medical institutions can reduce their waste generation. Minimization can be tackled from a variety of perspectives, including waste reduction at the source, recycling, and stock management. Reusing goods that are safe for users, such as washable tablecloths, dinnerware, and refill containers for cleaning supplies, can help reduce waste at the source. Recycling contributes to waste minimization through the processing of plastics and metals, as well as the composting of organic food waste. Finally, stock management will help set up an organized system of the medications inventory to minimize duplication and procurement of needless products that may expire, hence eliminating potential waste.

## MEDICAL WASTE SEGREGATION

Waste is being segregated by color coding method in most of the places. But there is no universal color-

ISBN: 978-984-35-7297-4

coding method to separate the waste. So, the process varies from place to place. As it is not universal, the process is not maintained properly while collecting waste. Often misplacement of the waste has been seen. The priority should be separating infectious and non-infectious waste. Then sharp objects should be separated from them. This should be done at the point of disposal, not at the point of treatment or recycling. Social awareness is the key to this issue helping to segregate efficiently. In the event of an error during waste segregation, it is crucial not to rectify it in order to avoid contaminating the other waste.

## MEDICAL WASTE COLLECTION AND TRANSPORTATION

Waste is collected from healthcare facilities and disposed on-site or off-site based on the facility. The waste should be collected not more than once per day. If collected more than once, it can accumulate and create pollution to the surroundings. Workers for collecting waste should be equipped with proper protective equipment to collect and sort the waste out. In most countries waste is collected but disposed illegally in dumping sites. Rather it should be collected and taken to the treatment facility. It happens due to third party dumping institution. They illegally dump MW for extra income. In developing countries, waste is collected and sold in the illegal market without any sterilization. They usually resell sharps for only profit, which should not be reused at any case with or without sterilization.

## MEDICAL WASTE TREATMENT

Before MW is disposed of, medical waste treatment is done to reduce the harmful consequences of this kind of waste on the surroundings and health. If proper treatment is not being done it can cause:

- Bacterial and fungal Infection,
- Infiltration into the soil and the underlying aquifers,
- Life risk to the habitats,
- Bioaccumulation.

There are several methods to treat MW. Mostly the hazardous waste is separated and treated accordingly. The description of these methods are shown below:

## INCINERATION

Incineration is the process of combusting waste at high temperatures. Usually it is between 800–1200 °C. It kills the pathogens in the waste and organic compounds harmful for human health. Also, it is a very primitive process and widely used. It alters the chemical compounds in the waste making it environmentally safe. This process produces fly ash, dioxin, mercury and furans. Dioxins are carcinogenic and they don't decompose easily. If combustion is done fully then there is no possibility of dioxin emission. The dioxins emitted can also be treated using selective non-catalytic reduction (SNCR) (Wielgosiński et al., 2020). Mercury impacts around 3-9% from incineration of MW around the world. Fly ash is the leftover solid material that comes from the burning process. It can be reused and recycled in the cement industry. It is seen that approximately 3 Kg of $CO_2$ is emitted from burning 1 Kg of Medical Waste (Wyssusek et al., 2019). This process is prohibited due to its impact on Greenhouse effect causing significant pollution.

## AUTOCLAVE DISINFECTION

This process slightly reduces the effects of Incineration by adding steam to temperature. Mainly the effect of steam and pressure is higher than temperature. The operational parameters consist of a duration of 60 minutes at a temperature of 121 °C and a pressure of 1 bar, succeeded by a subsequent cycle lasting 60 minutes at 134 °C to guarantee thorough disinfection of waste materials (Attrah et al., 2022). Though the effect of incineration is reduced by autoclave disinfection, it is not as effective as incineration. The pathogens are not removed properly as the temperature is not enough. Pretreatment is required in this case. Mercury and Carbon emissions are very low in this disinfection process.

## MICROWAVE DISINFECTION

Disinfection of MW can also be done by microwave insertion. Usually, it uses low temp. and reverse polymerization techniques to reduce the microorganisms in the waste. Disinfection processes are carried out at temperatures ranging from 177 to 540 °C, employing electromagnetic waves that have wavelengths between 1 mm and 1 m, with frequencies spanning from 300 to 3000 MHz (Giakoumakis et al., 2021). Generally, it is not recommended as it has high operational cost and unavailability.

## CHEMICAL DISINFECTION

Chemicals are sometimes used for disinfecting waste. It is primarily utilized for managing liquid infectious waste such as blood, urine, feces, or wastewater from hospitals. Widely used chemical

disinfectants consist of a 1% bleach solution or a diluted active chlorine solution at a concentration of 0.5%(C. Lee et al., 1991). It is apparently a faster way to disinfect MW but creates liquid and solid residue. The selection of treatment must be done carefully so to reduce Carbon and other harmful gas emissions effectively. Also, according to the economy, treatment should be selected. If countries having unstable economy use high maintenance disinfection it will not sustain in future. Also, if the waste is not properly disinfected it will create serious health concerns. So, the govt. should be careful selecting proper disinfection methods.

## MEDICAL WASTE RECYCLING

Most of the medical waste generated from MW facilities is non-hazardous. So, if they're disposed of to the landfills it will create unnecessary waste and become harmful to the habitats around them. Plastics, Batteries, Paper, Glass, Metal type waste can be recycled to other industries. Food and organic waste can be repurposed for composting, enhancing soil quality in agricultural applications. In incineration heat produced in substantial amounts can be used otherwise for heating water for centralized water heating system. The dioxins emitted can also be mitigated through the implementation of selective non-catalytic reduction (SNCR) (Wielgosiński et al., 2020). Mercury impacts around 3-9% of MW waste.

## MEDICAL WASTE DISPOSAL

Waste that cannot be recycled should be disposed of to the nearest landfills. But disposing of MW directly to the environment is not encouraged as it has negative impact. It contaminates the soil below and emits flue gas to the surroundings. Normal practices are to sterilize the waste first, then disposed of. It will create less impact and ensure a circular economy for society. Waste should be disposed remembering following measures(Attrah et al., 2022):

- Quick covering of waste,
- Burying it beneath existing municipal waste for at least three months,
- Waterproof base,
- At least 2 meters above the water table,
- Prohibition on chemical disposal.

## STUDY AREAS

As illustrated in Figure 3, there are three study areas according to our research. They are Satkhira, Khulna and Jashore accordingly. Jashore District encompasses 2606.94 $km^2$. Jashore District has 798,032 households and a population of 3,076,144 with an average of 3.79 people per household. Among the population, 510,121 (16.58%) inhabitants are under 10 years of age. The population density is 1,180 people per $km^2$ (2022 Census of Bangladesh). Conversely, Khulna ranks as the third largest city in Bangladesh, following Dhaka and Chittagong, and spans an area of 4,394.46 square kilometers (1,696.71 square miles). The Khulna City Corporation comprises 188,579 households and has a total population of 719,557, with 14.97% of individuals being under the age of 10. Furthermore, Satkhira District encompasses 3,817 square kilometers (1,474 square miles) and contains 566,752 households, resulting in a population of 2,196,582, with an average household size of 3.85 individuals. Within this district, there are 360,699 residents, representing 16.42%, who are aged 10 years or younger. The population density is 575 people per $km^2$. (2022 Census of Bangladesh)

With these study areas, the comparative analysis has been done with other developed areas like USA, China, Germany and EU. Also, the legislation of those areas was taken into consideration.

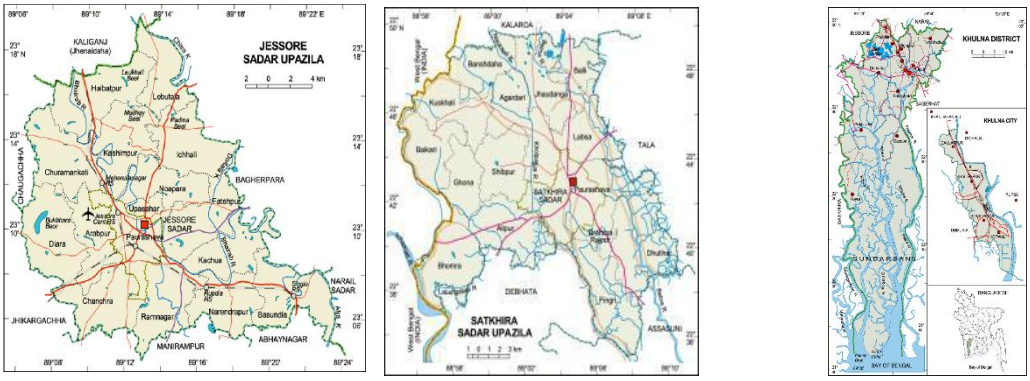


Figure 3 The location of the study area.

ISBN: 978-984-35-7297-4

## LEGISLATIONS

At present, Bangladesh does not possess a standardized and modernized system for the disposal and treatment of medical waste (MW). The management of medical waste disposal is conducted by the City Corporation throughout the country, which conflicts with the Bangladesh Medical Waste Management and Processing Rules established in 2008. These regulations stipulate the creation of an authority within each department, comprising three members led by the divisional director of the health department. According to these guidelines, institutions must obtain licenses to ensure that waste is disposed of in an environmentally safe manner. Prior to collection, transportation, and disposal, waste must be segregated to avoid the mixing of hazardous and non-hazardous materials. Furthermore, it is mandated that untreated waste should not be stored for more than 48 hours. Rule 5 specifies three categories of licenses: (1) wrapping and storing, (2) collection and transportation, and (3) refining and removal to a third party for disposal. Rule 7 necessitates that medical waste be kept distinct from general refuse during the processes of collection, wrapping, storing, and transportation. In 2018, the government collaborated with the private organization Prism Bangladesh Foundation to address hospital waste disposal. Prism is currently tasked with managing medical waste disposal in several major cities, including Dhaka (Shanta, 2023).

## CASE STUDIES

### Satkhira

A research conducted in Satkhira Sadar found that medical facilities produce around 3.5 tons of medical waste every day. On a per-bed basis, waste generation averages 1.33 kilograms per day, accounting for around 5.5% of total garbage. The waste comprises a range of materials(Saha et al., 2023), including:

- Pathological waste (tissues, organs).
- Infectious waste (contaminated gloves, bandages).
- Pharmaceutical waste (expired medicines).
- Plastic waste (disposable syringes, medical packaging).

Satkhira Pourashava manages the medical waste collection in Satkhira town, which takes place twice daily. Medical waste collection in Satkhira town takes place largely in the morning, according to 62% of respondents. An additional 21% claimed that collection occurs during midday, while 17% stated that collection occurs at random without a schedule set (Saha et al., 2023). Waste is originally separated at the source into color-coded containers supplied to healthcare facilities. The categories include:

Green: General waste such as food and packaging materials.
Red: Infected plastics, including syringes and tubing.
Yellow: Pathological waste, such as biological materials.
Blue: Metal and glassware.

Despite these efforts to separate waste, municipal and medical waste are commonly mixed during collection because they are often transported in the same vehicles. The lack of dedicated medical waste vans jeopardizes the effectiveness of the segregation system. For transporting these wastes often open vehicles are used which can cause contamination of waste and posing health hazards to health workers and surroundings. Once transported, the waste is dumped at an open spot near Binerpota, about 6 kilometers from Satkhira town. This site lacks sanitary landfill infrastructure, resulting in various environmental hazards. Waste leachate contaminates water, land, and air. The lack of sufficient waste treatment infrastructure increases health hazards for the local people. Illegal dumping of medical waste in Satkhira town causes substantial environmental degradation. The practice is frequently seen as a result of a lack of adequate cleaning staff, particularly at government hospitals where temporary cleaners are hired on an irregular basis. This leads to poor waste management and disposal. This improper disposal results in water pollution, including reduced dissolved oxygen levels and altered pH and biochemical oxygen demand (BOD). It also contaminates soil and air, creating health hazards for the surrounding communities. The lack of systematic waste management exacerbates these risks, making illegal dumping a critical environmental issue in the region. The medical waste recycling activities are minor and primarily focused on specific waste categories, like as placentas, which are segregated for reuse. There is no comprehensive mechanism in place to recycle segmented waste streams such as plastics and metals (Rahman et al., 2018). This absence of infrastructure reveals a critical gap in the waste management process, emphasizing the necessity to create a systematic and environmentally sound recycling framework in order to reduce trash volume and health concerns.

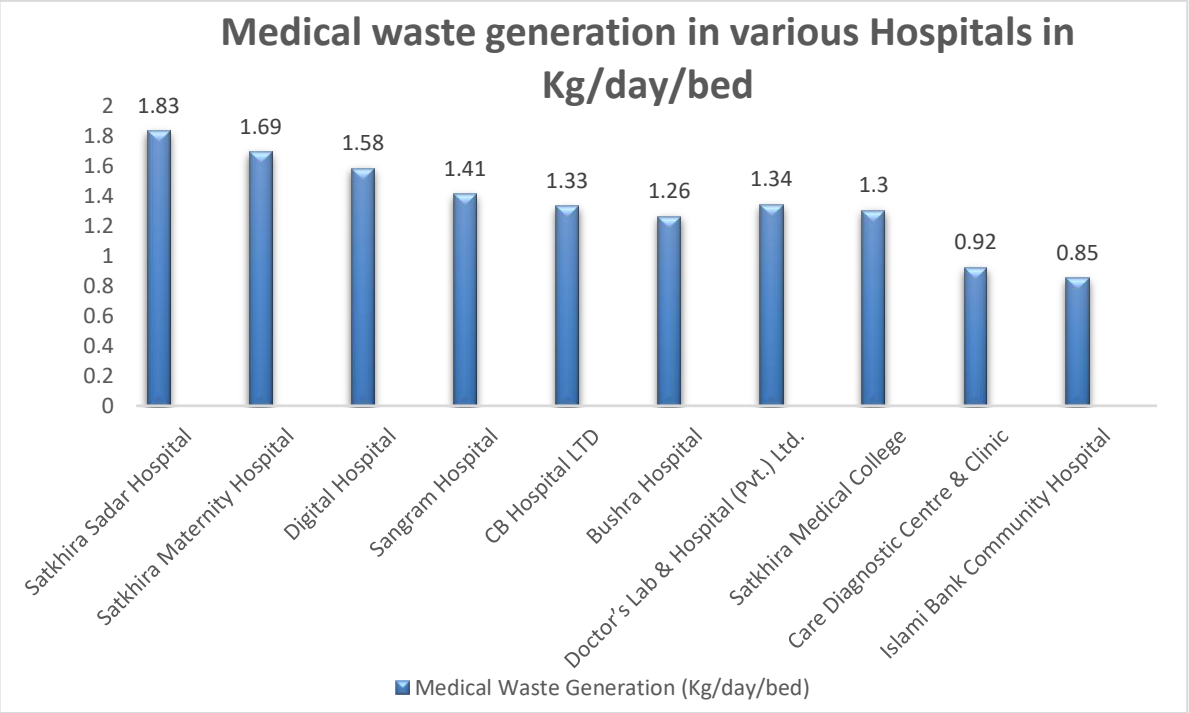


Figure 4 Medical Waste generation at different Medical Facilities in Satkhira

## Khulna

A crucial component of medical waste management is medical waste segregation, which guarantees the appropriate and safe disposal of different waste kinds. The efficiency of segregation procedures differs between Khulna's healthcare facilities. The state of medical waste segregation in government, private, and clinic settings is shown in Table 1 (Islam et al., 2023). It shows the proportion of institutions that use full segregation, moderate segregation, and no segregation. The information sheds light on the present obstacles and prospects for enhancing waste management procedures in the medical field.

Table 1 Segregation of Medical Wastes

| HCE Type | Proper Segregation (%) | Partial Segregation (%) | No Segregation (%) |
|---|---|---|---|
| Private Hospitals | 45% | 35% | 20% |
| Government Hospitals | 25% | 30% | 45% |
| Clinics | 35% | 40% | 25% |

Reducing hazards to the environment and human health requires efficient waste separation at different phases of the healthcare waste management process. The percentage of various waste categories that are separated at different phases, such as generation, within wards, and during collection time, in Khulna's healthcare facilities (HCEs) is shown in Table 2 (Islam et al., 2023). Additionally, it shows the percentage of waste that is not separated at all. The information shows where waste segregation should be strengthened to guarantee better disposal and management procedures, especially for plastic, sharp, and contagious wastes.

ISBN: 978-984-35-7297-4

Table 2 Percentage of various Waste Segregated during Collection

| Position of Waste Segregation by HCEs | At Time of Generation | In Ward | Collection Time | Do Not Segregate |
|---|---|---|---|---|
| **Sharp** | 28.12% | 22.58% | - | 49.30% |
| **Infectious** | 15.82% | 9.14% | 22.64% | 52.40% |
| **Plastic** | 30.25% | 33.01% | - | 36.74% |

The majority of medical waste in Khulna's healthcare facilities (HCEs) is temporarily kept in bins or color-coded containers (CCCs) outside the hospital. But frequently, these containers are utilized without being properly disinfected. Instances of unethical behavior have been reported, including employees reselling used syringes and other medical waste. The Batiaghata dumping site is one example of how waste is often disposed of in open areas or next to waterways, contaminating the land and rivers. Waste can occasionally be left on hospital grounds for long stretches of time without being properly disposed of or treated. Medical waste collection is handled by the Khulna City Corporation (KCC), which mostly uses small to medium-sized vehicles with open roofs, increasing the possibility of contamination and spills. 62% of medical waste is collected in the morning, 21% in the middle of the day, and 17% at random (Islam et al., 2023).

Only Gazi Medical College Hospital (GMCH**)** used a system of five color-coded containers for waste segregation, which is shown in the Table 3 and Figure 5 (Moniruzzaman et al., 2018):

Table 3 Uses of Color-Coded Containers

| Waste Category | Color of Container |
|---|---|
| General Waste (Recyclable) | Green |
| Sharp Waste | Red |
| General Waste (Non-Recyclable) | Black |
| Infectious Waste | Yellow |
| Liquid Waste (Blood and Body Fluids) | Blue |

Figure 5 Color coded containers (GMCH)

The remaining hospitals stored waste in two or three containers without proper separation, leading to the mixing of different types of waste.

## Jashore

A research study carried out in 2018 in Jashore city indicated that the quantity of clinical waste was measured at 0.79 tons per day. The town of Jashore generates a total of 54 tons of solid waste, which includes 3 tons of medical waste (encompassing both domestic and clinical waste), representing approximately 5.56% of the overall solid waste generation (Som & Hossain, 2018).

Table 4 Waste generation rate per patient in Jashore

| HCEs | No of beds | No of in patients | No of outpatient | Total generated waste (kg) | Waste generation rate (kg/patient/day) |
|---|---|---|---|---|---|
| Public | 300 | 400 | 800 | 610 | 0.51 |
| Private hospital / Clinic & Diagnostic | 650 | 370 | 1090 | 810 | 0.55 |
| Pathology | 0 | 0 | 250 | 90 | 0.36 |

Table 4 result emphasize waste produced by private hospital & clinic produces most amount of waste nearly about 0.55 kg/patient/day because of excess number of outpatients. On average medical waste of 0.98kg/day/bed consists of 10.89% infectious, 15.82% plastic, 3.46% sharp, 3.87% pathological, 60.94% domestic and 5.52% pharmaceutical waste from HCE of Jashore town. Like Satkhira & Khulna's health care facilities Jashore health care facilities also generate general waste without any hazardous effect, increasing overall volume of waste produced. According to a research conducted on 2013 waste generation rates of the pathology or diagnostic center of the public and private organization were 0.133, 0.086, and 0.168 kg/test/day respectively (Rahman et al., 2018).

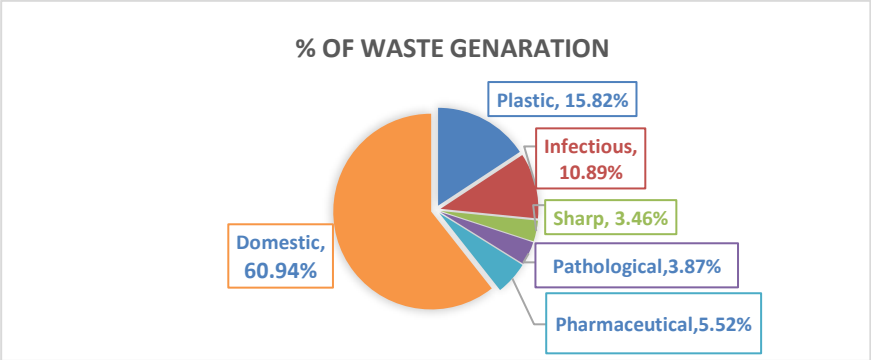


Figure 6 Type of medical waste in Jashore

The research findings show that only 28% HCEs of Jashore use color coded containers (CCCs) for separation of numerous kinds of waste while about 32% of hospitals don't have any CCCs. The present situation of the use of CCCs is shown in Figure 7. In Jashore over 50% of hospitals & clinics had color coded containers but insufficient knowledge & improper handling of medical waste both hazardous & non-hazardous got mixed with each other in container from beginning. More horrible picture found at the time of generation of waste. Most of the cleaner, sisters, ward boys use medical equipment without any safety protection, after use maximum time they took those in tray which results mixing of medical waste such as blade, syringes, needles, mask, waste containing chemotherapy drugs, paper, food waste, and office supplies. Around 49% of respondents dispose the infectious waste under bed & 44% respondents didn't dispose of the infectious waste in the bowl under the bed (Rahman et al., 2018). It was also found that the maximum of the respondents did not destroy the needles of the syringe immediately after being used. They disposed of it in the bowl under the patient bed directly. This mixing causes non contaminated waste to contaminated waste further making the environmental, human & animal health adverse.

ISBN: 978-984-35-7297-4

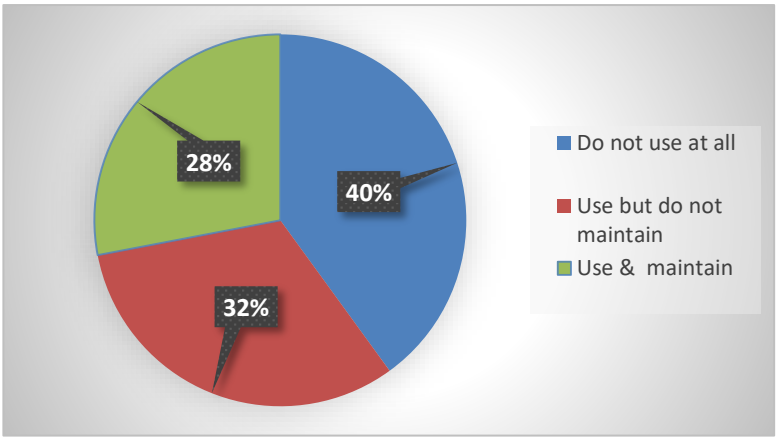


Figure 7 Percentage of using Color-coded containers (CCCs) in Jashore

In all HCEs studied, most types of waste were kept in the CCCs or in temporary storage or bin outside the hospital premises without any disinfection. It has also been initiated for some medical workers to earn some money by selling used syringes and additional medical waste. Some of the waste is dumped into the nearest Daratana river, constantly polluting the river water. Occasionally, waste was found to be dumped on the hospital premises for a long period of time without any disposal or disinfection process. Jashore Pourashava, handled medical waste by utilizing small to medium-sized garbage collection and delivery vans with an open top. In all three locations, the majority of medical waste (about 60%) was collected early in the morning. Furthermore, around 17% of garbage was picked up at random during midday periods (Som & Hossain, 2018).

## MANAGEMENT OF MW IN OTHER CITIES

### USA

Surgical procedures in operating rooms generate approximately 20-30% of healthcare industry waste in the United States, accounting for more than 1.8 billion kg. The majority of waste consists of disposable (one-time use) materials, equipment, and sterilized packaging. For example, the trash generated by a single normal operation exceeds that of a family of four in a week. Medical Waste is strictly regulated in United States. Medical Waste Tracking Act (MWTA) was developed in 1988. Some individuals contend that the development of regulations surrounding medical waste management was prompted by media coverage in the 1980s, which highlighted the frequent discovery of improperly discarded medical waste on beaches, leading to significant public outcry. As the leading nation in medical waste production, the United States generates more than 3.5 million tons of medical waste each year, with an average disposal cost of 790 USD per ton. Furthermore, healthcare facilities in the United States produce approximately 10.7 kg of waste per bed per day, which includes 2.79 kg of infectious waste per bed per day (C. C. Lee & Huffman, 1996).

Table 5 Legislations developed across USA

| Act | Year Enacted | Key Provisions |
|---|---|---|
| **Medical Waste Tracking Act (MWTA)** | 1988 | Established a cradle-to-grave tracking system, management standards for segregation, packaging, labeling, and storage |
| **Resource Conservation and Recovery Act (RCRA)** | 1976 | Provides guidelines for the management of hazardous and non-hazardous waste, including medical waste |
| **Solid Waste Disposal Act** | 1965 | Laid the foundation for federal waste management policies, later amended to include medical waste |

A group of engineers from the Idaho National Laboratory in Idaho Falls, Idaho, USA, have created a new, patented technology. It contributes to improved MW management and therapy. In order to lessen the quantity of hazardous MW that needs to be treated on-site, Med-shred, Inc. (Houston, TX, USA) has created a mobile shredding and chemical disinfection system. The machine has the ability to shred the MW into disposable municipal waste, which is subsequently soaked in a disinfecting solution and wetted with the disinfectant spray. The trash must then be moved to a drying chamber where hot off-gas will be used to dry it (Shareefdeen, 2012).

There are four types of disposal systems in USA. Over 70% of medical waste is disposed of through incineration as utilizing controlled air, multiple chamber air, and rotary kiln models, as estimated by the Environmental Protection Agency (EPA). For other waste, steam sterilization or autoclaving is necessary before landfill disposal. This process involves placing bags of infectious medical waste in a chamber, steaming them at temperatures between 120 and 135 °C for 30–50 minutes, and ensuring the waste is sterile and safe for landfill disposal. A separate study revealed that 49-60% of healthcare waste is incinerated, 20-37% is treated through autoclaving, and 4-5% is managed using alternative technologies. Furthermore, following the amendments to the Clean Air Act (CAA) in November 1990, the criteria for medical waste incineration became more stringent. These amendments set forth emission standards and restrictions for various pollutants, including mercury, dioxins, and furans (Windfeld & Brooks, 2015).

## China

China, the most populous nation globally, was not as developed as it is today. Over time, the amount of hazardous waste produced has escalated significantly. In 2005, the official reported volume of industrial hazardous waste (IHW) was 11.62 million tons, with 0.6% being discharged without regulation. However, the actual investigative data indicated that the volume of IHW exceeded 25.00 million tons, suggesting that the definitions associated with the term "hazardous waste" and the relevant identification systems are inadequate.

At the end of 2003, China enacted numerous regulations to adequately manage medical waste (MW). In that year, the Ministry of Health introduced the Medical Waste Control Act 380, marking the first formal legislation aimed at addressing medical waste within the frameworks of waste management and infectious disease control. Act 380 characterizes medical waste as solid waste originating from medical treatment and laboratory facilities within hospitals that poses a threat to human health. Concurrently, the Ministry of Health and the State Environmental Protection Administration issued Regulation 287 concerning medical waste. This regulation categorizes waste produced by healthcare facilities into five distinct groups: Tissues, Infectious Waste, Sharp Objects, Chemical Waste, and Medicine Waste. Furthermore, in 2008, Standard HJ 421-2008 ("Standard of Packaging Bags, Containers, and Warning Symbols Specific to Medical Waste") was implemented (Yong et al., 2009).

The Chinese government invested 1.9 billion USD in the deployment of seven dioxin monitoring centers and one MW disposal center in each central metropolis at the end of year 2004. In addition, 13 comprehensive treatment and disposal centers were planned for each province as part of the strategy. By the end of 2004, 177 formal disposal facilities had been built for industrial hazardous waste. To ensure proper trash management, most provinces have created an industrial hazardous waste disposal center (Duan et al., 2008).

## Germany

In Germany, medical waste management is regulated by a sophisticated system that prioritizes occupational and statutory safety, guaranteeing adherence to legal requirements while taking into account the operational and financial requirements of healthcare facilities. The nation divides medical waste into hazardous and non-hazardous categories in accordance with the European Waste Catalogue (EWC). Tight precautions are taken while handling hazardous waste, such as sharp objects, infectious materials, and chemical waste. One such precaution is the use of containers that are both leak-proof and puncture-proof and are labeled with hazard symbols. In contrast, non-hazardous garbage is handled similarly to household waste, which lowers expenses and complexity.

Comprehensive laws like the "Closed Subsistence Cycle Waste Management Act," which requires the appropriate management, segregation, and disposal of medical waste, serve as the foundation for German policies (Hansen et al., 2014). Additional rules prevent pollution during incineration and guarantee the safe transportation of hazardous trash. To ensure accountability and adherence to safety procedures, hospitals and other healthcare facilities must designate individuals in charge of waste management.

With programs to recycle materials like fly ash from incinerators for use in building blocks and concrete mixtures, the nation is a leader in waste recycling. The use of contemporary incineration technology reduces the emissions of dangerous compounds such as furans and dioxins. The creation of environmentally friendly disposal techniques and the encouragement of a circular economy in the healthcare industry are more examples of Germany's emphasis on innovation.

Germany modified its waste management procedures during the COVID-19 pandemic to handle the increase in medical waste, especially personal protective equipment (PPE). Segregation, safe disposal, and contemporary incineration methods were given more importance, which lessened the negative effects of this abrupt increase in waste production on the environment and human health. Germany's dedication to effective and sustainable medical waste management that strikes a balance

ISBN: 978-984-35-7297-4

between environmental preservation and public health and safety is demonstrated by these measures.

## EU

In the European Union, the European Commission (EC) issues waste laws directives that member countries must incorporate into their national legislation. The European garbage Catalogue (EWC), established by EC Decision 2000/532/EC, classifies garbage, including medical waste, according to Chapter 18. This is in accordance with the 1994 EC Decision 94/904/EC, which lists 237 different forms of hazardous waste. While the Directory on Hazardous Waste requires uniformity, country definitions differ, complicating data comparisons. Stricter emission limitations for incineration implemented in 2000 have resulted in a trend toward non-incineration alternatives such as autoclave sterilization, however adoption is slower than in the United States (Windfeld & Brooks, 2015).

## Covid-19 and Medical Waste

Covid-19 outbreak burst in worldwide during 2020 but the cases were found 1st in Wuhan, China on 31st December, 2019. It is assumed that the widespread of this outbreak was associated with big seafood and live animals that were sold in Wuhan (Rupani et al., 2020). Lockdowns were initiated across the world in phases during this crisis. In China, the generation of MW rose by more than 24%, reaching a peak of over 6000 tons in 2020 amidst the COVID-19 pandemic. A subsequent study revealed that the volume of MW decreased by as much as 30% in medium to large cities during the COVID-19 outbreak in China. Conversely, the production of MW with a high plastic content increased by approximately 400% in Hubei province (Teymourian et al., 2021). The first incidence was observed in Bangladesh on March 8, 2020, and as of July 6, 2022, nearly 2 million confirmed cases have been registered, with roughly 29 thousand individuals dying. The MWG rate was increased from an average of 1.6-1.99 kg/bed/day to 3.4 kg/day. In April 2020 alone, 14,500 tons of MW were generated (Dihan et al., 2023). In comparison previously 200 tons of biological waste was produced regularly but during pandemic it was surged to 14,000 tons (Chowdhury et al., 2022). Because trash generated during the global epidemic was infectious the risk of contamination and illness propagation was quite severe. The waste generated during March 2020 to June 2022 in Bangladesh is shown below (Dihan et al., 2023):

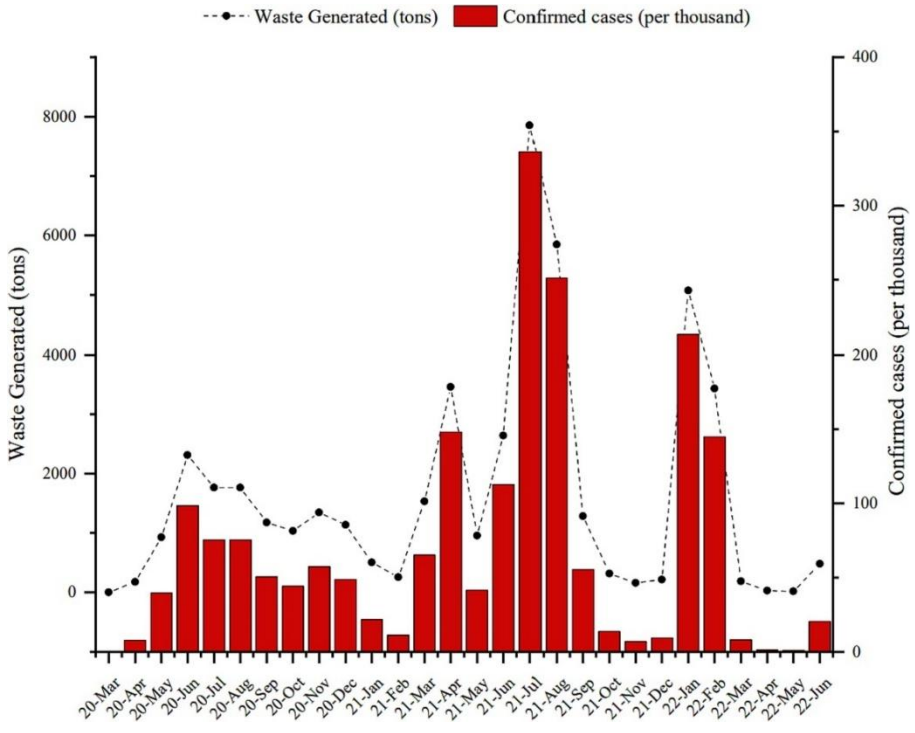


Figure 8 Medical Waste Generation from March 2020 to June 2022

So, we can say that as in Bangladesh the waste generation increased significantly it caused contamination of surrounding environment so conveniently. Also because of the low literacy rate in the country, the spread of disease was significantly higher than other developed countries. The death toll was also high as second highest in South Asia. The acknowledgement of the outbreak by the Govt. was also terribly slow, resulted in increased patient in Hospitals. Use of PPE was also not managed properly. During this time, people used masks and disposed them in the open. As there was no specific segregation process defined in the Act developed, people acted carelessly resulted in surge in death.

Still, after the outbreak people don't care about waste management. The main issue is the improper education system which does not include the basics of hygiene practices in rural level. Also, the tendency to not abide by the rules has also created this issue. Proper knowledge of Medical Waste Collection, Transportation and disposal should be given to the concerned people. The process for treatment of MW also should be selected efficiently according to the social structure and economy. According to the perspective of Bangladesh, mostly incineration is done which is more infectious to the environment. Other techniques such as autoclave disinfection, chemical disinfection, reverse polymerization and microwave disinfection can be used in this case. The technical operators should be selected carefully so that waste management is efficient. Moreover, strict laws and regulations of waste should be implemented, and proper knowledge of waste management should be distributed with prioritizing economic factor of the country.

## RESULT AND DISCUSSIONS

According to the study areas, the most common factors include the lack of proper knowledge for waste disposal. It is a concerning matter for developing country like Bangladesh. A country's total economy depends on its population. If the population is not involved, then there will be no economic surge as the country is growing substantially. Medical waste is a concerning matter, as it is a major part of waste generated among other solid and liquid wastes. It is not only hazardous but also infectious to the environment and human health. We can see the impact of medical waste during Covid-19. The waste generated was about 7000% of the waste generated before the outbreak happened. As lacking of waste management system, the patient rate was among the highest during Covid-19. The study areas show the improper collection, transportation, dumping and recycling. The most interesting part is that none of the municipalities have proper treatment facilities. There is contamination at every point from collection to disposal.

Table 6 Key Differences between Bangladesh and Developed Countries

| Aspect | Bangladesh (Khulna, Satkhira and Jashore) | USA | Germany | China | EU |
|---|---|---|---|---|---|
| **Regulations** | Limited enforcement of waste management laws (e.g., Bio-Medical Waste Rules 2008). | Comprehensive and strict (e.g., Medical Waste Tracking Act, RCRA). | Highly regulated under EU Waste Framework Directive and German Waste Management Act. | Increasing regulations, e.g., Law of Prevention and Control of Environmental Pollution. | Comprehensive frameworks under EU Waste Framework Directive and Basel Convention compliance. |
| **Infrastructure** | Insufficient waste treatment facilities; reliance on incineration. | Advanced infrastructure for segregation, sterilization, and non-incineration treatments. | State-of-the-art facilities for recycling, incineration, and advanced sterilization. | Rapidly developing but uneven access to modern facilities across regions. | Advanced technologies, with emphasis on circular economy and sustainable solutions. |
| **Segregation at Source** | Often inadequate; limited awareness among healthcare workers. | Strict enforcement with color-coded waste bins and labeling requirement | Comprehensive source segregation policies enforced nationwide. | Segregation improving but often inconsistent in rural areas. | Mandatory segregation with strict penalties for non-compliance. |

| | | | | | |
|---|---|---|---|---|---|
| | | s. | | | |
| **Technology Used** | Basic technologies like incineration dominate. | Sophisticated methods, including autoclaving, chemical treatment, and microwave sterilization. | Cutting-edge technologies like pyrolysis, plasma gasification, and advanced autoclaves. | Transitioning from basic incineration to innovative and eco-friendly methods. | Heavy investment in eco-friendly technologies like bioremediation and thermal treatment. |
| **Public Awareness** | Limited public and institutional awareness. | Extensive campaigns to educate healthcare workers and the public. | High awareness due to stringent policies and regular training. | Awareness campaigns are increasing, especially in urban areas. | Public education emphasized under environmental directives and policies. |
| **Environmental Impact** | Significant due to improper disposal and burning practices. | Low due to regulated disposal methods and environmentally friendly technologies. | Minimal impact is due to recycling emphasis and strict emissions control. | Varies regionally; better in developed cities but worse in rural areas. | Low due to circular waste policies and eco-friendly technologies. |
| **Recycling and Reuse** | Minimal; poorly developed recycling systems. | Recycling encouraged non-contaminated materials like plastics and metals. | Robust recycling systems for a wide range of medical and industrial materials. | Recycling infrastructure improving but still developing in some regions. | Strong focus on recycling and reuse to align with sustainability goals. |
| **Cost and Funding** | Limited government funding and high operational costs. | Significant investment from both public and private sectors. | Well-funded systems with a focus on efficiency and innovation. | Increased funding but still insufficient in rural areas. | High funding and subsidies to promote sustainable waste management practices. |

In developed countries there are strict regulations at every point of MWM. Due to the emission of greenhouse gas emissions, the use of dioxin and mercury in producing medical equipment has reduced due to strict laws. The use of PVCs in generating medical products has also been reduced. In fact, some countries in the EU have successfully removed the use of dioxin and mercury in their healthcare facilities. Proper treatment methods can be applied using the analysis of the social strata of the areas as the people care less about the environment than their own development. The comparative analysis is shown in table 6. The key differences between them are public awareness and waste disposal system. Proper research can help to mitigate these issues in compliance with government. A research suggested the following waste management system in Khulna (Moniruzzaman et al., 2018):

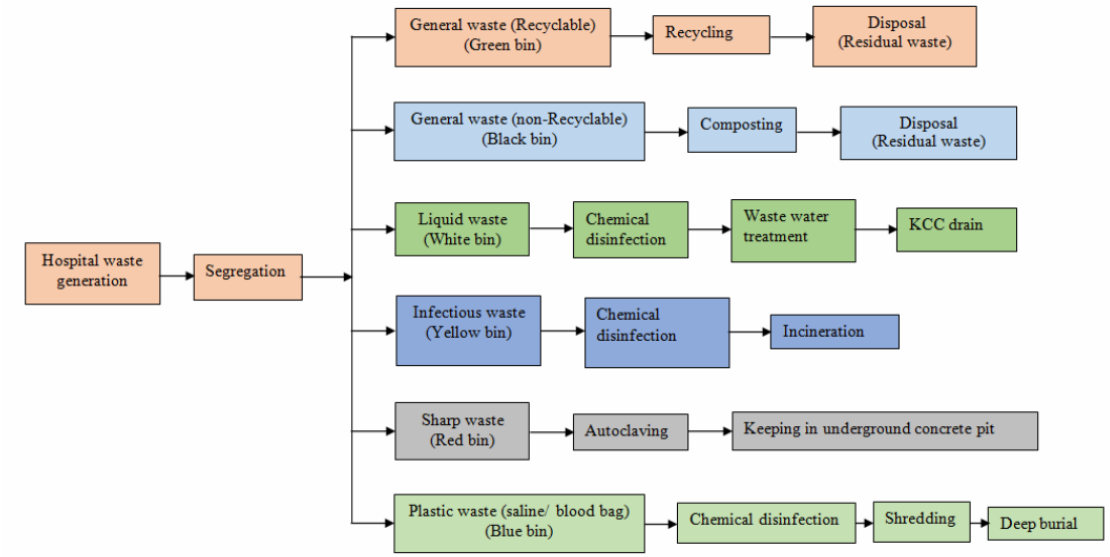


Figure 9 Proposed Hospital Waste Management system in KCC

## CONCLUSIONS

Medical waste contributes a significant amount of waste but is always neglected, considered as a similar kind of waste as municipal waste and treated accordingly. The main study areas reflect mixing of hazardous and non-hazardous medical waste with other waste which is the main concerning matter. Almost all the HCEs collect waste randomly during the day at different times. It affects the contamination of waste, which is evident. The sanitary landfill capacity should be more than what is already in place. Improper segregation at point of disposal in every point is also a big issue. Another big problem is seen that workers in the HCEs resell syringes, blades and other harmful waste which gets into humans and brings up new diseases. Transportation of waste is done carelessly in open vehicles and dumped causing seepage into the soil and pollution in nearby air. Treatment facilities is not incorporated at any point of waste management process. Though incineration is done with zero precautions and control causing environmental pollution. The law developed in 2008 states a body of three members under the supervision of the Divisional Director of the Health Department, the least of which should have been done. But not in single municipalities it is followed. In other developed nations, they have gone so far ahead that they patented technology which includes mobile shredding and chemical disinfection on-site. Govt. and political inclusion in every sector is a major concern which demotivates the nation's people to think about the hygiene practice. Proper knowledge about disposal of medical waste is not given. From child to age old person, don't even know the effect of dumping waste causing earth inhabitable. It is the least we can do for the sake of our environment that we develop the thinking which is waste can be recycled, reused and treated. Govt. should give proper incentives to healthcare workers and knowledge spread to all the people. If treatment facilities cannot be developed according to the social structure of the area then the use of hazardous medical products should be reduced. Dioxin, Mercury, Fly Ash, PVCs can be reduced in production like syringes, thermometers, dressings, bandages, sticking plasters, gloves etc. As a developing country we should remember that the circular economy should be maintained in all these processes. Treatment facilities can be developed by local producers covering incineration, autoclave disinfection and chemical disinfection in proportion to help the sustainability of development throughout the nation.

## RECOMMENDATIONS

Medical Waste Management is a long process as it takes into account so many steps. Developing countries like Bangladesh must adopt to this process as soon as possible to cope with rest of the world. Knowledge is the key to the waste management process. If people don't know the adverse effect medical waste creates, they won't be aware of its proper disposal and treatment. Protective measures should be implemented during collection of waste. Some recommendations about medical waste management are given below:

- Educate healthcare individuals on the necessity of categorizing medical waste at the point of

generation.

- The hospital authority should keep more color-coded container bins.
- Sufficient & suitable waste collection instruments should be kept.
- Establish a regular trash collection schedule to prevent excess accumulation.
- Specialized vehicles should be used for transporting medical waste to prevent contamination.
- Verification of occupational safety via education, training, and suitable personal protective equipment.
- Enforce law more strictly in collection of medical waste & its proper separation including proper transportation.
- Acquire a suitable new place to deposit medical waste separately.
- The government should provide incentives for new research and outcomes about medical waste treatment and management.
- Political awareness should be increased otherwise the dream of developed nation will not be fulfilled.

## REFERENCES

Akter, N. (2000). Medical waste management: A review. *Research Reports (1999): Health Studies*, *XXVII*, 370–394.

Attrah, M., Elmanadely, A., Akter, D., & Rene, E. R. (2022). A Review on Medical Waste Management: Treatment, Recycling, and Disposal Options. *Environments*, *9*(11), 146. https://doi.org/10.3390/environments9110146

Chowdhury, T., Chowdhury, H., Rahman, M. S., Hossain, N., Ahmed, A., & Sait, S. M. (2022). Estimation of the healthcare waste generation during COVID-19 pandemic in Bangladesh. *Science of The Total Environment*, *811*, 152295. https://doi.org/10.1016/j.scitotenv.2021.152295

Dihan, M. R., Abu Nayeem, S. M., Roy, H., Islam, Md. S., Islam, A., Alsukaibi, A. K. D., & Awual, Md. R. (2023). Healthcare waste in Bangladesh: Current status, the impact of Covid-19 and sustainable management with life cycle and circular economy framework. *Science of The Total Environment*, *871*, 162083. https://doi.org/10.1016/j.scitotenv.2023.162083

Duan, H., Huang, Q., Wang, Q., Zhou, B., & Li, J. (2008). Hazardous waste generation and management in China: A review. *Journal of Hazardous Materials*, *158*(2–3), 221–227. https://doi.org/10.1016/j.jhazmat.2008.01.106

Ghanimeh, S., Gómez-Sanabria, A., Tsydenova, N., Štrbová, K., Iossifidou, M., & Kumar, A. (2019). Two-Level Comparison of Waste Management Systems in Low-, Middle-, and High-Income Cities. *Environmental Engineering Science*, *36*(10), 1281–1295. https://doi.org/10.1089/ees.2019.0047

Giakoumakis, G., Politi, D., & Sidiras, D. (2021). Medical Waste Treatment Technologies for Energy, Fuels, and Materials Production: A Review. *Energies*, *14*(23), 8065. https://doi.org/10.3390/en14238065

Hansen, D., Mikloweit, U., Ross, B., & Popp, W. (2014). Healthcare waste management in Germany. *International Journal of Infection Control*, *10*(1). https://doi.org/10.3396/IJIC.v10i1.006.14

Islam, Md. S., Asadujjaman, M., & Rahman, Md. S. (2023, February 25). *HOSPITAL AND CLINICAL WASTE MANAGEMENT SYSTEM IN KHULNA CITY*. Waste Safe 2023 – 8th International Conference on Integrated Solid Waste and Faecal Sludge Management, Khulna, Bangladesh.

Lee, B.-K., Ellenbecker, M. J., & Moure-Ersaso, R. (2004). Alternatives for treatment and disposal cost reduction of regulated medical wastes. *Waste Management*, *24*(2), 143–151. https://doi.org/10.1016/j.wasman.2003.10.008

Lee, C. C., & Huffman, G. L. (1996). Medical waste management/incineration. *Journal of Hazardous Materials*, *48*(1–3), 1–30. https://doi.org/10.1016/0304-3894(95)00153-0

Lee, C., Huffman, G., & Nalesnik, R. (1991). Medical waste management. *Environmental Science & Technology*, *25*(3), 360–363. https://doi.org/10.1021/es00015a607

Moniruzzaman, S. M., Islam, S. I., Hasan, N., & Apu, I. K. (2018). *Study on hospital waste management in six selected hospitals in Khulna city*.

Prem Ananth, A., Prashanthini, V., & Visvanathan, C. (2010). Healthcare waste management in Asia. *Waste Management*, *30*(1), 154–161. https://doi.org/10.1016/j.wasman.2009.07.018

Rahman, M., Islam, S., Argha, D. B. P., & Haque, M. (2018). *PRESENT SCENARIO OF MUNICIPAL SOLID WASTE MANAGEMENT IN SATKHIRA MUNICIPALITY*.

Rupani, P. F., Nilashi, M., Abumalloh, R. A., Asadi, S., Samad, S., & Wang, S. (2020). Coronavirus pandemic (COVID-19) and its natural environmental impacts. *International Journal of Environmental Science and Technology*, *17*(11), 4655–4666. https://doi.org/10.1007/s13762-020-02910-x

Saha, S., Paul, A., Shaharia, R.-A., & Tabassum, S. (2023). *MEDICAL WASTE MANAGEMENT (MWM) AS AN ICON FOR SAFE TOWN DEVELOPMENT: A STUDY IN SATKHIRA TOWN OF BANGLADESH*.

Shanta, S. P. (2023, December 6). The legal side of medical waste disposal. *Dhaka Tribune*. https://www.dhakatribune.com/opinion/op-ed/333088/the-legal-side-of-medical-waste-disposal

Shareefdeen, Z. M. (2012). Medical Waste Management and Control. *Journal of Environmental Protection*, *03*(12), 1625–1628. https://doi.org/10.4236/jep.2012.312179

Som, U., & Hossain, Md. S. (2018). Medical Waste Management is Vital for Safe Town Development: An Incident Study in Jessore Town, Bangladesh. *European Journal of Sustainable Development Research*, *2*(3). https://doi.org/10.20897/ejosdr/2668

Teymourian, T., Teymoorian, T., Kowsari, E., & Ramakrishna, S. (2021). Challenges, Strategies, and Recommendations for the Huge Surge in Plastic and Medical Waste during the Global COVID-19 Pandemic with Circular Economy Approach. *Materials Circular Economy*, *3*(1), 6. https://doi.org/10.1007/s42824-021-00020-8

Tsai, W.-T. (2021). Analysis of medical waste management and impact analysis of COVID-19 on its generation in Taiwan. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, *39*(1_suppl), 27–33. https://doi.org/10.1177/0734242X21996803

Wielgosiński, G., Czerwińska, J., Szymańska, O., & Bujak, J. (2020). Simultaneous NOx and Dioxin Removal in the SNCR Process. *Sustainability*, *12*(14), 5766. https://doi.org/10.3390/su12145766

Windfeld, E. S., & Brooks, M. S.-L. (2015). Medical waste management – A review. *Journal of Environmental Management*, *163*, 98–108. https://doi.org/10.1016/j.jenvman.2015.08.013

Wyssusek, K. H., Keys, M. T., & Van Zundert, A. A. J. (2019). Operating room greening initiatives – the old, the new, and the way forward: A narrative review. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, *37*(1), 3–19. https://doi.org/10.1177/0734242X18793937

Yong, Z., Gang, X., Guanxing, W., Tao, Z., & Dawei, J. (2009). Medical waste management in China: A case study of Nanjing. *Waste Management*, *29*(4), 1376–1382. https://doi.org/10.1016/j.wasman.2008.10.023