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BIOMEDICALWASTE MANAGEMENT CURRENT STATUS AND FUTURE PROSPECTIVES: A REVIEW

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ABSTRACT:

Biomedical waste management (BMW) is one of the biggest challenges of the present day times because it has a direct impact on the health and environment. Biomedical waste which includes various types of waste from hospitals, medical research centers, Clinics and nursing homes, is variable in characteristics and composition. Today about one fourth of the total biomedical waste is found hazardous. Biomedical waste management is of vital importance as its improper management poses risks to the health care workers, waste handlers, patients, community in general and largely the environment. The practices done for biomedical waste management are poor in most of the organizations, unawareness of people about the lethal hazards of biomedical waste can be a reason for this behaviour. Proper segregation, handling, storage, treatments & disposal of biomedical waste are necessary in order to develop biomedical waste management system in better way. The objective of the study is to assess the impacts of biomedical waste and practices that are currently followed for biomedical waste management including treatment and disposal. Various innovations are discussed in the paper which seems to be very efficient and reliable. The objective of these innovations is to eliminate the risk of polluting the environment, reducing health risks and also to bring down the stress in the biomedical waste management procedures. Biomedical waste management should be done very carefully according to the given innovations, otherwise it may lead to deadly diseases and environmental pollution.

KEYWORDS:

BIOMEDICAL WASTE, INFECTIOUS WASTE, INCINERATION, BIOMEDICAL WASTE MANAGEMENT.

1. INTRODUCTION

Biomedical waste management is a significant problem of concern due to the environmental hazards and public health hazards associated with the biomedical waste generated from healthcare facilities. Biomedical waste (BMW) generated from health-care facilities is capable of making perilous condition for humans and animals as well as changes the properties of local groundwater and soil [2]. Increasing population across the world resulting in the rising number of patients, which in turn give rise to the increasing volume of medical waste. Hence there is a need of appropriate management of the biomedical waste that is producing at an ever-growing rate. The biomedical waste management continues to be a serious problem, especially, in most of the healthcare establishments of the developing countries[3]. Another major reason for the increase in the variety of medical waste in present day times because of the wide use and rise of pandemics[1]. The significance of proper biomedical waste management has been identified in emerging disease preparedness across the world [4]. An example of this is the pandemic of corona virus disease 2019 (COVID-19) that originated in Wuhan, China. Covid-19 has become a public health challenge not only for China but for countries around the world. Hospitals in Wuhan generate more than 240 tons of medical waste per day during the peak of the virus outbreak.

Healthcare establishments generate biomedical waste includes hospitals, clinics, medical centres, home health care, private practices, blood banks, veterinary offices, clinical facilities, research laboratories, clinical laboratories, and all unlicensed and licensed medical facilities[5][6]. Despite problems arising from these unwanted wastes, a civilised society cannot do without a healthcare system and this is a basic requirement for human kind. The world Health Organisation defines hospital solid waste as any solid waste that is produced in the diagnosis, treatment or immunization of human beings or animals, in research pertaining thereto, or testing of biological, including but not limited to: soiled or blood soaked bandages, culture dishes and other glassware [7]. It also includes discarded surgical gloves and instruments, needles, lancets, cultures, stocks and swabs used to inoculate cultures and removed body organs[6]. Biomedical waste fundamentally consists of pathological, infectious, toxic chemicals, heavy metals, pharmaceuticals as well as sharps that are tainted with blood, tissues, organs, infectious agents etc.[8]and also contains wastes that are genotoxic or radioactive [8][9]. If these substances are not properly handled they can cause unfriendly adverse health effects to man and the environment [6]. According to World Health Organization (WHO) about 75–90 % of healthcare waste generated is non-risk or non-infectious and the remaining 10–25 % of healthcare waste is infectious or hazardous that can capable of causing a variety of health hazards[10]. If both these non-infectious and infectious waste are mixed together then the whole quantity of waste becomes contaminated and dangerous[10][1].

Some of the health hazards resulting from the exposure to hazardous hospital wastes includes mutagenic effects, teratogenic effects, carcinogenic effects, respiratory damage, damage to central nervous system, reproductive system damage and others. Other Infectious diseases like diarrhoea, cholera, typhoid, leptospirosis, human immunodeficiency virus and hepatitis B virus can also be spread through the ineffective management of biomedical waste especially hazardous hospital waste [12]. Ecological nuisance emerging from the mismanagement of biomedical waste are foul smell, cockroaches, flies, vermin and rodents as well as untreated biomedical waste disposed in landfills can contaminate the underground water tables [11].

The large quantity of waste generated from healthcare facilities has become a condemnatory issue in both developing and developed countries. As reported by WHO based on a biomedical waste management survey in 22 developing worlds, about 18 to 24% of healthcare establishments manage their biomedical waste improperly. In India, every year about 0.33 million tons of BMW is generated and per day the BMW produced from healthcare facilities varies from 0.5 to 2.0 kg [13]. The biomedical waste in urban areas is about 1% of total municipal waste but the mixing of BMW with municipal waste makes the entire municipal waste dangerous and infective [10][14][15][16][17](70).The generation of biomedical waste is differ among and within the countries based on the infrastructure , practices followed for biomedical waste management, proportion of waste and reusable items generated on the basis of outpatients. Advancement in healthcare technologies and use of more disposal products are other main reasons for the increasing biomedical waste. The exposure to hazardous biomedical waste can cause health hazards to those who handle it, especially to the waste collectors.

In order to avoid deleterious effect on the environment and human health the BMW should be managed in a sustainable manner [18][19][17]. The management of biomedical waste is an integral part of traditional and contemporary health care system and it includes all the actions and activities from its point of generation to final option of disposal [20].The biomedical waste management involves waste segregation, practices of waste collection, storage, medical waste treatment, transport and final disposal. The main purpose of segregation is to separate infectious waste from the non infectious waste so that it can be treat prior to disposal by incineration or autoclaving. The improper segregation can happen by the lack of appropriate labelling in the waste collection containers and this increases the cost associated with waste management[10][21]. The waste handling workers who segregate biomedical waste in open place in the absence of personal protective equipment's such as gloves, shoes is further exacerbated the problem of BMW management [16][17]. The biomedical waste management practices mainly based on the policies and clear plans that provides continuous enhancement ensures appropriate management of biomedical waste [2]. These biomedical waste management practices should be integrated into trainings of employees and evaluation of management process [22]. In developing countries, United Nations Environment Program and the International Solid Waste Association are responsible for providing training and guidance on hazardous waste management [23][2].

All the studies on biomedical waste reported that a significant portion of this waste is amongst the most hazardous of all wastes arising in communities, because of this in order to avoid negative health and environmental impacts the BMW should be managed according to the relevant regulations carefully [24][25][26].

2. NEED OF BIOMEDICAL WASTE MANAGEMENT IN HOSPITALS

The biomedical waste generated differs among the hospital networks internationally and regionally. Rising population and increasing number of healthcare establishments due to the urban development resulting in the production of biomedical waste in a large-scale. The poor biomedic al waste disposal options adopted becomes highly non-hygienic for the environment and create dangerous health hazardous for inhabitants[27]. The direct and indirect impact on soil, water, air and human health has become the major reasons for the great need biomedical waste management in hospitals.

2.1 Impact of biomedical waste on water

The inappropriate biomedical waste disposal leads to the leach out of different pollutants into the ground water from the dumping sites of biomedical waste and may cause a undesirable effect on the quality of water [27]. The landfill leachate from biomedical waste usually have the presence of heavy metals and this will cause a dangerous effect to the environment particularly in unlined landfills where dispersal of leachate into ground water may happen. The heavy metals in the lecahate from the biomedical waste exceed the drinking water standards and waste water reuse. The concentrations of Al, Cr, V, Mn, Co, Ba, Ni, Pb, and Fe from leachate was found to be 2.050, 2.800, 0.9775,0.503,0.128, 0.8575, 0.773, 0.130, and 39.25 mg/L respectively. These concentrations are above the standard values and thus cause the contamination of surface and ground water [28].Also, there is the presence high concentration of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in biomedical waste incinerated ash and their improper disposal results in the formation of troublesome amounts of hazardous materials and may contaminate surface and groundwater[27]. Hence, the toxicity of ash should be eliminated before the landfillin the disposal or reutilization. The study of BMW incinerated ash showed an increased hardness (1320 mg/L) and chloride (8500 mg/L) content in leachate, which is above the permissible limits for drinking water set in the guidelines by World Health Organization (WHO) and Environment Protection Agency (EPA) [29].

2.2 Impact of biomedical waste on soil

The biomedical waste may have a direct impact in the soil quality of nearby waste dumping sites due to improper and unscientific disposal. There will be a change in the chemical and biological properties of soil ecosystem due to the mixing of different pollutants with the soil [27]. Dumping of biomedical wastes reduces soil quality and vegetation abundance and also notable changes in the physical and chemical soil properties has been observed near dumping sites. Soils at the waste dumping sites have high pH, TDS, and EC regime in comparison to control sites. There is higher concentrations of lead (Pb),copper (Cu), zinc (Zn) ,nickel (Ni) and chromium (Cr) were also found at the dumping sites[30].

2.2 Impact of biomedical waste on air

The burning of biomedical waste poses a serious threat to the human health and environment. The burning of healthcare waste pollutes the environment and mixes various pollutants to dangerous levels for human health [27]. It releases pollutants that are harmful and causing a variety of respiratory problems [31]. About 10-25% of the total waste generated by healthcare organizations is biomedical waste, which is perilous to the environment and human. These hazardous biomedical wastes require specific treatment and management. Incineration is the traditional method of treating infectious waste. However, depending on the composition of the waste, incinerators emit a variety of pollutants, which can lead to poor health and environmental degradation [27]. The burning of biomedical waste emits significant pollutants such as acid gases, particulate matter, oxides of nitrogen, metals, sulphur and xenobiotic substances. The burning of biomedical waste may cause some health impacts such as higher incidences of cancer, hormonal defects, respiratory diseases, and congenital abnormalities. Global warming, eutrophication and photochemical smog formation are other issues associated with biomedical waste burning.

2.3 Impact of biomedical waste on human health

The exposure to hazardous biomedical waste can result in various types of infections, including skin, respiratory, and upper and lower abdominal infections, as well as acquired immunodeficiency syndrome (AIDS), hepatitis, Congo-Crimean haemorrhagic fever, anthrax, brucellosis, and tuberculosis(85). If sharp (needles, broken glass, blades, etc.) waste is not handled, packed, processed or properly disposed of, it can cause injuries to laboratory professionals and supporting staff. Blood-borne infections can result from the Needle stick injury. According to WHO, due to unsafe injection practices around 20 million infections of HIV (human immunodeficiency virus), hepatitis B, and hepatitis C were reported yearly. Therefore, it is clear that improper and inadequate waste management has serious implications for public health and significantly affects the local environment[32][33].

3. RULES AND REGULATIONS OF BIOMEDICAL WASTE

Biomedical waste management is a major health and environmental issue especially in developing worlds[8]wherein most of the developed countries, there is a well established regulatory policy framework for the biomedical waste management [34] with drivers such as public health protection and European Directives transposed into national legislation (e.g. the Hazardous Waste Regulations 2006 in the UK). The deleterious effect of the biomedical waste on human health and environment is a worst case scenario in most of the developing countries[10] due to the improper management and absence of sustainable waste management solutions [2].A wide range of range of rules and regulations have been formulated for biomedical waste management in developing countries [35].Table 3 shows the list of legislations and regulatory authorities for biomedical waste management in various developing countries[35].

TABLE 3: LIST OF LEGISLATIONS AND REGULATORY AUTHORITIES FOR BIOMEDICAL WASTE MANAGEMENT IN VARIOUS DEVELOPING COUNTRIES ADAPTED FROM MUSTAFA ALI.2017[35]

County	Regulatory authority	Legislation
China	Ministry of Health, State Environmental Protection Administration	Medical Waste Control Act 380, Regulation 287
Iran	Ministry of Health	Medical Waste Management Regulations, 2008
Jordan	Ministry of Health	Medical Waste Management Regulations, 2001
Turkey	Ministry of Environment and Forestry	Medical Waste Control Regulation, 1993, 2005

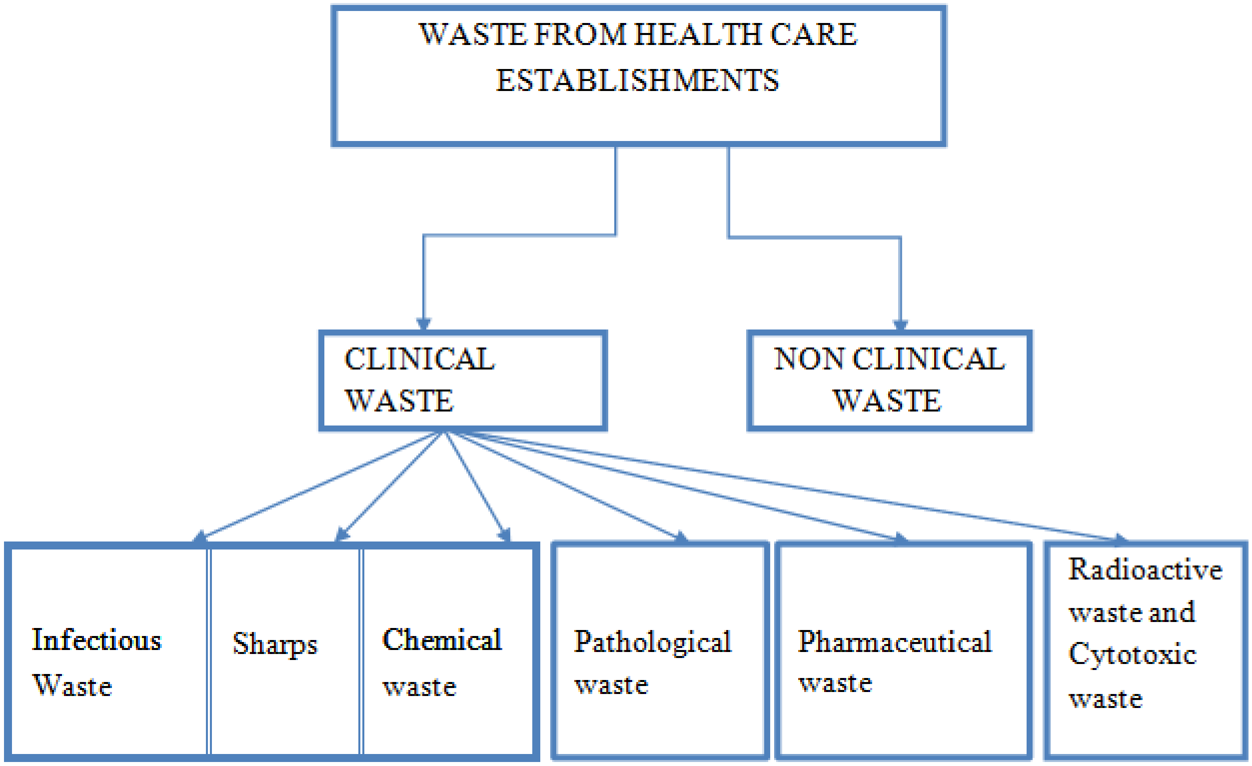
Brazil	National Environmental Council of Brazil	CONAMA (2001) Resolution No. 283
India	Ministry of Environment and Forests	Bio-Medical Waste (Management and Handling) Rules, 1998
Vietnam	Ministry of Health	Regulation on Healthcare Waste Management
Botswana	National Conservation Strategy Agency	Clinical Waste Management Code of Practice of 1996
Cameroon	Ministry of Public Health	1964, Law on The Conservation of Public Health, 1996 Framework Health Law
Serbia	Ministry of Health	National Guide for the Safe Management of HCW in Serbia, 2009
Egypt	Ministry of Environment	Decree No. 338/1995 and No.1741/2005 of Environmental Law No.4 (1994)
Pakistan	Ministry of Environmet	Hospital Waste Management Rules, 2005
Laos	Ministry of Health	Healthcare Waste Management Regulation, 2004
Mauritius	Ministry of Health Ministry of Environment	Public Health Act, 1925 and Standards for Hazardous Waste Regulations, 2001
Nepal	Ministry of Population and Environment	National Health Care Waste Management Guidelines, 2002

4. CLASSIFICATION AND COMPONENTS OF BIOMEDICAL WASTE

Biomedical waste, also called clinical waste, usually refers to by-products of health care activities in hospitals and other health care providers, as well as in health research centers, medical laboratories and veterinary. Definitions of medical waste vary according to different rules and legislation[36]. Each country classifies names and their medical waste a little differently. World Health Organization (WHO), typically classified biomedical waste as follows:

1. Infectious waste: This includes wastes that are contaminated with blood and other body fluids (e.g. from discarded diagnostic samples), cultures of infectious agents from laboratory work (e.g. waste from post-mortems, infected animals from laboratories), or waste from infected patients (e.g. bandages, swabs and disposed medical equipments).
2. Sharps waste: Syringes, disposable scalpels, needles, and bladesetc.
3. Pathological waste: human tissues, body parts, organs or fluids and contaminated dead bodies of animals.
4. Pharmaceutical waste: Expired, discarded and contaminated medicines and vaccines.
5. Chemical waste: Reagents and solvents used for laboratory preparations, sterilants, disinfectants, and heavy metals contained in medical equipments (e.g. mercury in broken thermometers) and batteries.
6. Radioactive waste: Products contaminated with radio nuclides including radioactive diagnostic material or radio therapeutic materials.
7. Cytotoxic waste: Waste containing substances with genotoxic properties (i.e. high risk substances that are mutagenic, carcinogenic or teratogenic), such as cytotoxic drugs and their metabolites used in cancer treatment.

FIG 4.1: THE CATEGORIES OF WASTE FROM HEALTH CARE FACILITIES .ADAPTED FROM SOHRAB HOSSAIN .2011[3]



The relative proportion of components of medical waste generated from health facilities largely depends on health care facilities, biomedical waste management practices (e.g. handling, segregation, disposal), and waste management rules and regulations[36]. The medical waste can be divided into non infectious and infectious or hazardous waste. According to World Health Organization (WHO) and US Environmental Protection Agency (US EPA) it is estimated that 75% to 90% of the waste generated by health care is non-infectious or general waste [10] because this non infectious waste does not contain any dangerous or risky waste and hence this does not require special handling, treatment and disposal [37]. The remaining 10–25% of hospitals waste is considered as hazardous or infectious waste. These waste includes infectious waste, pathological waste, pharmaceutical waste, chemical waste, sharps and radioactive waste, majority of which are carcinogenic, harmful, toxic, and infectious materials[10][3][38][39]. The major constituents of biomedical waste as a whole include tissues, absorbable cotton, single-use disposable plastics and pathological wastes [23]. For the successful implementation of any biomedical waste management project it is necessary to have accurate and sufficient availability of information about the quantities and composition of the waste is a fundamental condition [40][39].

5. CURRENT BIOMEDOCAL WASTE MANAGEMENT PRACTICES FOLLOWED GLOBALLY AND THEIR DEMERITS

Biomedical waste management is considered a problematic issue due to its large scale production, serious threats to human health and cost associated with the waste disposal [41][22][42][43][3]. The developed countries follow strict guidelines on health care waste segregation, storage, transportation and treatment[38][44]. On the other hand, developing countries seem to have limited resources when it comes to effective management of biomedical waste (BWM)[45][3][35].In developing countries, the sustainable management of biomedical waste is mainly restricted by inefficient segregation, collection and transportation of wastewater, lack of adequate personnel training, poor waste collection and recovery of potential wastes, infectious waste handling in the absence of proper personal protective equipment, illegal dumping of wastes and mixing of biomedical waste with municipal waste [41][46][47][48][49][50][2].Poor law enforcement and monitoring of the rules is mentioned in some studies as other reasons for the inappropriate biomedical waste management [2]. Therefore, effective management of biomedical waste across these countries require extensive implementation and monitoring of national regulations[35].The process of biomedical waste collection, segregation, transportation, treatment and disposal which are globally adopted are described below:

5.1. Waste Collection and Segregation

Waste segregation plays an important role in improved biomedical waste management. It is necessary to control the quantum of infectious waste and also the amount of mixed waste otherwise the waste volume will go beyond the control of management[51][52]. In many developed countries, biomedical waste is segregated into color coded, labeled bags or containers [53][38] . In developing countries as well, local waste standards require different waste streams to be segregated into labeled and color-based waste bags or containers [35]. In general, waste including needles, blades, scalpels or contaminated sharp objects, that can cause punctures and cuts are collected and sealed in white plastic containers[52]. Yellow color, strong leak proof containers or bags are used for storing wastes that are infectious such as human and animal anatomical waste, soiled wastes that are contaminated with body fluids or blood, like dressings, cotton swabs, plaster casts, expired or discarded medicines, discarded linen and beddings contaminated with blood or body fluid [52].Contaminated recyclable wastes such as bottles, syringes, intravenous tubes, urine bags, catheters and gloves are collected in red bags or containers. Chemical waste and incineration ash of biomedical waste are stored in black color plastic bags [52]. Red lead box labelled with a radioactive symbol is used for storing radioactive waste [2] and cytotoxic drugs are collected in their original packaging[54]. One reason why hospitals should be encouraged to separate infectious waste from other wastes is that this method has the potential to reduce hospital waste disposal costs and also helps to eliminate the high costs associated with specialized handling, treatment, and disposal of infectious waste[55]. In waste management system, the mixed waste may cause particular problems due to the difficulty of finding suitable methods for all hazards present in that wastes[55]. Studies show that health workers are not well educated and most of them do not have specialized training in clinical waste management[56][42][49]. Most healthcare facilities do not have the appropriate color-coded bags or containers for sorting different types of waste [8][3]. For example, some health care facilities in Nigeria and Mongolia used plastic bags, paper bags or cardboard boxes to collect biomedical solid waste[56][49][3]. According to a case study of Mostaganem Hospitals in Algeria , biomedical must be segregated in specific bags (yellow bags for infectious clinical waste and black bags for general non-contaminated waste) however infectious clinical waste is often mixed with the general waste [43]. A study in Egypt reported that the medical wastes segregation in various surveyed hospitals, was not done properly according to rules and standards[6].A study in China reported that infectious waste was mixed into municipal waste due to lack of adequate segregation, in other cases, municipal waste collected as medical waste [54]. These kinds of practices result in the increasing volume of infectious waste and treatment cost.

5.2 WasteStorage

Hospital waste storage regulations generally require that the waste should be temporarily stored in properly labelled separate storage rooms[10][35]. The area where the hospital waste is stored before it is taken to the final waste disposal site is called a temporary waste storage area. This area should be kept in such a way that it should be well sanitized, safe and accessible to authorized persons only[10][57]. After the biomedical waste is segregated and collected, it is transferred from the source point to area of temporary storage by the staffs in accordance with current regulations. Temporary storage location, storage containers and storage management have a direct impact on the environmental and health hazards and therefore must be thoroughly hygienic. After the medical wastes are segregated and collected, the staffs move them from the location of generation to temporary storage based on the current regulations [10][54].According to a study in HCFs of Botswana the Central storage rooms in some HCFs were found to have no locking system, allowing unauthorized access there at any time, which is dangerous considering the amount and type of waste stored. The rooms themselves were not in good condition and plastic bags containing waste were placed on the floor[1]. As per the studies, in some hospitals the containers used for on-site storage were in poor condition and these containers were placed near the main street inside the hospital buildings or placed on the street side curb. In addition, most of these containers were exposed without any cover, which poses another risk and also some health care facilities have no temporary storage space and waste is dumped in the corner of a hospital room and until taken to the off-site[58].

According to several studies, the following are some of the major globally facing problematic aspects in the storage practices:

1. Temporary storage locations are unsatisfactory and are close to municipal waste storage.
2. In some cases the medical waste is stored with municipal waste.
3. There are no officials in charge of storage areas, such that anyone can pick up biomedical waste from these hospitals.
4. Workers usually do not wear adequate protective gear, which increases health risks.
5. In some cases the temporary storage areas were not sufficiently cleaned after the delivery of medical waste to waste treatmentfacilities.

By scientific standards, infectious diseases in the tropical areas can be stored for up to 24 hours during the hot season and up to 48 hours during the cold season [10]. In most cases, the disposal company's medical waste collection schedule was often uncertain, creating a more complex problem for the hospitals[54] .

5.3 Offsite Transportation

Nowadays, tonnes of biomedical waste are needed to be transported to centralized treatment facilities around the world for their disposal. According to the World Health Organization, the regulation for biomedical waste transport in European countries is international regulation of the carriage of dangerous goods by road, commonly known as ADR. The European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) applies to 48 countries. The off-site transportation of biomedical waste to the final disposal site is handled by disposal companies in most of the developing countries like as China. Disposal companies arrange special trucks to collect biomedical waste from various hospitals every 1-2 days. Offsite transportation time is usually determined by the distance travelled and the biomedical waste quantity and the costs of off-site transport are included in the total costs for waste disposal paid by the hospitals[54]. In countries like Korea, online tracking system is used to track the movement of biomedical waste from the point of generation to the final destination [53]. The following are the issues reported in various studies regarding this off transportation:

1. In many cases, the biomedical waste was transported through inappropriate methods. For example, the drivers or workers manually handle the medical waste bags with no protective measures.
2. The Logistics containers are not utilized fully in the transportation process, which often increases the risk to people and the environment. In addition, some sharp medical waste often punctured plastic and paper bags.
3. In some cases, Medical waste is often carried along with industrial waste.

6. BIOMEDICAL WASTE TREATMENTS CURRENTLY FOLLOWED

Waste treatment leads to the reduction in waste volume, risk of infection, weight and organic compounds [10][57].Many medical waste treatment technologies have emerged since the beach wash-up events in the late 1980s. A single technology is not suitable for all types of biomedical waste, and it is important that for treatment and disposal of wastes at their facilities the hospitals should select individually the most appropriate technologies. No single technology is suitable for all types of medical waste, and it is crucial for hospitals to individually select the most suitable technologies for treatment and disposal at their facilities. Key factors to be consider when selecting technologies for hospital waste include availability of existing treatment methods, environmental impacts, occupational hazards, efficiency and cost of the technology and state regulatory considerations [55]. Various technologies are used for biomedical waste treatment all over the world and these include mechanical, thermal, irradiative, biological and chemical methods. In developing countries, currently a significant portion of biomedical waste collected is incinerated [42][54]. Some countries, such as Germany, Portugal and Slovenia have phased out medical incinerators to prevent environmental pollution [59][35]. Globally accepted treatment technologies can be divided into the following categories:

6.1 Thermal Treatment

In this process, heat is used to destroy or decontaminate biomedical waste. Commonly used technologies include incineration, autoclave, hydroclave and microwave.

6.1.1 Incineration

Incineration was the most widely used treatment for solid biomedical waste [6].Many of the benefits of incineration have led to its worldwide use as the best means of biomedical solid waste treatment and disposal [60][53][37][3]. This process is usually chosen for waste that are non-recyclable, non reusable and waste that cannot be disposed in a landfill site[3]. Incineration is traditionally the primary means of a hospital for the treatment and disposal of medical waste [54]. When used for biomedical waste treatment, it has many benefits, including reducing the amount of waste, sterilizing waste materials, eliminating toxins, and recovering electricity or heat during incineration [53]. While using Incineration as a treatment option for biomedical waste it reduce about 90% of waste volume [61] and inherent toxicity [2]. However, some disadvantages of incineration includes it's the ability to expel toxins into the surrounding area, high maintenance and operational cost of incinerator and the need of disposing ashes [53]. Incineration technology has received some criticism from the public and researchers in recent years, due to its strict environmental protection regulations and laws [54]. Options for waste disposal are limited in less developed and transitional countries ,so small-scale incinerators are used as an interim solution[49]. When operating without air pollution control devices, incinerators can emit a variety of harmful pollutants. They can also emit harmful pollutants if they are not working properly or not well maintained or fitted with a gas cleaning equipment [1]. These contaminants include particulate matter, toxic metals, acid gases and toxic organic compounds of incomplete combustion (e.g., furans, dioxins etc) [3]. These contaminants especially dioxins can be carried too far away from their source of emission and accumulate in the water, soil and food sources and contaminate them[3]. The emission of pollutants from the incinerator is also happens when it is operating below the recommended temperature. The low temperature also results in incomplete burning of waste and the resulting ash moves to the cold part of the incinerator and where it hardens into slag. This can disrupt airports, disable burner and disrupt normal flow through the furnace. To prevent this temperature of combustion chamber should be at least 750 ° C to avoid ash fusion and slagging, but not to exceed 1000 °C [6] .Long residence time (>2 or 3s) and high temperature (900–1200 °C), are essential for effective incineration [6].Improperly incinerated waste, particularly plastic-containing waste, give rise to toxic gases such as dioxins and furans that can cause carcinogens[62][1]. According to the World Health Organization polyvinyl chloride items (e.g. IV tubes, blood bags etc.) which containing chlorine or heavy metals collected in red color coded containers (e.g. mercury from broken thermometers) should never be incinerated[1].Properly designed and operated modern air pollution control devices can significantly reduce many air pollutants from medical waste incinerator. Common air pollution control devices used in biomedical waste incinerator include scrubbers, cyclones and bag filter filters [53].

Properly designed incinerators will burn the waste completely and leave residue in the form of ash, while placing the incinerator units in the correct position in relation to the hospital and surrounding communities reduces the risk of pollutant emissions[11]. Unfortunately, in hospitals, especially in developing countries, the majority of incinerators are poorly designed and have operational problems [56][42][58]. For most developing countries incineration is an inappropriate technology due to the high economic start-up costs and the labour capital required to carry out combustion operations[34][56][11][58]. In addition, there is still a need to dispose ash and non-combustible waste, especially in landfills, which pose a significant risk to humans and the environment [64][65]. Another concern is on the dangers of infectious microorganisms is that, if infectious biomedical waste is incinerated, the gas emission and ash from the incinerator may have contagious microorganisms [43][3]. Various studies reported the presence of viable micro-organisms in the exhaust gas from several modern incinerators [3].So many developed countries around the world are stopping the incineration of biomedical waste and turning to alternative technology of incinerator due to high maintenance cost and serious environmental impact [66][67][68][38].In developed countries like Korea, starved air incinerator is used for medical waste treatment. This starved air incinerator usually has two furnace chambers. In the first chamber, the waste is incinerated with less than the stoichiometric air required, resulting in an effluent rich in organics. The effluent gas is then incinerated in the secondary chamber where complete combustion is achieved by providing air more than the required amount [53].

6.1.2 Autoclave

Autoclaving is currently perceived as a significant strategy for treating different types of infectious biomedical waste [11]. Autoclaves have been used since 1876 to sterilize various infectious biomedical wastes[3]. Autoclaves are commonly used to treat sharp items tainted with blood and other non-chemical wastes. The waste which contain hazardous chemicals substances such as radioactive waste, waste from chemotherapy treatment, mercury waste and other chemical waste is not possible to treat in autoclave[37].Autoclaves have a temperature range of 50–250°C, but they are ideal for killing bacteria at 160°C[3]. Its significant disadvantage is that it can't deal with enormous amounts of hazardous waste[11] and also it is not appropriate for treating large items such as large body parts or animal carcasses, as their characteristics and mass make it difficult or time consuming for the entire material to reach a certain temperature [10][3]. It is considered as an alternative technology of the incinerator for treating biomedical waste, but it is seen as a more expensive method than incineration [69][53]. Autoclaving is costly because it is considered as a dual treatment option for medical waste, as another treatment is needed to the final disposal of the autoclave waste[53][3]. In autoclave the steam is in direct contact with waste in a controlled manner to disinfect the waste for a sufficient time. Although the rate of waste reduction is very low, autoclaving is usually used as a backup treatment or as a treatment before disposal to sanitary landfills. [55] .

6.1.3 Microwave

Microwaves are electromagnetic waves with frequencies between radio and infrared waves[3]. Wavelength of microwaves ranges from 1 to 1,000 millimetres and a frequency of 1,00 megahertz to 3,000 megahertz. Microwave frequencies commonly used for disinfection are (2,450 ± 50) MHz and (915 ± 25) MHz [70].The microwave passes through the medium and is absorbed by the medium to generate heat. The heat is generated by the substance molecules vibrating and rubbing for billions of times per second, thereby achieving the effect of high temperature disinfection [70]. By using microwaves the biomedical waste is heated from inside to external surfaces of the materials[37]. In order to create the thermal process, it is important that the waste is moistened by adding naturally occurring moisture or steam..In some cases this technology is used to inactivate the microorganisms in the waste is by applying low frequency radio waves. Microwave treatment for biomedical waste is expensive compared to incinerators and developing countries is possible to afford the cost of this.[37] [3]. Developed countries are replacing unwanted incineration with alternative treatment technologies such as microwave sanitation that are more environmentally friendly for biomedical waste[1].

6.2 Chemical treatment

Chemical treatments are mainly used to decontaminate liquid waste, so it can be expelled locally. To convert hazardous waste into less hazardous substances it uses a variety of technologies such as oxidation, reduction, pH neutralization and precipitation [71][52].Chemical treatment of biomedical waste commonly used in combination with mechanical crushing treatment [70]. Normally, biomedical waste after crushing is treated with chemical disinfectants (sodium hypochlorite, chlorine dioxide, calcium hypochlorite etc.) for a sufficient period of time. During the chemical disinfection process, the organic matter decomposes and kills or inactivates the infectious microorganisms [70].Ozone, sodium hydroxide, ultraviolet radiation, liquid chlorine, chlorine dioxide, and sodium hypochlorite disinfection are common technologies for disinfection of hospital wastewater [72][73].Figure 6.1

shows the wastewater disinfection system[70].

FIGURE 6.1 FLOW CHART OF HOSPITAL WASTEWATER DISINFECTION PROCESS (REFS:[70][72])

6.2.1 Chlorine-containing disinfectants

Chlorine is a powerful oxidizer [74][75] and was one of the first disinfectant agents used to disinfect hospital wastewater[76].When using chlorine as disinfectant, a vacuum siphon fixed-ratio chlorine dosing system is usually adopted in the hospital wastewater treatment system. After primary treatment and secondary treatment usually, 30 mg/L - 50 mg/L and 15 mg/L - 25 mg/L chlorine are injected into wastewater respectively [70]. Applying the actual amount of chlorine into the waste water controls the residual chlorine remains in the outlet of wastewater treatment and reduction in the quantity of contaminants in the waste water [75][77][78]. The most important reaction of chlorine disinfection is

$$Cl_2 + H_2O = HClO + HCl$$ [76]

6.2.2 Sodium hypochlorite

Sodium hypochlorite disinfectant can be prepared using a standard NaClO generator, which will significantly reduce the cost. A dual siphon automatic fixed-ratio dosing chlorine system is commonly used for sodium hypochlorite disinfection. The available chlorine content in sodium hypochlorite is about 5% -20%.

The mechanism of sodium hypochlorite disinfection is:

$$NaClO+H_2O=HOCl+NaOH$$

The use of sodium hypochlorite is more efficient compared to other chlorine-containing disinfectants, because it is characterized by low toxicity, lower operation and preparation costs, more stable operation ,simple equipment, easier control, which making it more practical in small hospitals[70][76].

6.2.3 Ultraviolet light (UV)

Ultraviolet light (UV) are electromagnetic wave having a wave length between 200 nm and 400 nm. The UV was first used as a disinfectant in the year 1910 to disinfect drinking water. The UV can divided based on different wavelength into 4 wavebands, including ultraviolet A (315 nm -400 nm), ultraviolet B (280 nm-315 nm), ultraviolet C (200 nm-280 nm), and vacuum ultraviolet (100 nm-200 nm). All the four wavebands, vacuum ultraviolet are not used for the purpose of disinfection because the wastewater can absorb vacuum ultraviolet. The structure of DNA and RNA of the bacteria, single-celled microorganisms and viruses can be damaged by UV bands with wavelength between 200 nm and 300 nm. Therefore, the best bactericidal effect can provide by the ultraviolet B and ultraviolet C [70][76].

6.2.4 Ozone

Ozone is a powerful disinfectant and it is highly known for its bactericidal impact. In developed countries ozone is largely utilized in wastewater treatment and water supply engineering due to its bactericidal effect [79][80]. In treatment using ozone, as a first stage the wastewater flows into the sedimentation tank and then into the second stage purification. After necessary treatment, it flows into a controlled storage tank. Using a sewage pump it is then pumped to the contact tower and waste water is exposed to 15 mg / L - 20 mg / L ozone in the tower for about 10 - 15 minutes before discharge [76].

6.3 Mechanical treatment

Mechanical treatment of biomedical waste includes shredding and compaction. The purpose of compaction process is the compression of the waste to reduce waste volume. Shredding is mainly given to convert biomedical wastes into a more homogenous form so that waste can be handled easily and efficiently sterilized[53]. The process such as grinding, granulation, pulping etc. are included in shredding [81].Usually after shredding sterilization of the waste given by loading it into an autoclave [53]. Needle destroyers are used to destroy the needles, which comprise the bulk of the sharps [81].

7. BIOMEDICAL DISPOSAL OPTIONS

In the 1980s, a number of incidents involving biomedical waste disposal caused great concern among the people of the United States[55]. This leads to the outspread of AIDS and hepatitis B virus (HBV) epidemics among the public and they reacted with fear. This widespread incidents forced the US Environmental Protection Agency (EPA), the Occupational Safety and Health Administration (OSHA), the Centers for Disease Control and Prevention (CDC) and the Nuclear Regulatory Commission (NRC) to form guidelines and standards for biomedical waste treatment and disposal [55].

The World Health Organization has suggested that the choice of biomedical waste disposal methods should be cost-effective, easy to implement, minimum impacts to human health and environmentally friendly. Open dumping and land filling is the most widely recognized method for biomedical waste disposal. In some hospitals around the world biomedical waste without disinfection is still mixed and dumped with general waste in landfills [1]. In addition, the wind can blow away pollutants from the dumped waste, which in turn spreads air pollution to nearby communities. Although open dumping of hospital waste is inexpensive and no other alternative to waste disposal is available at a reasonable cost, it is commonly used but poses a risk to public health and environmental pollution[1].

7.1 Landfill

Landfill is a region of land for biomedical waste disposal and the purpose of landfill is to avoid the contact of waste with the surrounding environment, especially groundwater [82]. General and medical wastes are dumped in the landfill, until landfill is full this process is repeated, and then the landfill is covered with soil. During the normal operation of the landfill, on a daily basis the waste is spread, compacted and then applied with a layer of soil. Normally, landfills are the easiest and inexpensive method of waste disposal[11]. However, if a landfill is not managed properly, it raises concerns about the risk of human health and environmental pollution [83][82][3]. In three phases waste is produced from landfill waste disposal process and these are solid (i.e., degraded wastes), liquids (i.e., leachate, contaminated waste water) and gas (commonly called landfill gas) [57][3]. Landfill gas inhalation and exposure to groundwater that are contaminated with landfill leachate poses a serious risk to human health 65]. Landfill gas mainly contains methane and carbon dioxide; it also contains low concentrations of other gases, some of which are dangerous [65]. Greenhouse gases (GHG) such as methane and carbon dioxide are the major constituents of landfill gas. But carbon dioxide is easily absorbed for photosynthesis and methane decomposes easily, which is estimated to be 20 times more potent as a GHG[3]. At the same time, landfill leachate poses a threat to the surface and groundwater system [65] and also landfill sites contain a highly variable concentration of salts, trace metals, halogenated organic compounds, and organic acids that can pollute nearby water and soil (World Resource Foundation, 1996). According to some reports, it was found that the landfill leachate shows carcinogenic and mutagenic effect [3].

Currently, in many places around the world landfills act like open dumps. Every day, public and biomedical waste is dumped into landfill and then incinerated, causing human health hazards and environmental pollution concerns. Burning is aimed at reducing the amount of waste and preventing the spread of paper but it becomes a source of toxic chemicals [53]. It is more likely to produce toxic chemicals such as dioxins and furans due to burning. Depending on the direction of the wind, when the waste is burned, the smoke will reach the nearby communities and dispersing toxic pollutants [1].Another issue associated with these landfill is many weeks later after disposing hospital waste in a landfill microorganisms such as Staphylococcus aureus, Salmonella spp, Enterococcus spp, and other enterobacteriaceae were found in landfill leachate. Therefore, it can be consider that microorganisms can persist for a long time in biomedical waste disposing landfills [3]. In many parts of the world, biomedical waste is limited to landfill disposal unless it is disinfected from infectious microorganisms that pose a risk to human health [84]. For example, hospital waste was strictly controlled by European landfills due to the contagious nature of the waste and public hatred. From this side, the waste can be properly sorted and disposed in a sanitary landfill which is a modern engineering landfill .In sanitary landfills waste can be decomposed into biologically and chemically inert materials in a setting isolated from the environment [85][10].

7.2 Open dumping

The main problems associated with open dumps, whether onsite or offsite, are open access to unauthorized persons and environmental pollution; Poor protection of municipal waste handlers and recovery of certain malware. In addition, these dumps are aesthetically unpleasing, dangerous to health and safety and are breeding grounds for vectors such as mosquito-borne malaria parasites. The disposal of hospital wastes without adequate design considerations in open dumps or landfills pose serious health and environmental hazard. Leachates below the dump or surface runoff may contain heavy metals and other organic contaminants, which can cause surface and groundwater contamination[86][87].In developing and transitional countries the lack of proper waste disposal facilities is mainly due to limited financial and financial resources, which in turn lead to the stability of hazardous practices such as the discharge of chemical waste into the wastewater system and open dumps [1]. These practices is ineffective and poses the greatest risk to human health and the environment [42][2]. Open dumping for biomedical waste has been replaced by land filling in many areas due to problems such as leakage of toxins into the environment and easily accessible by animals and insects. In addition, wind can easily blown over these waste dumps and as a result air pollution spreads to nearby communities [1].

8. VARIOUS ECO FRIENDLY BIOMEDICAL WASTE MANAGEMENT PROCESS GLOBALLY FOLLOWED

The various environmental friendly procedures that can be performed in the waste management process are as follows:

8.1 Reduce

It involves the process and policy of reducing the quantity of waste generated by an individual or community. This approach helps to conserve our natural resources[20].

8.2 Reuse

The high cost and limited space for the disposal of biomedical waste ash generated from the solid waste incineration has led to the development of recycling technologies and the use of ash in various systems. Several studies have confirmed the successful utilization of biomedical waste ash in agriculture and manufacturing to reduce the flow of its hazardous components into the environment [88][20].

8.3 Solar energy in waste management

Solar heating is an inexpensive way to disinfect infectious biomedical waste in less economically developed countries [89]. In most developing countries, solar energy is readily available and can be used to treat infectious waste.[89]. BMW should be incinerated in accordance with the recommendations by Indian pollution control but this leads to the emission of dioxins in large quantities, which are designated as carcinogens by the WHO. In addition, the high cost of incineration can lead untreated BMWs in to the environment and pose a great risk to public health. In such cases the use of solar energy for powering autoclave is an appropriate approach in waste management in a small hospital setting [90].In India using solar energy a portable autoclave was developed[90]. It was also reported that at different stages of solar disinfection there was a significant decrease in chemical oxygen demand (COD), electrical conductivity, total solids, volatile solids, alkalinity and microbial colony[20].

8.4 Electro- Thermal-Deactivation (ETD)

ETD also known as microwaving is a new waste treatment technology in which waste is kept in sealed and insulated containers and then subjected to a high strength oscillating electrical field generated by low-frequency radio waves. Medical waste directly absorbs the energy and heat at a temperature of 90–100 °C. Electro-Thermal-Deactivation (ETD) are as effective as incineration in reducing the waste volume. After the medical waste is treated with EDD, the recyclable plastics and syringes are separated and taken to plastic recycling companies. Non-recyclable materials are shredded and disposed of in landfills as normal solid waste. ETD is available in limited geographical areas because it is a copyrighted technology owned by Stericycle Company [55].

8.5 Supercritical fluid carbon dioxide sterilization

Different sterilization methods such as gamma radiation, ethylene oxide(EtO), electron-beam, steam and hydrogen peroxide plasma, have limitations with respect to their biomedical applications [91].All of these technologies expensive and difficult to control and regulate because they require high temperatures and pressures[92][91]. Therefore, the above methods of sterilization are not appropriate for biomedical solid wastes because at high temperatures heat sensitive reusable wastes may be destroyed. Therefore, it is essential to determine the low temperature sterilization technology, where supercritical fluid (SCF) sterilization technology is very promising. SCF is any compound at a pressure and temperature above the critical values. The pure gaseous component above the critical temperature of a compound cannot be liquefied regardless of pressure. The critical pressure is the vapour pressure of the gas at extreme temperatures. Only one phase survives in the supercritical environment. Fluid, as it is called, is not a gas or a liquid, but an intermediate to the two extremes .The solvent power at this phase approximating liquids and transport characteristics to gases. SCF as a liquid shows high diffusivity and low viscosity compared to gas[3]. These features support mass transfer phenomena such as matrix extraction or impregnation.

The most widely used SCF is CO_2 because of its antimicrobial properties, low critical parameters (31.1C, 73.8 bar), low cost and non-toxic, non-flammable, abundant availability, reusable and environmentally friendly properties [92][3]. The use of supercritical CO_2 to inactivate organisms is noteworthy [92]. The unique property of carbon dioxide is that it makes an attractive medium for sterilization. Carbon dioxide converts to a supercritical state, often referred as dense phase gas at relatively low temperatures and pressures. The characteristics of supercritical CO_2 allow deep penetration of substrates, which leading to their use in areas ranging from bioremediation to extraction of natural products [93].

8.6 Plasma incineration

Plasma incineration technology is relatively new technology for waste disposal. The essence of this technology is to transfer energy through plasma, so that the waste decomposes rapidly into smaller molecules and atoms. Therefore, there are no large molecule intermediate products. Most of the gases produced in this technology are burned and for complete combustion it is sent to the secondary combustion chamber. After simple purification it is then expelled into the atmosphere. Compared to traditional incineration technologies, plasma incineration has higher energy efficiency, which makes it a better application potential [94][70].

Bioconverter is an emerging biological method for the disposal of biomedical waste. Here to decontaminate biomedical waste a solution of enzymes is used and the resulting sludge is put through an extruder where water from the sewage disposal is removed and the remaining solid is dumped to the landfill. Another method for the safe disposal of biomedical waste is the use of biodegradable plastics. Many biomedical implants made from biodegradable plastics are subjected to biodegradation using microbial extracellular enzymes. These microorganisms use these biodegradable polymers as substrate under starvation and in the unavailability of appropriate substrate. More research is needed on the large-scale economic production of biodegradable plastics [10][95].

10. FUTURE PROSPECTIVES TO BE ADOPTED

The management of biomedical waste is an area of great concern for the environmentalists, waste management professionals due to the presence of infectious and non-infectious materials and heterogeneous nature of the waste stream. The Improper management of biomedical waste will adversely affect the overall environment[99]. Developed countries produce higher quantity of biomedical waste than developing countries. It has been established that the rate of hospital waste generation depends on the economic development of a country [38]. Most of the developed countries have adequate financial investment, effective waste management systems, trained waste management staffs and mechanisms for processing waste[1]. Incineration has been a conventional treatment in developed countries for medical waste containing contagious and hazardous substances[53]. Nowadays in majority of developed countries, the incinerators are equipped with expensive air exhaust control devices to comply with local and state regulations[91]. Also developed countries are replacing unwanted incineration with environmentally sustainable alternative technologies for biomedical waste treatment, including, chemical disinfection, microwave technology, dry heat disinfection, superheated steam disinfection, and pyrolysis [1].

In developing countries major challenges restricting the sustainable management of biomedical waste includes improper segregation, poor waste collection, transportation of waste stream, lack of adequate training to the staffs, poor legislation, infectious waste handling without using personal protective equipment, dumping of illegal waste and mixing of medical waste with municipal waste[2][49][46][41][48]. In developing countries the most common treatment methods adopted for biomedical waste are open dumping or land filling and incineration without proper measures to deal with the emission of toxic pollutants to air, water and soil. Generally incineration is considered as the best solution for biomedical waste treatment therefore existing low-temperature incinerators should be banned, and modern incinerators equipped with proper air pollution control devices can be used as a means of treating and expelling the clinical solid[49]. The problem is that most of the hospitals in developing countries cannot afford to buy latest technology incinerators that are more eco friendly[3]. Therefore, developing countries are trying to develop new initiatives for more comprehensive projects related to eco-friendly management of biomedical waste [1].For managing and treating this complex biomedical waste effectively, innovative and cost-effective solutions can be developed and implemented [2].

At the present day times, the pharmaceutical industries trying to develop various green chemistry methods by minimizing the use of environmentally hazardous reagents and by designing alternatives methods. The general rule of waste management, i.e. 3 Rs - Reduce, reuse and recycle, should be adopted for future scientific and proper management of waste [20].

11. CONCLUSION

In this review, the existing practices of biomedical solid waste management were explored to determine the most suitable management technology for biomedical waste in health care facilities. This review also highlighted the impact of improper management of biomedical waste on soil, water, air and human health. Nowadays, a variety of biomedical waste is increasing due to the widespread use and emergence of infectious diseases. In developed countries there are systemic mechanisms for biomedical waste management but this is not same in the case of developing countries. In developing countries the common methods used for waste treatment and disposal are incinerators without air pollution control devices and open dumping or land filling. These treatment and disposal methods have a negative impact on the human health and environment. It is crucial for hospitals to choose more environmental friendly treatment technologies and disposal methods for the biomedical waste. Waste reduction, reuse and recycle should be implemented to reduce the amount of hospital waste disposed. Studies should also be conducted to convert biomedical waste into useful products and energy. This will help to prevent pollution of environment and health hazards.

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