ABUAD Journal of Engineering Research and Development (AJERD)
ISSN (online): 2645-2685; ISSN (print): 2756-6811

Volume 7, Issue 1, 14-27

Healthcare Waste Management: An Overview

Muktar Oladapo RAJI[1,2], Adeniyi Ganiyu ADEOGUN[2]

[1]*Works Department, University of Ilorin Teaching Hospital, Ilorin, Nigeria*
mraji@uithilorin.org.ng

[2]*Department of Civil Engineering, Kwara State University, Malete, Nigeria*
adeniyi.adeogun@kwasu.edu.ng

Corresponding Author: mraji@uithilorin.org.ng, +2348031961804
Date Submitted: 01/01/2024
Date Accepted: 22/03/2024
Date Published: 01/04/2024

Abstract: *Healthcare waste (HCW) is a vital global issue that cannot be overlooked due to its threat to humans and the environment stemming from its infectious and hazardous nature. This study examines previous works undertaken on healthcare waste management (HCWM) practices around the world, notably the developing countries with a particular interest in segregation, collection, transportation, treatment, and disposal of HCW. This study draws attention to the environmental hazards arising from each stage of HCWM. Factors affecting HCWM practices have also been discussed. This study revealed evidence of poor HCWM practices in many developing countries. It also showed the impacts of human and non-human factors on HCWM practices. Proper documentation, sufficient budget, adequate supply of HCWM materials, frequent training of healthcare workers, and development of local manuals and guides are essential if a country is determined to achieve an efficient and sustainable HCWM system. Liquid HCW needs to be investigated as much as the solid HCW. Exploration of HCW minimization, reuse, and recycling opportunities is recommended for future research. The use of Modern-day technology such as Artificial Intelligence and geographic information system (GIS) has provided good results so far. However, they can be explored further for prediction, real-time monitoring, and reporting of HCW. The present study can be adopted as a guide in discussing issues about HCWM.*

Keywords: *Healthcare waste management, Developing Countries, Environmental Hazards, Artificial Intelligence, Geographic Information System.*

1. INTRODUCTION

It is ironic that activities in healthcare facilities, undertaken to restore and maintain human health, are also endangering human life due to the wastes produced as by-products of these activities [1, 2, 3].

Healthcare waste (HCW) refers to any solid or liquid waste generated from the diagnosis, treatment, or immunization of human beings and animals or during research that can cause infections in humans [4]. Healthcare waste has been referred to by other names including medical waste [5, 6, 7], hospital waste [2, 8] and biomedical waste [4, 9].

World Health Organization (WHO) specifies that healthcare waste comprises all the wastes generated in hospitals and other health facilities, mortuary and autopsy centres, testing laboratories and animal research centres, blood banks and collection services, and nursing homes for the elderly [10].

Two types of HCW are produced in healthcare facilities: solid and liquid HCW. According to WHO [10], solid healthcare wastes are categorised into nonhazardous waste; which constitutes the majority (85%), infectious waste (10%), and hazardous HCW (5%). Nonhazardous wastes are similar to domestic wastes, infectious wastes comprise the cultures and stocks of infectious agents, wastes contaminated with blood and its derivatives, wastes from infected patients, discarded diagnostic samples, infected animals from laboratories, contaminated materials and equipment, body parts and carcasses of animals while the hazardous healthcare wastes comprise chemical and radioactive wastes. Liquid HCW or healthcare wastewater is any water whose quality has been compromised by activities in healthcare facilities [11]. Such activities include health-care-related processes like radioactive diagnostic, treatment, and laboratory procedures and general processes such as cooking, cleaning, laundry, and bathing. WHO [11] classifies liquid healthcare waste into greywater, stormwater, and blackwater. Figure 1 shows the types of solid HCWs and a few examples, while Figure 2 depicts the categories of liquid HCWs.

The quality of liquid HCW depends on the source of generation or origin of the contaminant. These contaminants can be organic, soluble organic, inorganic, or soluble inorganic particles. Some sources of contaminants of liquid HCW are general medical areas, kitchens, laundries, theatres, and laboratories.

Developing countries often report higher amounts of hazardous waste because of a lack of segregation of HCW into hazardous or non-hazardous fractions [12]. This conforms to the United States Environmental Protection Agency (USEPA) guide [13] to pollution prevention, which states: "By current law, any waste mixture of non-hazardous and hazardous or infectious wastes must be handled all as hazardous wastes". The COVID-19 pandemic has caused an appreciable rise in the amount of HCW generated [14]. Items like hand sanitiser, rubber boots and gowns, disposable gloves, masks, and plastic from various personal protective equipment constitute the bulk of this waste.

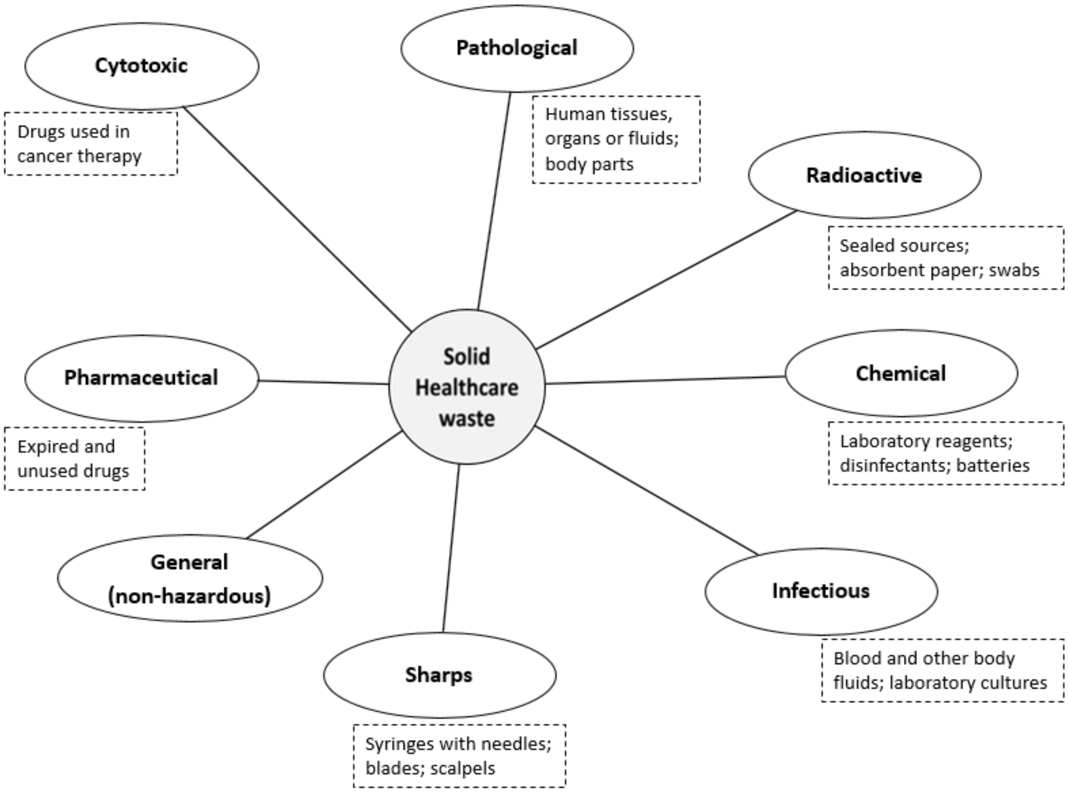

Figure 1: Types of solid HCW

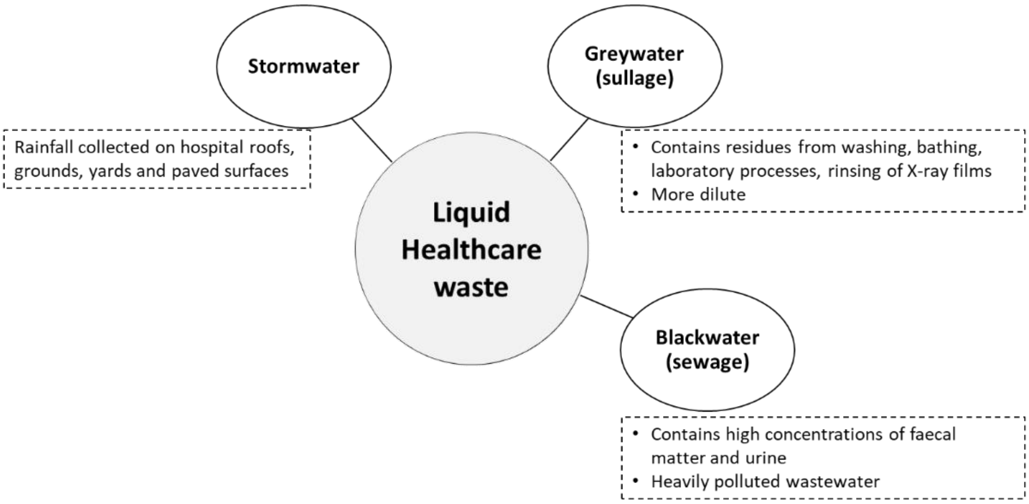

Figure 2: Types of liquid HCW

HCWM is a key global issue that is linkable to some of the 17 Sustainable Development Goals (SDGs) more importantly good health and wellbeing (SDG 3), clean water and sanitation (SDG 6), decent work and economic growth (SDG 8), and responsible consumption and production (SDG 12) [15]. Safe and sustainable HCW is indispensable in maintaining human health and preserving the environment.

2. LITERATURE REVIEW

This segment highlights some key concepts related to HCWM such as the impacts of poor healthcare waste management, factors affecting poor HCWM, and prevalent HCWM practices in some countries. Figure 3 depicts core issues associated with healthcare waste management.

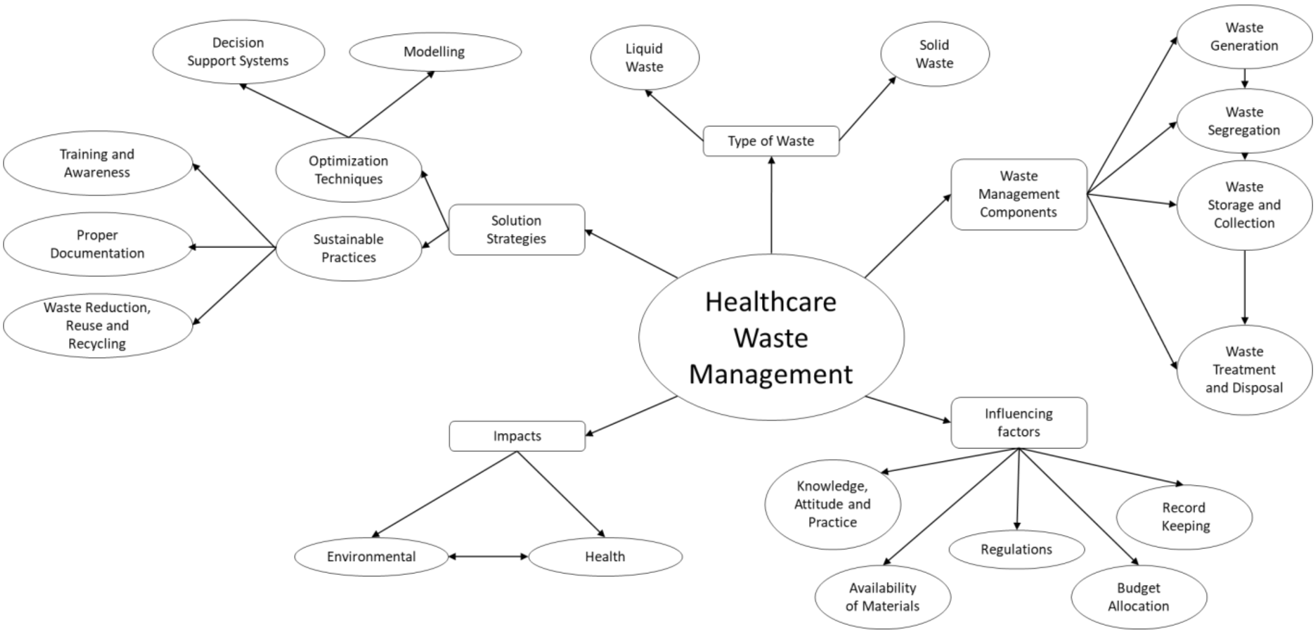

Figure 3: Core issues of healthcare waste management

2.1 Impacts of Poor HCWM

An evaluation of 24 countries in 2015 by WHO and UNICEF revealed that just over 50% of the sampled facilities had an efficient HCW disposal system [12]. Developing countries face environmental risks due to inappropriate hospital waste disposal practices [16]. Incinerators without air pollution control systems (APCs) emit toxic gases through the chimneys causing air pollution [17]. Incineration processes also generate bottom and fly ash which can contain high levels of organic and inorganic compounds and heavy metals [18]. The indiscriminate disposal of untreated HCWs through open dumping and landfilling can lead to contamination of surface water and groundwater sources used for drinking and other purposes [6, 12, 16]. The release of mercury, which is a toxic pollutant from HCW, is also a major concern [16, 19]. Figure 4 depicts some environmental hazards associated with each waste management component.

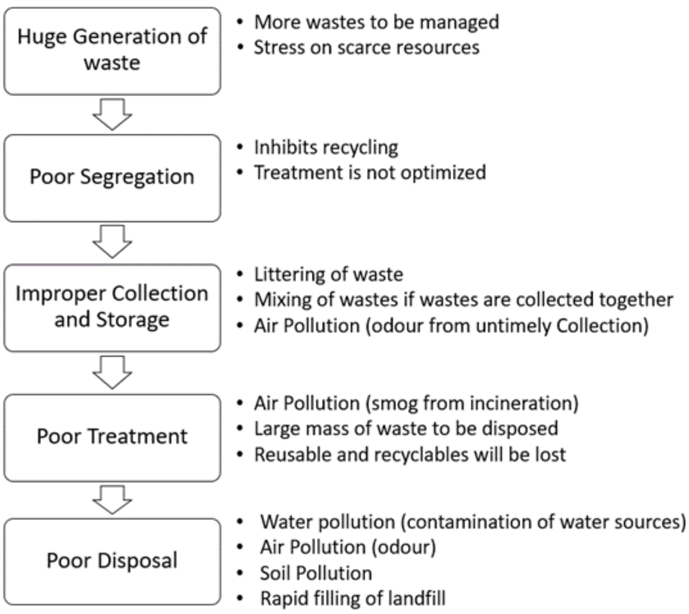

Figure 4: Environmental hazards of poor HCWM

Improper management of HCWs increases the risks of health hazards [16, 17, 20]. The classes of people who are potentially at risk are all medical personnel, patients, the personnel directly involved in waste collection, transportation and disposal, hospital support staff such as engineers, administrative staff, and visitors to the establishment most especially the patient relatives. However, these risks may extend to other members of the community in situations where the wastes are not sterilized or incinerated at the source and disposed of together with other municipal solid wastes [21]. Needle-stick injuries are common among health workers, waste handlers, and scavengers. A study by Adu et al. [17] reported that a study in Taiwan revealed that over 8,000 health workers sustained injuries from 7,550 needle sticks and sharps, out of which 66.7% of these injuries involved a contaminated hollow-bore needle. More than 30 prominent diseases including typhoid, hepatitis B, hepatitis C, and HIV have been linked to improper HCWM [22]. Adu et al. [17], in their study, showed that Hepatitis and HIV have been detected in children who have come in contact with infected sharps waste in waste dumpsites. Other health hazards associated with improper HCWM are chemical burns from disinfection, radiation burns, thermal injuries from open burning, and incineration. High blood pressure, vomiting, headache, heart pain, and cough have also been associated with HCW handling [23]. Landfills can become breeding sites for disease-carrying organisms.

2.2 Assessment of HCWM Practices

HCWM is a major issue and has become a key aspect of the national health policies of many countries [24]. WHO has published technical guidelines and reports on the safe management of HCWs in developing countries [10, 11]. Quantitative and qualitative methods are the major techniques used to assess HCWM practices in a healthcare facility. Quantitative techniques have been used exclusively in countries like India [4], Thailand [7], Egypt [25], Ghana [17, 20], and Nigeria [1,8]. Quantitative approaches involve mainly the use of structured questionnaires and the results are analysed using descriptive statistics like frequency Distribution and percentages. The reliability of the questionnaire can be determined by the Kappa Test-Retest as done by Alimohammadi et al. [26].

Some studies have employed other techniques than basic descriptive statistics to analyse these data. Bivariate analysis such as the Pearson correlation coefficient was used by Alimohammadi et al. [26] and Mbuvi et al. [27] to determine the correlation between the variables affecting HCWM. Agyekum and Wilson [28] employed linear regression to study the correlation between some variables and waste management practices at studied health facilities. Pearson's Chi-square test has also been used to determine the correlation between variables affecting HCWM [1, 8, 29, 30, 31, 32, 33]. The Fisher's test has also been used in conjunction with the chi-square test [34]. However, the results of the bivariate analysis have been further exploited by some studies. The independent variables that were significantly associated with HCWM practices in the bivariate analysis were utilized for multivariate analysis; which involved performing binary logistic regression based on adjusted odds ratios with a 95% confidence interval and a P-value [3, 27, 34, 35]. Principal Component Analysis (PCA) was employed by Oyekale and Oyekale [36] to combine some variables into indices of risky and safe HCWM, which were analysed for the healthcare facilities studied. These indices were then used to develop models using the ordinary Least Square Regression.

Qualitative approaches have also been used exclusively in countries like Nigeria [37] and Iraq [38]. Qualitative approaches include on-site investigations and personal and group interviews. While some vital information might be lost during direct interviews, on-site investigations can reduce the bias from the interview process [38]. Qualitative approaches have also been combined with quantitative techniques in many works of literature [6, 17, 39, 40]. Qualitative techniques can produce more accurate results than quantitative techniques since respondents can narrate the true situation and this can also be confirmed by physical observation. A typical example of this was observed in the study of Dawood et al. [41] where a discrepancy was observed between the responses in the questionnaire and the actual waste management situation in the hospital.

2.3 Solid HCWM Practices

Waste generation, segregation, storage, collection, transportation and disposal are the key elements of the solid waste management process. This section highlights some prevalent practices in the world concerning these elements.

i. Solid HCW segregation:

Segregation or sorting is the responsibility of the waste producer and must be done in the closest proximity to the point of generation [10]. Sorting wastes into colour-coded plastic bags or containers helps in identifying categories of healthcare waste. This ensures the appropriate disposal of waste according to its risk level [20]. The availability of a consistent colour coding and labelling system for various categories of HCW aids in the efficient collection and treatment of waste [17]. WHO recommends that HCW be separated into different categories as shown in Figure 5. However, WHO also recommends the minimum standard of segregating HCW using the three-bin system as depicted in Figure 6.

Studies in Ethiopia [35] and Palestine [19] revealed a lack of segregation of healthcare wastes as the entire wastes were collected in a single container without considering the risks arising from the hazardous fractions. A study in Ghana indicated that colour coding was not a common practice across the three categories of hospitals studied [20]. In another study in Ghana, Adu et al. [17] also reported that there were efforts to segregate hospital wastes, most especially in high-risk areas. However, these efforts were nullified by a lack of uniform colour coding and labelling systems for the various types of wastes. Mbuvi et al. [27] in their study in Kenya also reported that one-third of health institutions used unlabelled containers which were not sufficient and healthcare wastes were not separated from ordinary wastes. They also indicated that the containers were coated with very thin and easily perforated plastic bags leading to leakage and spilling. This situation is identical to the one reported by Al-Khatib et al. [19] where there were frequent ruptures in the waste sacks. A case study conducted in China [40] revealed that none of the hospitals segregated their medical waste accordingly. Kwikiriza et al. [43], in their study in Uganda, indicated that although sufficient waste-collecting bins were available, the lack of coloured liners for the bins made segregation inconsistent.

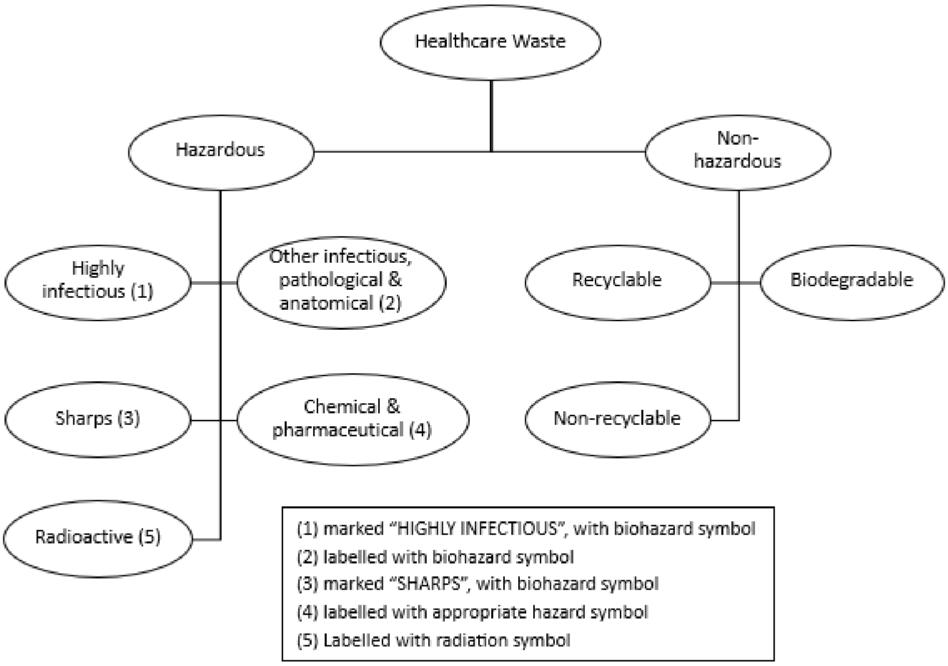

Figure 5: Recommended HCW segregation

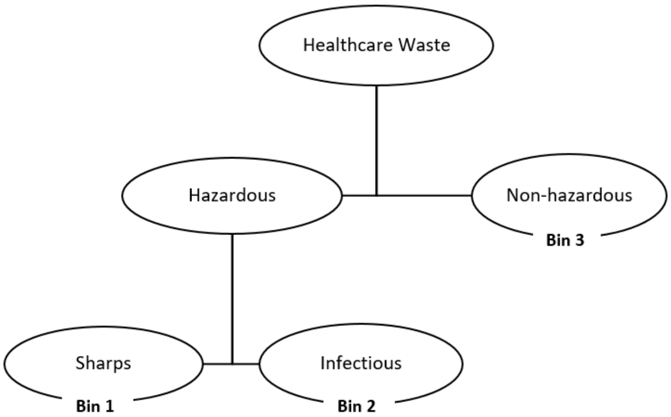

Figure 6: Minimum HCW segregation (three-bin system)

These results are different from the works of Khedre et al. [25] and Akkajit et al. [7] with studies carried out in Egypt and Thailand respectively. Both studies showed that the use of colour coding to identify and classify waste was highly practised, which indicated a high level of understanding of HCWM. Dawood et al. [41] also reported that in Iraq, non-hazardous wastes were placed in black bags and collected for disposal as municipal waste while the hazardous waste was collected in yellow bags. Similarly, Awodele et al. [39] in their study in Nigeria reported the prevalent use of colour codes for identification of wastes. They also reported the common use of safety boxes for sharp collections following the necessary precautions. In a similar study in Nigeria, Macaulay and Odiase [42] reported that sharps were segregated in separate improvised cartons while all other wastes were mixed with municipal wastes. They commented that this is not a suitable practice because other healthcare wastes apart from sharps are also harmful; likewise, the cartons used for segregating the sharps are made of cardboard paper that is susceptible to punctures and leaks.

Segregation of wastes is important as seen in a study where all the infectious wastes are not segregated; thus, leading to the wastes receiving the same treatment, thereby increasing the overall cost of managing the waste [44]. Improper medical waste separation increases the exposure of healthcare workers and waste handlers to infections, injuries, and other occupational risks [45]. In a study in Croatia, Kanisek et al. [46] concluded based on their analysis that 60–80% of the sharp injuries in non-healthcare workers (cleaning staff) are due to improper mixing of sharp objects with infectious wastes.

ii. Solid HCW collection, transportation and storage:

Tagging waste bags and containers with dates, type of waste, point of generation; transporting wastes using well-defined routes that would prevent contact with patients and other neat areas, and a well-planned collection schedule are some of the WHO recommendations for proper HCWM. Studies carried out in Uganda [43], Iraq [41] and Palestine [19] revealed manual transportation of wastes, either by hand or in a wheelbarrow. Awodele et al. [39] also reported the use of hand, trolleys, and wheelbarrows while one of the selected hospitals in the study used a makeshift constructed truck to transport waste. This method is still not effective as a single trolley was used to transport all the waste generated. Likewise, in Thailand, a study revealed that incorrect knowledge about the transportation of waste was prevalent [7].

WHO recommends that containers of HCW be stored temporarily in designated areas close to the medical area but far from patients and public access. In the absence of designated areas, a locked room or utility room for keeping cleaning equipment, linen and waste can be used. In China, about three-quarters of the hospitals sampled had designated storage areas to store medical waste and enough experts to manage the waste appropriately [40]. This situation is also similar to that of Egypt [25]. However, in Nigeria and Palestine, as observed in studies by Ugbena [37] and Al-Khatib et al. [19] respectively, a lack of designated storage areas for storing HCW in the hospital was reported. Also, in Iraq, as discovered by Dawood et al. [41], piles of waste were found in open areas and around the incinerator.

iii. Solid HCW treatment and disposal:

Treatment of HCW minimises the risks to humans and the environment. Where possible, waste materials should be reused to minimise the quantity of waste [10]. However, if this is not feasible, proper waste treatment should be carried out before final disposal. Incineration is the prevalent method of treating of HCW in developing countries [17, 47]. In Ghana [17] and Ethiopia [35], most incinerators are operated above their capacity and have chimneys without air pollution control devices (APCDs) which makes the chimneys release gases containing toxic organic and inorganic pollutants thereby causing air pollution. There is also the issue of a lack of proper sorting of wastes before feeding into the incinerators which would increase the operation time of the incinerator [17]. Gidarakos et al. [18] sampled bottom ash from a hospital medical waste incinerator in Greece where about 880 kg of hospital waste is incinerated every day. Based on the chemical analysis results, they concluded that the bottom ash posed a danger to drinking water and soil.

Modern treatment methods like autoclaving, microwave and steam sterilization have been adopted by developed countries to treat HCW, which have proven to be more sustainable and efficient than incineration, but the high cost and complexity have limited the adoption of these modern methods to a few developing countries [16]. In Iraq, although incineration is the common method of treating HCWs, few facilities treat wastes through autoclaving [38]. A similar situation was observed in Brazil where the majority of the HCWs are incinerated while the rest are autoclaved before going to thermal treatment [44]. The double treatment of autoclaving and thermal treatment was attributed either to the highly infectious nature of the waste, lack of segregation or the choice of the waste management companies. Likewise, Adu et al. [17] revealed that a hospital in Ghana has phased out incineration and now uses an autoclave installed for infectious waste sterilization.

Awodele et al. [39], in their study, revealed that in the hospitals studied in Nigeria, the wastes are collected, segregated accordingly, and transferred to the on-site storage and the municipal waste management authority collects the waste and transfers it to the transfer loading station to be treated by hydroclaving. Also, in Uganda, a study revealed transportation of HCW from the hospital storage site to a processing plant outside the hospital in a dedicated refrigerated vehicle; yet many of the staff in the hospital opined that the hospital should dispose of the waste instead of sending it out [43]. In Palestine, hazardous and infectious wastes are autoclaved for sterilization, which can then be safely disposed of with other HCWs and ordinary wastes at the landfill [19]. They noted that pathological wastes like truncated human parts and embryos from abortions are handled according to legal religious practices, which may require delivering such wastes to the owners to be buried as they wish.

Proper disposal of HCW is crucial in reducing reduce environmental impacts and the risk of infection [44]. Dawood et al. [41], in their study in Iraq, revealed that even though sorting of waste was done, though not at the required level, the method of disposal of HCW was not done appropriately. This is evident from the practice of collecting hazardous wastes in yellow bags and burning them without separating the plastic wastes, injections and needles. In a study in China, many of the healthcare facilities burnt the hazardous medical wastes, some dumped their wastes into landfills while some rural healthcare facilities mixed and disposed of hazardous HCWs with municipal waste or sold them to recycling vendors [40]. Similarly, a study in Thailand showed that HCW was disposed of in the municipal solid waste bin placed along a public road [7]. Afolabi et al. [48] surveyed some private facilities and discovered that open burning was the predominant method of disposing of HCW while some were buried or dumped along with municipal wastes.

2.4 Liquid HCWM Practices

The disposal of liquid HCW has not gotten much attention as solid wastes. Liquid HCWs are generally disposed of through the existing sewage system of the hospital [19, 38, 43]. Liquid HCWs like laboratory and X-ray chemical waste disposed of in drains and into soakaways can contaminate the groundwater; making it unsafe for drinking [43]. For instance, Mensoor [38] observed that in Iraq, a hospital located at the Tigris Riverbank dumped its liquid biomedical waste into the sewage system of the hospital and concluded that this would eventually lead to contamination of the Tigris River with biomedical and chemical substances. This is not far-fetched as pathogenic microorganisms are present in blood and urine [19]. Agyekum and Wilson [28] also reported instances where a hospital in Accra, Ghana was alleged to have discharged their liquid healthcare waste into the city's main sewers which had long-term adverse health effects on nearby residents.

2.5 Factors Affecting HCWM

i. Knowledge, occupation and self-awareness of standard safety practices:

Knowledge and self-awareness of healthcare workers are fundamental drivers in HCWM [7]. A study in Nigeria [39] revealed that the healthcare workers undertook adequate awareness and training programs that manifested in proper segregation, categorization and disposal of HCW. Studies in Egypt [25], Palestine [19] and Ethiopia [35] revealed that healthcare workers do not undertake adequate pre- and post-employment training programs concerning HCWM. Similarly, a study in Croatia observed a lack of knowledge and awareness about proper segregation and associated risks [46]. In Nigeria, Ugwu et al. [6] reported a high level of awareness about the dangers of HCW in the medical facilities studied. Some studies have shown that while the medical staff had ample knowledge about HCWM, the non-medical staff who collect and dispose of the wastes had limited knowledge and awareness about HCWM [43, 49]. It is worth noting that knowledge and awareness of HCWM may not correlate to the level of education. This is based on a study by Odonkor and Mahami [20] in Ghana where they discovered that healthcare professionals with bachelor's degrees had more knowledge of HCWM and were more willing to undertake training programs than those with master's degrees or higher qualifications. Lakbala and Lakbala (as cited in [20]) attributed the lack of willingness of workers with higher qualifications to undertake training programs to their busy schedules or the impression that the programs had no direct impact on their speciality and promotion. Efficient HCWM can be achieved if workers are trained and have the necessary skills to handle waste correctly [28].

Some studies discovered a correlation between the type of occupation and the level of HCWM practice. Awodele et al. [39] and Olaifa et al. [49] observed that nurses showed a better understanding of the HCW categorization than other professionals did. However, this was surprising, as it would be anticipated that doctors, dentists, and medical technologists who have regular contact with hazardous healthcare materials should have more knowledge about HCWM [49]. Awodele et al. [39] attributed the nurses' superior knowledge to their frequent training in hospital waste management. Likewise, in Ghana, the Diagnostic staff exhibited better waste-sorting behaviour than doctors, nurses and other staff [17]. A study in Thailand revealed a positive correlation between working experience and level of knowledge about HCWM [7].

ii. Attitude to proper HCWM:

A good attitude towards safe HCWM is important since a waste management system with well-trained and well-motivated staff is more efficient than an expensive system with unmotivated and uneducated staff that does not recognize their duties and risks of HCW [49]. A study in Ghana revealed that the majority of healthcare professionals believed that proper HCWM like the use of protective equipment, waste disinfection, and proper disposal had no positive influence in minimizing the risks of infections [20]. Similarly, some studies have shown the indiscriminate and inconsistent use of waste bins by hospital staff, which reflects a poor attitude towards proper HCWM [9, 43]. Similarly, Macaulay and Odiase [42] observed a poor attitude among the sanitary staff responsible for collecting and storing HCW, which they attributed to their low level of education and poor training.

In contrast, Gao et al. [40] and Akkajit et al. [7] reported good and positive attitudes towards HCWM in their case studies. Olaifa et al. [49] also observed a positive attitude towards proper HCWM but poor knowledge about the dangers of improper HCWM. The attitude of some healthcare workers to HCWM can also be linked to the assignment of duties to workers as evident in some studies. Kwikiriza et al. [43] reported that some clinical staff attributed the role of segregation of wastes to the porters who transport the waste. Segregation of waste, which must be done at the point of generation, is the responsibility of the patient's healthcare giver as observed in studies by Khedre et al. [25] and Al-Khatib et al. [19] where the medical staff are in charge of separating the waste. Proper segregation of HCW is the obligation of the person who produces the waste [10].

iii. Availability of manuals/guidelines and waste management committees:

In Ghana, Agyekum and Wilson [28] observed that generally, hospitals lack waste management manuals; however, they made use of Ghana's national plans and strategies for medical waste management. Dereje et al. [3] observed better HCWM practice in private hospitals in Ethiopia compared to public hospitals, which they attributed to adequate supervision and assessment procedures in private hospitals. Ugbena [37] discovered that all facilities studied in Nigeria had infection prevention committees whose tasks are to ensure proper HCWM, review current practices and make recommendations to the management on issues about HCWM. In one of the facilities, Ugbena [37] also discovered the incorporation of members from the local community into such committees, which buttresses the notion that people living around such facilities also need to be aware of the dangers of HCW. Malik et al. [9] also observed the poor attention of the HCWM committees in the hospitals studied. A peculiar case observed in China revealed that there is a lack of coordination among the agencies involved in HCWM, which makes it difficult to supervise and monitor the level of compliance with the established policies [40]. Wassie et al. [35], based on their study in Ethiopia, concluded that the presence of guidelines or manuals and assessment by regulatory bodies determined the degree of HCWM in the clinics studied. The lack of laws, rules, and regulations regarding HCWM makes it difficult to provide proper guidance and training, monitor and assess the level of compliance and impose sanctions accordingly.

iv. Availability of HCWM materials:

The availability of waste disposal materials is fundamental to waste management [20]. Studies in Bangladesh [23] and Uganda [43] revealed a lack and improper use of personal protective equipment (PPE) such as gum boots, gloves, caps, and overall coats. Elsewhere, studies of private healthcare facilities in Nigeria [48] and Ethiopia [35] reported high use of PPE in waste handling. However, an earlier study in Nigeria [39] on two public and five hospitals in a state in Nigeria reported improper use of PPE. Som and Hossain [23] observed an inadequate supply of baskets for the collection and storage of waste. Kwikiriza et al. [43] also reported a lack of correct liners for waste bins which led to improper segregation of wastes and adversely affected the final disposal.

v. Ownership of healthcare facility:

Healthcare facilities are generally categorized based on their size, function and type of services rendered into four classes namely tertiary, secondary and primary healthcare facilities and private/diagnostic service laboratories [29]. Tertiary health-care facilities have sophisticated equipment and many specialists. Secondary facilities can handle fairly complications while primary facilities are limited in terms of healthcare delivery [29]. Some studies have compared the HCWM practices of private and public hospitals. A study in Ghana [20] showed that private hospitals had an adequate supply of waste disposal materials compared to public hospitals. A study in Ethiopia [35] revealed better HCWM practices among private clinics with adequate budgets for waste management than those without it. A study in China showed that public clinics relied on funding from local governments that already have limited resources [40]. This affected the HCWM practices in these clinics. A study carried out in Ethiopia [3], found that there is a tendency for healthcare workers in private hospitals to observe better HCWM practices, which could be influenced by the public perception that private clinics should have better equipment and a neat and infection-free environment compared to public hospitals.

2.6 Modelling Applications in HCWM

The first step in setting up a system for managing medical waste is gathering sufficient data about the quantity and composition of the generated solid HCW. The rate of generation of HCW determines the collection system, size of storage facilities and the capacity requirements for treatment and disposal systems [14]. Some of the factors influencing the rate and type of HCW generated include the type of healthcare facility, type of services provided, number of patients, location of the facility and the waste management system [50, 51]. A sustainable HCW management system can only be achieved if the waste generation is predicted accurately, making modelling an integral part of the waste management system [51].

Data collection is essential to construct a sound predictive model. HCW generation data are collected through surveys, questionnaires, and field investigations [14]. Predictive models can help in the planning, operation and optimization of an efficient HCWM system [52, 53, 54]. Scientists have developed models to predict the rate of generation of HCW [14]. Statistical analysis can be used to predict HCW generation by evaluating the correlation between significant factors and the quantity of waste generated [14, 53]. The regression analysis has been used extensively in estimating and forecasting the HCW generation rate. Awad et al. [21] in their study conducted in Jordan, developed linear regression (LR) and nonlinear regression (NLR) models to predict the quantity of medical waste to be generated. They discovered that the significant variables affecting HCW generation are the number of beds occupied, patients admitted and the type of hospitals. Debita et al. [55] also applied LR to predict the HCW generation rate in Romania using the number of patients as the input parameter.

Sabour et al. [56] predicted the HCW generation rate in Iran using Multivariate (multiple) linear regression (MLR) with the number of active beds and number of hospitals as input variables. They were able to develop an equation to predict the total HCW for any year. Tesfahun et al. [53] employed MLR to predict the HCW generation rate in Ethiopia using the number of inpatients and outpatients as input parameters. They discovered that these two parameters were significant in the HCW generation rate. Similarly, Çetinkaya et al. [51] used MLR to predict the rate of HCW generation in Turkey. Among age classification, gross domestic product (GDP), number of polyclinics, number of beds and number of inpatients, they chose age classification of patients and gross domestic product per capita to be the most effective parameters of waste generation. The MLR equations developed by Al Fatlawi and Al-Alwani [14] to predict the quantity of HCW generated in Iraq utilized hospital capacity, bed occupancy, number of inpatients, and number of outpatients as input parameters.

Idowu et al. [57] applied MLR to estimate the rate of waste generation from two healthcare facilities in Lagos, Nigeria. Their study revealed that the number of beds and the number of patients were significant parameters for HCW quantity. The study in India conducted by Thakur and Ramesh [50] in which MLR, Artificial Neural Networks (ANN), and Polynomial regression equations were used to develop predictive models revealed that the type of healthcare facility, and number of beds occupied were significant factors. Golbaz et al. [54] conducted a study in Iran to predict the HCW generation rate. They applied MLR in addition to several machine learning tools including ANN, Fuzzy Logic-Artificial Neural Networks (ANFIS) and Support Vector Machines (SVM). They used seven parameters as input including the number of active beds, the number of hospital staff, and hospital ownership type. All the input variables were modelled against three output (target) groups namely infectious hospital waste, general hospital waste and total hospital waste. They found out that each of the input parameters had varying significances on the target groups. Erdebilli and Devrim-Içtenbas [58] also predicted HCW generation in Turkey using ensemble voting regression (VR) algorithms based on machine learning. The algorithms employed were Random Forests, Gradient Boosting Machines (GBM) and Adaptive Boosting Algorithms. The input variables were gross domestic product (GDP), crude birth rate, number of hospitals, and number of beds available. They discovered that GDP was the most effective parameter in predicting the quantity of HCW. Details of the various studies reported on the prediction of HCW are presented in Table 1.

Table 1: Healthcare waste generation modelling

Prediction Tool	**Input Variables**	**Country**	**Author**
LR, NLR	Number of active beds, number of patients, type of hospitals	Jordan	[21]
MLR	Number of active beds, number of hospitals	Iran	[56]
MLR	Number of patients, the number of beds	Nigeria	[57]
LR	Number of patients	Romania	[55]
MLR	Number of inpatients, number of outpatients	Ethiopia	[53]
MLR, ANN, Polynomial regression equations	Type of healthcare facility, bed occupancy	India	[50]
MLR	Age classification (3 classes), gross domestic product per capita	Turkey	[51]
MLR, Neuron-based machine learning (ANN, ANFIS), Kernel-based machine learning (SVM, LS-SVM, FSVM)	Number of active beds, number of the hospital's wards, number of hospital's staff, hospital ownership type, number of occupied beds, number of inpatients, number of hospital's activity years	Iran	[54]
Random forests, gradient boosting machines, adaptive boosting	Crude birth rate, gross domestic product, number of hospitals, number of beds available at the hospitals	Turkey	[58]
MLR	Hospital capacity, bed occupancy, number of inpatients, number of outpatients	Iraq	[14]

The use of geographic information systems (GIS) has been applied to HCWM. Forghani et al. [59] applied GIS and Expert Systems to select hospital waste disposal sites in Mashhad, Iran. Their findings indicated two suitable disposal sites and the current disposal site was deemed inappropriate. In a similar study in Iran, Torkayesh et al. [60] generated GIS suitability maps based on the weight of location criteria from a Best-Worst Method model in order to pinpoint several sites for the construction of a landfill.

3. METHODOLOGY

We conducted a focused literature search on Google Scholar, Science Direct, and PubMed to identify the relevant literature on HCWM globally. The search strategy used to search the databases was:
((“healthcare waste” OR “medical waste” OR “infectious waste” OR “clinical waste” OR “hazardous waste” OR “biomedical waste”) AND (“management” OR “practices” OR “modelling” OR “prediction”)).

This Literature review considered literature published in 2004-2021; and can be accessed in full text in portable document format (pdf). A separate search was carried out for literature and documents produced by government bodies, and NGOs (non-governmental organisations) such as the World Health Organisation by visiting the websites of the organisations.

The inclusion criteria were articles that focused on HCWM practices (segregation, storage, treatment etc.), factors influencing HCWM practices, HCW modelling and prediction; and were published in English language. Articles that did not meet the inclusion criteria were excluded. Another key criterion employed was to choose the most recent publication on a particular aspect of HWCM in a country. However, in cases where different publications focused on different regions in the same country; then the different publications were included. Duplicate publications were expunged manually.

The distribution of articles chosen by year of publication is depicted in Figure 7 while the distribution of articles by country is shown in Figure 8.

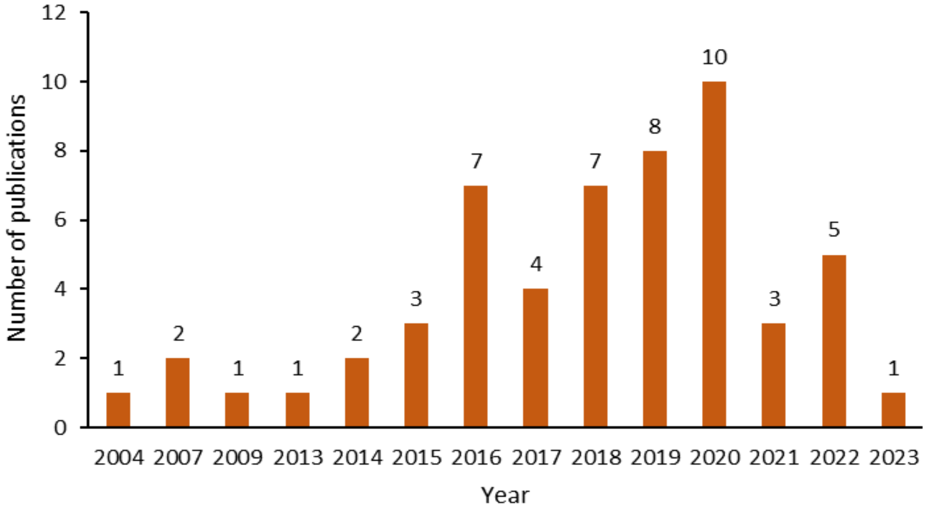

Figure 7: Yearwise distribution of studied publications

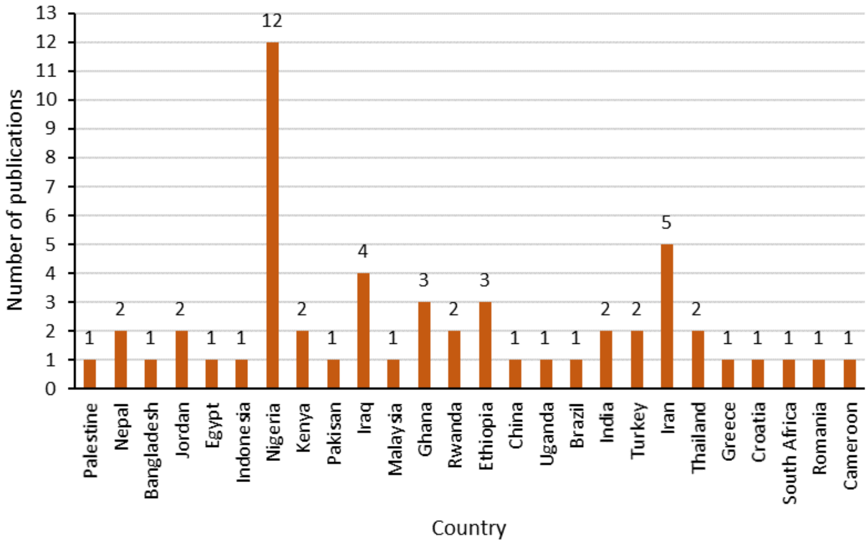

Figure 8: Distribution of studied publications by country

4. DISCUSSION

Over 50% of the publications studied reported poor waste segregation practices such as the use of single or insufficient waste containers, and lack of colour coding and labelling systems. Poor segregation of wastes increases environmental hazards, the risk of infections, and injuries among healthcare workers. Healthcare facilities with poor segregation practices are prone to also have poor collection, storage, and transportation systems. This is evident from the studies reviewed. Manual transportation of HCWs using hands, trolleys, and wheelbarrows was reported in a number of studies. The nature of HCWs requires specific storage and collection procedures. An example is hazardous waste which should not exceed 48 hours storage period [11]. Lack of designated storage areas has been reported in studies carried out in Nigeria, Palestine, and Iraq while the contrary has been observed in China and Egypt.

Nearly 50% of the studies revealed incineration as the most prominent HCW treatment technique. Common issues with incinerators in use in some countries are overloading and lack of air pollution devices in the chimneys. Countries like Ghana, Iraq, and Brazil have started treating HCWs through autoclaving. However, the high cost and technicality of autoclaving and other modern treatment methods are barriers for many developing countries. Proper disposal of HCW significantly reduces environmental impacts and the risk of infection [44]. Open burning, burying of wastes, and landfilling are the common methods of HCW disposal observed in the reports studied. Mixing of HCW with municipal waste is also common among the developing countries. Almost 30% of the publications revealed poor disposal of liquid HCW through the existing sewage system, while almost 70% did not include the assessment of liquid HCW disposal in their studies. This reveals that liquid HCWM is understudied.

HCWM practices are influenced by certain factors which are also critical in discussing HCWM. Adequate knowledge about HCWM was reported in only 25% of the publications studied as observed in countries like China and Thailand. This would inevitably increase the risks associated with HCWM. Studies in countries like Egypt, Ethiopia, and Palestine have reported poor knowledge and awareness of HCWM practices. Varying levels of knowledge and awareness have been reported across Nigeria. The studies have shown that the type of occupation, level of education, and level of experience influence the knowledge about HCWM.

Misconceptions about who to segregate waste; whether the clinical staff or the porters have also contributed to poor HCWM practices. Availability of waste disposal materials, waste management manuals, and adequate budget are also critical issues that have been studied. Laws, rules, and regulations regarding HCWM help to monitor and assess the level of compliance and provide proper guidance on training. Some studies have opined that adequate budget and supply of waste materials in private clinics account for better HCWM practices compared to public clinics.

In an attempt to plan and develop an efficient HCWM system, several authors have developed models to predict HCW generation rate using tools such as regression analysis and Artificial Intelligence tools (e.g. Artificial Neural Networks and Support Vector Machines). Input parameters to the model include number of beds, number of patients, and type of hospital. Proper siting of HCW disposal sites using tools such as GIS has been carried out by some authors.

5. CONCLUSION AND RECOMMENDATIONS

This study attempted to discuss essential elements of HCWM. It is evident that despite the widespread knowledge of the risks of poor HCWM, it is still practised in many countries notably the developing ones. Liquid HCWM has not been studied as much as solid HCWM; which is evident from its low inclusion in many studies. An efficient HCWM is essential for the preservation of human health and the environment. However, this cannot be achieved without proper waste management principles from the point of generation to disposal. In the same vein, proper HCWM practices cannot be carried out without adequate knowledge and training of healthcare workers and waste handlers, adequate financial allocation, availability of HCWM materials and a dedicated waste management committee. This study can be a guide for discussing the key issues relating to HCWM.

Further research can identify other core aspects of HCWM. The impacts of many other factors on proper HCWM can be studied in the future. More research needs to be done on the proper management of liquid HCW. Healthcare waste minimization, reuse and recycling opportunities are areas that can be included in further studies. Application of modern computer technology like the use of Artificial Intelligence for prediction and GIS for real-time monitoring and reporting of HCW can be further explored.

Even though the HCWM guide by WHO can be adopted internationally, countries still need to come up with their local manuals and guides, which will reflect the available budget, manpower, technological know-how and locally available materials and be better suited to manage their HCWs. Frequent training and sensitisation of healthcare workers and the general public, proper documentation of HCW generation rate, appropriate segregation, collection, transportation, storage, treatment, and disposal practices which conform with national and international standards are required to achieve an efficient and sustainable HCWM system.

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