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PATHWAYS TO SCIENTOMETRIC BIOMEDICAL WASTE MANAGEMENT IN COVID-19 ERA

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ABSTRACT

Biomedical waste management (BMW) is in the spotlight due to the enormous impact of the COVID-19 pandemic on public health and hospitals. Further, countries with large populations generate significantly higher amounts and variety of both hazardous and non-hazardous BMW, leading to a need for a comprehensive strategy for effective BMW management. The improper, unscientific disposal of BMW causes environmental pollution and presents a continuing, significant health hazard to the individual and the community. The present study provides a comprehensive assessment of the various types of BMW generated and critiques their current disposal strategies. A detailed appraisal of current, in-place BMW management guidelines from various world organisations is presented, and emerging protocols for BMW disposal during the ongoing COVID-19 pandemic are assessed. Finally, new state-of-the-art technologies, which can lead to breakthrough improvements in various stages of BMW generation, collection, treatment and disposal process, are examined. The secondary applications of BMW are highlighted, and recommendations for enhancing the BMW lifecycle practices are presented.

Keywords: Biomedical waste, Waste disposal guidelines, Waste management, COVID-19, treatment technologies

INTRODUCTION

In recent years, the medical and pharmaceutical sectors have worked relentlessly to provide society with high-quality healthcare. Scientific advancements and sophisticated medical facilities have enhanced life expectancy and the standard of living. They have, however, paved the way for toxic and hazardous wastes (Peng *et al.,* 2020). These wastes are known as biomedical waste (BMW) or healthcare waste (HCW). They are the waste materials created in healthcare institutions and research labs during the diagnosis, treatment, and immunisations of humans or animals, along with research activities associated with manufacturing or testing (Singhal *et al.,* 2017). In the manual released by the World Health organisation on safe and efficient management of Healthcare waste (WHO, 2020), 75-90% of the healthcare waste is non-hazardous and often called general health care waste. The remaining 10-25 % of the waste is considered hazardous. The hazardous nature of healthcare waste is exacerbated by Infectious agents, chemical compositions that are genotoxic or cytotoxic, biologically aggressive drugs, radiation, and used sharps (Askarian *et al.,* 2010; Hantoko, *et al.*, 2021). Biomedical waste cannot be treated in the same way as municipal waste. Biomedical wastes contain a number of bacteria and viruses like Herpesvirus, Mycobacterium tuberculosis, helminths, hepatitis-A,B and C, H5N1 virus and many others (Ramteke and Sahu, 2020). Negligence towards BMW will maximise the risk of developing life-threatening infections that are predominantly transmitted through faeces, saliva, and eye secretions. Hence all the waste management workers and anyone working closely with BMW must be equipped with PPEs, three-layer masks, splash-proof aprons/gowns, nitrile gloves, gumboots and safety goggles (Bao *et al.,* 2021).

Although the Biomedical waste generated is detrimental, under normal circumstances, they are manageable. Managing biomedical waste becomes extremely difficult and complex in a viral outbreak (Sharma *et al.,* 2020). The covid-19 epidemic has disrupted the entire world. Sars covid-2 has infected over a million people in over 219 countries, and the virus continues to be a severe public health hazard due to its continual mutations (Tripathi *et al.,* 2020a). Considering the rapid increase in the number of COVID-19-infected patients, along with the disease's highly transmissible characteristics, the volume of healthcare solid wastes generated has skyrocketed. According to a study undertaken by (Benson *et al*., 2021a; Sangkham, 2020) a total of 16,659.48 tonnes of biomedical waste is generated every day throughout Asia, with India accounting for around 20% of the total.

Moreover, the increased usage of personal protective equipment (PPE) during the COVID-19 pandemic compared to normal conditions has further led to the spike inhealthcare waste (Benson *et al.,* 2021a; Chand *et al.,* 2021a; Kumar *et al*., 2021). Furthermore, several countries have begun to offer vaccinations to the public. Although vaccinations havecurtailed the impact of Covid-19, Theyhave further accumulated biomedical waste. The pandemic has immensely altered the dynamics of BMW in many countries (ADB, 2020).

Currently, Millions of infected face masks, gloves, and materials used to diagnose, detect, and cure SARS-CoV-2 and other human infections are undergoing the irreversible process of becoming infectious wastes. They, in turn, may cause environmental and health issues if they are incorrectly stored or handled (Chand *et al*., 2021a; Závodská *et al*., 2014). Furthermore, due to theincreased BMW, the process of improper medical waste disposal leading to environmental pollution is evident and consequential (Kanhai *et al.,* 2021). In this regard, many health care agencies worldwide like WHO, CPCB and many other government agencies have revised their guidelines on BMW managementto curb the spread of the virus. Guidelines regarding frequent sanitation, segregation of waste into colour-coded bags, disposal of treated wastes etc. are issued in numerous countries (ADB, 2020). The recommendations issued by the authorities have their share of merits and demerits, so it is critical to weigh them all and come up with a single customised approach for effectively managing the BMW. This study intends to examine the recommendations published by several nations to establish a single integrated approach for the efficient management of BMW. The handling and administration of BMW in situ entails several processes. Collection, segregation, disinfection, storage, transportation, and final disposal are all necessary procedures in the safe and efficient management of bio-medical waste (Chand *et al*., 2021a; Závodská *et al*., 2014). Amongst all of them, waste segregation is regarded as the most complex and challenging procedure. The current study addresses this issue by reviewing existing literature on robotic arms and image processing techniques to segregate BMW. Since BMW production is enormous, and all of the treated BMW ends up in landfills, it is crucial to consider the secondary applications of incinerated biomedical waste ash (IBWA) in various industries to avoid problems associated with leaching and air pollution (Das *et al*., 2021). Overall, This review is an extensive study of the state-of-the-art research and practices involved in managing the BMW in its lifecycle, treatment technologies available, and the alternate uses of the medical waste (Alam *et al.,* 2020; Kainthola *et al.,* 2019).

METHODOLOGY

After reviewing the literature available online, authors themed the structure of the paper, based on several commonalities. Authors have focused on classifying the different biomedical waste available efficient management strategies, guidelines for waste management and the alternative uses for the waste. Several papers were downloaded after datamining from reviewed journals, science direct, PubMed, newspaper articles, google scholar, media reports etc., for extracting the information as presented in the papers. For writing a few sections of the paper, all the relevant papers were mentioned in the row, with the mined data in the columns in excel before including the main body.

Biomedical waste scenario in India

Due to COVID-19, the BMW generation has been rapidly increasing. There is a tremendous increase in the amount of biomedical waste generated Fig. 1 depicts the increase in BMW from the year 2018 to the year 2020. The generation of Biomedical waste is expected to increase further due to the virus's constant mutation (Gautam *et al.,* 2010a). According

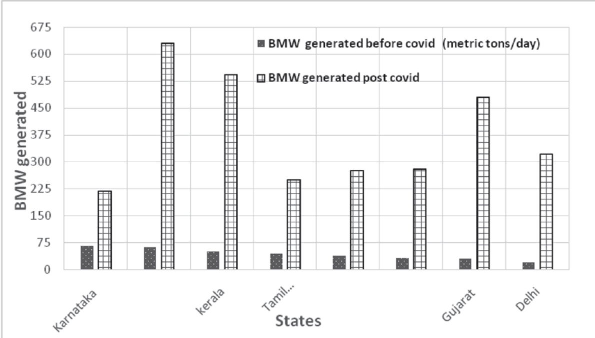

Fig. 1. Comparison of BMW generated in India before and after covid

to the Central Pollution Control Board (CPCB, 2021), data collected in 2021 indicates that the average amount of COVID-19 waste has gradually increased from 53 Tonnes per Day (TPD) in February' 2021 to 203 TPD in May'2021. India has now prioritised the vaccination process for its 136.64 million citizens. India has conducted a record vaccination campaign by vaccinating more than 90% of the population, which has also further accumulated biomedical waste (Goswami *et al*., 2021). In India, currently, only 193 CBWTF's are being operated at complete efficiency. India is currently building 25 new common treatment facilities (Benson *et al.,* 2021b; Hantoko *et al.,* 2021). (Capoor and Bhowmik, 2017; Sangkham, 2020). Out of the 193, CBWTF's some treatment facilities in India are being underused, and some of them are overused. **Fig. 2** demonstrates the comparison between the wastes generated versus the CBwtf's engaged in treating the waste. In states like Kerala and Delhi, where BMW generation per day is about 26 tons/day and 7 tons per day, only 1 and 5 CBWTFs are engaged, respectively (CPCB, 2021). This inequality imposes much strain on the CBWtfs since the trash created is massive yet

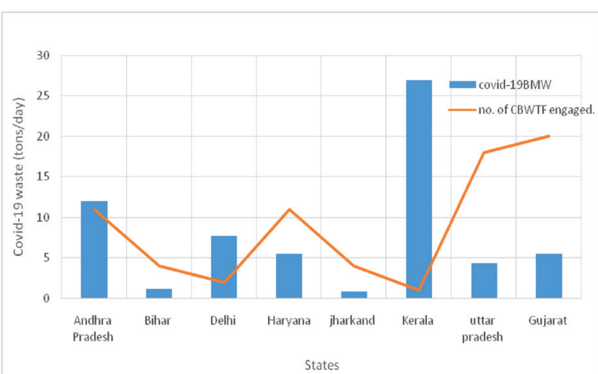

Fig. 2. Comparison BMW generated versus CBWTF's in the state

has few treatment facilities (Faizan, 2021; Soliman and Ahmed, 2007). On the contrary, CBWTFs are underutilised in a few states. Gujarat, for instance, produces around 7 tonnes of BMW per day but utilises up to 20 CBWTFs. The same is true for Uttar Pradesh and Haryana (Agrawal *et al.,* 2021; Amariglio and Depaoli, 2021; Rajan *et al.*, 2019). The infrastructure and human resources to handle the incremental quantity of BMW are inadequate. Nevertheless, India is still pushing to manage BMW waste with the country's limited resources efficiently (Behera, 2021a). The Indian government has released a new application called the Covid19 BMW app. This application helps in tracking, Biomedical waste. Details regarding the covid-19 application and the guidelines issued regarding BMW are discussed in the next section (Ministry of environment, forest and climate change, Government of India, 2021).

Characterisation of BMW

Studies suggest that the composition and characteristics of healthcare waste have remained largely unchanged from the pre-covid period, with the exception that the volume created has grown dramatically. Aside from that, it is clear that waste created by non-healthcare organisations has increased sharply (Chand, *et al*., 2021a; Hantoko, *et al*., 2021). Characterisation of the physicochemical composition of Biomedical waste is a significant part of the waste assessment process. This information is critical in establishing waste-reduction strategies. Setting up an effective recycling programme mandates knowledge of the composition of non-hazardous waste or general health care waste (Singhal *et al.,* 2017). The physicochemical characteristics of the infectious waste are used to define equipment specifications for treatment methods. Some steam and microwave treatment systems, for instance, require a minimum amount of moisture in waste; the organic load and water content influence some chemical processes (Gautam *et al*., 2010a).

Classification of Health Care waste

BMW is classified into hazardous and non-hazardous waste. The hazardous wastes are further sub-divided into six categories. They are chemical wastes, radioactive wastes, pathological waste, pharmaceutical wastes, sharps wasteand infectious waste (Bao *et al.,* 2021). **Fig. 3** gives a detailed description of the classification.

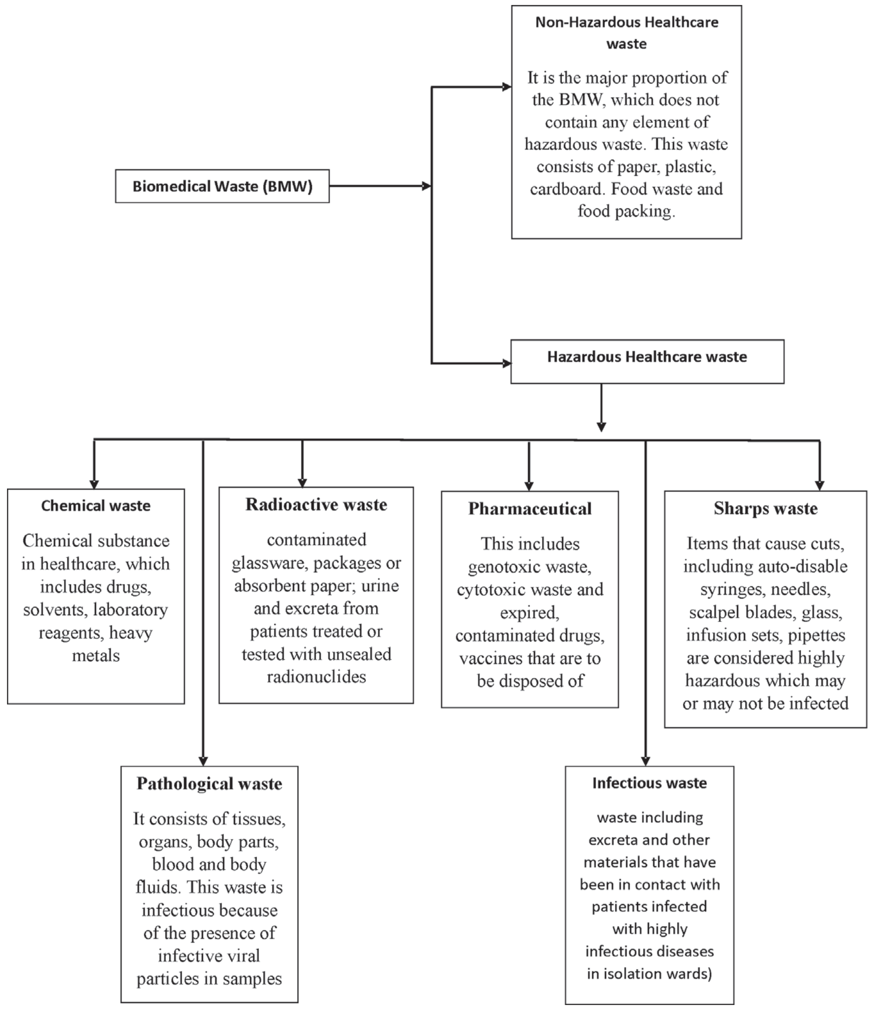

Fig. 3. Classification of BMW

Hazardous healthcare waste

- **Chemical waste**. Chemical waste is solid, liquid, and gaseous chemicals that have been dumped as a result of diagnostic and experimental work. They are toxic, corrosive, flammable, reactive, oxidising. For instance, formaldehyde is a significant source of chemical waste (Pons and Adam, 2018). It's used in pathology, autopsy, dialysis, embalming, and nursing facilities to clean and disinfect equipment, preserve specimens, and disinfect liquid infectious waste. Hazardous chemical wastes containing high levels of heavy metals are a subtype of harmful chemical waste and are often very poisonous. Mercury is an example of a highly hazardous chemical commonly found in healthcare institutions (Kanhai *et al.,* 2021).
- **Infectious waste**: Waste that contains pathogens (bacteria, viruses, parasites, or fungi) in concentrations or quantities big enough to cause sickness in vulnerable hosts are termed infectious waste. Infectious agent cultures and stocks from laboratory work; waste from surgery and autopsies on infectious disease patients. Waste from infected patients in isolation wards (e.g. excreta, dressings from infected or surgical wounds, heavily soiled clothes with human blood or other body fluids); (Das *et al.*, 2021).
- **Sharp waste**: Sharps are objects that can cause cuts or puncture wounds, such as needles, hypodermic needles, scalpels and other blades, knives, infusion sets, saws, shattered glass, and nails. Regardless of whether or not they are contagious, such materials are typically classed as hazardous healthcare waste (Chand *et al.,* 2021a).
- **Pathological waste**: Tissues, organs, body parts, human foetuses and animal corpses, blood, and bodily fluids are all examples of pathological

waste. this group should be considered a subclass of infectious waste (Achuthan and Madangopal, 2016; Col *et al.,* 2003a).

- **Radioactive waste:** Radioactive waste consists of radionuclide-contaminated solid, liquid, and gaseous materials. It is created as a result of techniques such as in-vitro body tissue and fluid analysis, in-vivo organ imaging and tumour localisation, and a variety of investigative and therapeutic methods (Soliman and Ahmed, 2007).
- **Pharmaceutical waste:** These are the waste materials Expired, unused contaminated pharmaceutical items, medications, vaccines, and sera that are no longer needed and must be handled properly are examples of pharmaceutical waste. Discarded materials utilised in the handling of medicines, such as bottles or boxes containing residues, gloves, masks, connecting tubing, and medication vials, are also included in this category (Munirathinam, 2019).

Non-hazardous health care waste: As mentioned earlier, 75-90% of biomedical waste generated is considered non-hazardous. Non-hazardous waste or general healthcare waste is the waste that has not come into contact with virulent agents, hazardous chemicals, or radioactive substances and does not include sharps. Paper, cardboard, and plastics make for more than half of the non-hazardous waste created by hospitals, with the rest comprising of discarded food, metal, glass, textiles, plastics, and wood. These wastes may be processed as municipal waste and do not require further treatment before disposal. All general HCW at health care facilities and isolation wards can be disposed of directly to the local municipal body (Chand, *et al.,* 2021a; Hantoko, *et al.,* 2021).

BMW guidelines available

The WHO is collaborating with international agencies, governments, and partners to rapidly expand scientific knowledge about the COVID-19 virus, track its spread and virulence and is constantly advising countries and individuals on how to protect their health and prevent the outbreak from spreading (Table 1). On March 3, 2020, WHO published guidelines for the safe handling and disposal of COVID-19 waste, with revisions on March 24, 2020, and April 23, 2020. The most recent recommendations, released on June 29, 2020, address infection control and prevention for COVID-19 patient care and waste management (WHO, 2020). These guidelines mainly focus on the safe collection and disposal of BMW waste. The guidelines issued by WHO for safe management of BMW specifies that infectious waste generated during patient treatment, especially for patients with COVID-19 infection, should be collected in clearly labelled sharp boxes (Pons and Adam, 2018). The waste generated should be treated on-site, but it is crucial to know where and how it is disposed of if it is transported elsewhere. Non-infectious waste should be separated from infectious waste into separate containers, and they can be disposed of as municipal solid waste (Bao *et al.,* 2021; Chand *et al.,* 2021a; Messerle *et al.,* 2018). Waste generated in the waiting room is also labelled as non-hazardous and should be disposed of in sturdy black bags that are sealed before being collected by municipal waste services. In the absence of municipal services, safe burying and controlled burning techniques can be used as a temporary solution (Scheme 2016; WHO 2020). After removing them, all personnel and frontline workers who handle BMW should wear proper PPE and practise strict hand hygiene routines. Clean and disinfect locations where COVID-19 patients undergo treatment regularly at least twice daily. Sodium hypochlorite, 0.1 per cent for disinfecting surfaces and 0.5 per cent for cleaning blood or body fluid spills in healthcare facilities are now recommended by WHO. Several disinfectants, including routinely used hospital disinfectants, are also effective against viruses like SARS-CoV-2 (Ramteke and Sahu, 2020; Tripathi *et al.,* 2020b). Excreta of COVID-19 patients must be gathered in a clean bedpan or diaper and disposed of cautiously into a separate toilet or pit latrine reserved for COVID-19 cases. Faeces must be considered a biohazard in all healthcare organisations and should be treated accordingly ((Verma et al., 2008a)).

CPCB GUIDELINES (INDIA): The Central Pollution Control Board has established several guidelines regarding BMW management. The CPCB has issued separate recommendations for isolation wards, quarantine centres, testing laboratories, CBWTFs, and local pollution control boards (Environment and Change, 2020).

Guidelines for isolation wards

According to the Biomedical Waste Management (BMWM) Rules, 2016, biomedical wastes must be collected in separate colour-coded containers with double-layered bags and labelled as "COVID-19 waste". Biomedical waste can be directly lifted from the ward to CBWTF (Behera, 2021; Chand *et al.,* 2021a; Ramteke and Lal, 2020). **Fig. 4** gives an idea about the segregation of waste into colour-coded containers. General waste in isolation wards shall be disposed of as per solid waste management rules 2016 (Environment and Change, 2020; Ramteke and Lal, 2020). Non-disposable items must be utilised for serving food to reduce waste generation. These items must be handled with care and disinfected according to hospital rules. Wet and dry solid waste bags must be tied securely in leak-proof bags and should be treated with sodium hypochlorite solution and delivered to a ULB's authorised waste collector daily. Trained sanitation staff must be provided with PPE to treat biomedical and solid waste separately. Daily disinfection of the inner and outer surfaces of storage containers/bins and trolleys with a 1 per cent sodium hypochlorite solution is mandatory (Chand *et al.*, 2021; Tripathi *et al*., 2020).

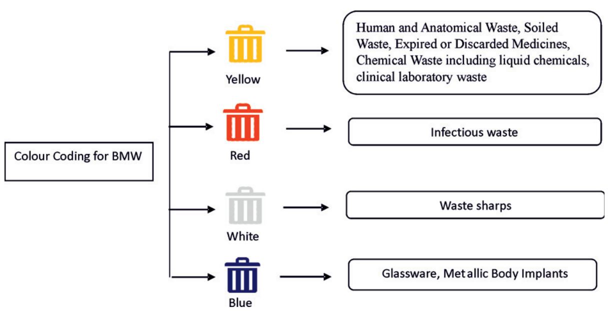

Fig. 4. Colour-coded segregation of BMW

Guidelines for Sample Collection Centers and Laboratories

All of the regulations for BMW management specified in isolation wards must be followed in research centres and laboratories. COVID19 diagnostic centres and laboratories must adhere to strict waste disposal rules. Vacutainers, viral transport media, pipettes tips, and nasopharyngeal swabs must be sterilised by autoclaving, microwaving, hydroclaving, or chemical disinfection before being disposed of under the red colour category (Chand *et al*., 2021a; Rajan *et al*., 2019).

Guidelines for Quarantine Centres

If BMW is generated at quarantine camps, it should be collected separately in yellow bags provided by ULBs. These bags should be placed in separate dustbins. General waste should not be stored in yellow bags.Masks and gloves worn by people who are not infected with COVID-19 should be kept in a paper bag for at least 72 hours before being disposed of as general waste (Moher *et al.*, 2016). Those in charge of quarantine centres should contact the CBWTF administrator to arrange for the collection of biomedical waste when it is generated. COVID-19 garbage should be stored separately in a temporary storage facility in a specific collecting box until it is handed over to CBWTF authorised staff. Waste collected can be picked directly from the ward into the CBWTF collection van. Designated trolleys and collection bins should be placed in COVID-19 isolation wards. A label "COVID-19 Waste" is pasted on these items (Gupta *et al.*, 2009). The opening or operation of the COVID-19 ward and COVID-19 ICU ward must be reported to SPCBs/PCCs and respective CBWTF located in the area.

Guidelines issued for Common Biomedical Waste Treatment Facility (CBWTF)

The CBWTF operator is responsible for performing sanitation protocols regularly, and the assigned vehicle should be cleaned with sodium hypochlorite solution after each trip. COVID-19 waste should be disposed of as soon as possible after arrival at the site. CBWTF may run their facilities for more hours if necessary to treat and dispose of more biomedical waste generated by COVID-19 treatment by informing SPCBs/PCCs (Goswami *et al*., 2021; Tripathi *et al*., 2020). The CBWTF operator shall keep a separate record of all BMWs generated, treated, and disposed of.

Guidelines for discarding PPE and masks

In general, discarded masks and gloves should be stored in a paper bag for at least 72 hours before being disposed of as dry general solid waste. PPEs that have been discarded by the public at commercial premises, shopping malls, institutions, workplaces, and other locations should be kept in a separate bin for three days before being disposed of as dry general solid trash after cutting/shredding (Chitnis *et al*., 2005; Kumar *et al*., 2015). PPEs worn by health professionals accompanying a COVID-19 diseased body to a crematorium should be treated as BMW and disposed of according to the terms of the SWM Rules, 2016 and the BMW Management Rules, 2016.

Waste disposal guidelines, People's Republic of China

The Ministry of Ecology and Environment of the People's Republic of China issued "COVID-19 Infected Medical Waste Emergency Disposal Management and Technical Guide". This Guide provides technical assistance for emergency waste disposal in the time of COVID-19. Hospitals that treat COVID-19 patients should improve their packaging and classification methods (Wu *et al*., 2021). Packaging must be done following standard protocols for packaging special containers, and each bag must have a warning symbol. Each bag should have a red contagious warning sign on it, and harmful medical wastes should be put in sharp boxes and wrapped in yellow bags. In addition, packaging size must fulfil the requirements of the corresponding feeding equipment; thus size must be considered. Health care facilities can temporarily retain BMW generated, but not for more than 24 hours, and care must be taken to ensure that the waste is not mixed with domestic waste or other non-infectious waste (Rajan *et al.*, 2019).

The collected waste shall be transported only with the help of special medical waste transport vehicles and vehicles that have been modified concerning the special medical waste transport vehicles. BMW should reach the disposal facility in less than 48 hours. After each trip, the transport vehicle should be appropriately disinfected (Inoue *et al.*, 2020). Priority should be given to COVID-19 BMW over all other wastes at the facility. Maximum storage time at the disposal facility should not be more than 12 hours. When the load is enormous, alternative disposal facilities such as hazardous incinerators, household incinerators, and industrial furnaces can carry out the disposal procedure. However, care should be taken to ensure that the waste treated and disposal facilities are compatible. To avoid cross-contamination, the feeding process into the incinerator should be automated (Hantoko *et al*., 2021). Several countries and organisations have issued treatment guidelines for COVID-19 waste. The European Commission released recommendations for waste disposal to achieve a high degree of human health and environmental protection. The recommendations include preventing or reducing waste management service distortions, coping with a growing amount of medical waste, improving workplace health and safety, and providing safe processing of residential garbage generated by residents with verified cases (Capoor and Parida, 2021; Hantoko *et al*, 2021). The Mexican government createdguidelines for better COVID-19 prevention techniques for municipal solid waste processing. Details and significant features of some guidelines are provided in Table 1.

Biomedical Waste management strategy

Collection and segregation

The best way to lower and effectively manage biomedical waste is segregation and identification of the waste. Sorting biomedical waste into colour-coded plastic bags or containers is the best way to identify the different types of waste (Col *et al*., 2003b). At the point of generation, BMW should be separated into colour-coded containers following the schedule I of the biomedical waste rules 2016. All the waste produced from hospitals and isolation wards is sealed using double-layered bags as a precaution to ensure there are no leaks. The biomedical waste collected from COVID-19 patients should not be combined with regular waste, and separate designated bins and trolleys for COVID-19 waste should be used. All bins and trolleys should be labelled appropriately and should not be placed in public areas (Riegman *et al*., 2019). Apart from this, dedicated sanitary workers are assigned to collect and dispose biomedical waste with proper safety equipment. All the containers, trolleys should be cleaned with 0.5% sodium hypochlorite every day. Wastes generated from quarantine centres and homes of suspected COVID-19 patients should be appropriately segregated. Not all wastes generated by quarantine centres come under biomedical waste (Kumar and Gupta, 2017). Wastes such as plastics, leftover food, utensils, bottles used by suspected patients come under general municipal solid waste, and they can be sent to the local municipal solid waste collector. Only wastes like tissues or swabs used masks, gloves contaminated with body fluids of COVID-19 patients, including used syringes, medicines, etc., are considered biomedical waste. All the biomedical waste generated should be collected in yellow bags provided by the local urban body (Gupta *et al.*, 2009; Kumar and Gupta, 2017).

Storage and Transportation

After segregating waste into their respective colour-coded bags, they are sealed and disinfected with 1% sodium hypochlorite. The collected biomedical waste should be labelled so that the type of waste, site of generation, date of generation are all clearly stated. This helps the working staff prioritise the waste for disposal (Patil and Pokhrel, 2005; Soliman and Ahmed, 2007). The waste that has been collected should be kept in the specified storage location. Biomedical waste generated in quarantine centres should not be retained for longer than 48 hours after it is generated. Daily activities are disrupted because of social distancing, lockdown, and restrictions on exit-entry across city borders, and this has altered the scheduling of waste collection (Col *et al.*, 2003b; Gautam *et al.*, 2010b). To fulfil the requirement, the frequency of collection should be increased. COVID-19 waste should be handled by specially qualified personnel and trucks. Sanitised vehicles, skilled waste pickers and drivers, designated routes and waste tracking systems are all required for safe transportation. Workers exposed to COVID-19 biomedical wastes must receive special training and proper protective equipment (PPE). Over-crowded routes and rush hour periods should be avoided at the time of transit. The BMW will be transported to common bio-medical waste disposal facilities (CBMWFs) for final disposal. In the absence of CBMWFs, the generated waste can be sent to a local hospital approved for incineration and disposed of following the BMW guidelines 2016 (Ganguly and Chakraborty, 2021; Salman *et al.*, 2007). Due to different types of risk involved during transportation, i.e., traffic, accidents, technical failure etc., routing optimisation technique can be used for transferring waste to disposal sites, as it upholds the risk-free life for all humans. Agarwal *et al*. (2021), used the Cohort intelligence algorithmic with emphasising risk associated with transportation.

Disposal

The disposal process is determined by the hospital and its waste disposal facilities. Some hospitals incinerate on-site and dispose of the biomedical waste, while others do it in a remote location. Few hospitals perform sterilisation and dispose of it into a licenced landfill in 2021 (Hadi and Rahmatinia, 2018; Patil and Pokhrel, 2005). COVID-19 wastes should be disposed of as soon as they arrive at the disposal location. If the waste load is enormous, the transported solid waste can be temporarily held in a separate area designated for COVID-19 waste. COVID-19 disposal sites should be carefully designed to avoid pollution of any form. Since the biomedical waste generation is high, alternative options like MSW incinerators, cement kilns, industrial furnaces can be used as additional support. The government of Spain has approved to incinerate cement plants upon request. Furthermore, China also uses MSW incinerators as an emergency treatment (Chand *et al.*, 2021b; Singh *et al*., 2019). In areas with limited centralised treatment facilities or no thermal treatment facilities, COVID-19 wastes should be buried in deep secured landfills.

Technologies for biomedical waste management

Biomedical waste generation has increased because of the pandemic. This has had an impact on current waste management techniques at all stages. From collecting and sorting waste to final disposal, the COVID-19 outbreak has influenced all of these steps (Gay *et al.*, 2021; G. Singh *et al.*, 2019). As mentioned earlier, segregation and identification of biomedical waste is the best way to lower and effectively manage biomedical waste. However, due to the pandemic, the efficiency of segregating infectious waste has been reduced. Because of the reduced workforce, hospitals and other medical facilities find it harder to store and maintain a record of all waste generated (Mezzah *et al*., 2021). Apart from that, the existing lockout restrictions have disrupted the waste collection scheduling process. It has also affected the frequency and efficiency with which collection trucks operate. We must explore alternative waste management methods. One possible solution to the challenges outlined above could be technology. Internet of Things (IoT) enabled devices such as RFID tags, robotic arms, and sensor-equipped waste collection trucks **(Fig. 5)**, an automated data gathering system can be implemented (Luo et al., 2021). The IoT is a network of objects such as devices, automobiles, home appliances, and other items equipped with electronics circuits, software, sensors, and network connectivity to gather and share data. The IoT enables things to be sensed and remotely accessed

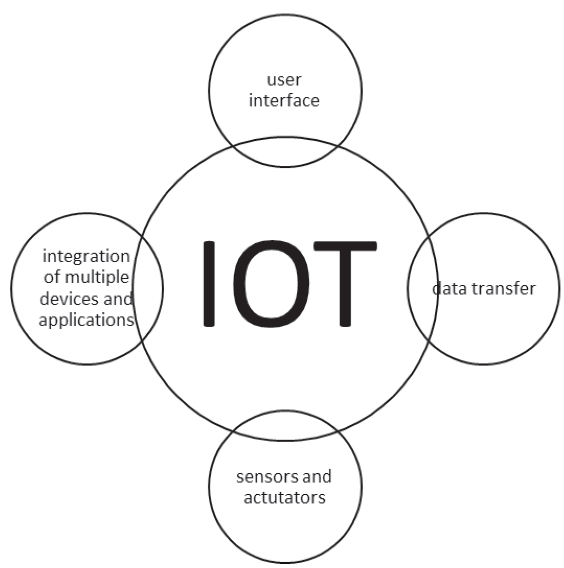

Fig. 5. Components of IOT

using existing network infrastructure, allowing for more direct integration of the physical world into computer-based processes with greater efficiency and accuracy (Iyer *et al.*, 2021; Luo *et al.*, 2021; Mezzah *et al.*, 2021). An IoT network is made up of four layers: (a) a sensing layer that allows sensors and actuators to work together, (b) a networking layer that allows data to be transferred across wired or wireless networks, (c) service layer, which integrates multiple services and applications (d) interface layer, which shows information to the user (Munirathinam, 2019).

The Indian government recently launched the covid19BWM app. This application is a simple but elegant tool for tracking the generation, collection, and disposal of COVID-19 Bio-medical waste generated at various Health Care Facilities/ Hospitals (HCF), Quarantine Centers, Isolation Wards, Testing Labs,and Urban Local Bodies involved in the waste collection from Home Quarantine Centers (Alimohammadi *et al.*, 2018; Benson *et al.*, 2021a). This service enables information to be shared across many stakeholders. The government of India proposed this system keeping in mind the existing internet infrastructure of the country (Munirathinam, 2019). The app requires all stakeholders (from the trash generator to the waste disposer) to register. When the waste generating facility completes the registration process, a drop-down menu appears, displaying all of the nearby cbwtfs. The user must then choose a cbwtf that is accessible and willing to take BMW. The waste generator's user interface prompts the user to define the colour of the bag to be discarded, along with the bag's weight. The waste generating facility can also look at the cumulative sum of waste they dispose of (Chitnis *et al.*, 2005; Kanhai *et al.*, 2021; Liao and Ho, 2014). After the waste generator has requested a pick-up, a notification will be sent to the waste handler and they have the option to accept or reject the waste in the application (Sharma and Gupta, 2017). The waste handler's user interface allows the waste handler to select the waste generation facility and the amount and the kind of waste they intend to pick up. Immediately after the waste handler's pick up the waste, a notification will be sent to the CBWTF's and they schedule a time for the waste handlers to dispose of the waste. The app instantly sends data on all treated waste to the CPCB (Bao *et al.*, 2021). **Figure 6** depicts a clear understanding of this mechanism.

This is an outstanding initiative taken by the

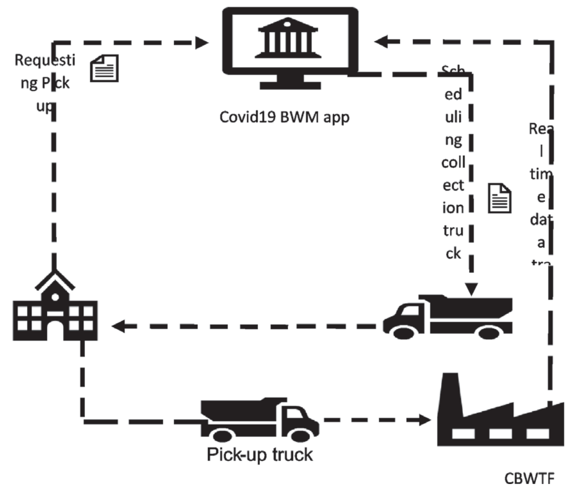

Fig. 6. Schematic of the working of covid-19 BMW app

government of India. The covid-19 BWm app has brought all stakeholders together on a single platform, which proves to be a significant step forward in the direction of a successful BMW management system. This application alleviates the strain on some CBWTfs by distributing waste equally across all CBWTfs in a particular city (Chitnis *et al.,* 2005; Kanhai *et al.,* 2021; Liao and Ho, 2014). The covid19 BMW app makes good use of the limited CBWTf's in India. Because the CBWTfs are chosen based on the location of a specific health care institution, problems related to peak hour traffic and truck frequency will be reduced (Kumar *et al.,* 2021). Till June 2021, 193 Out of 198 CBWTF's have registered on the Covid-19 BWM app (CPCB, 2021). The current system could further be developed by using weight sensors and RFID tags So that automated pick up of the waste can be facilitated and Manual inaccuracies, such as improper data entry, can also be eliminated.

Systems involving weighing sensors and RFDI tags were found in the literature, with minor modifications. The proposed system in the literature will be implemented at the source of the BMW, where the colour-coded bags will be marked with Radio frequency identification tags (RFID) (Raundale *et al.*, 2017). RFID systems gather and transfer data using radio waves without the involvement of human beings. RFID tags are indexed automatically by the computer (Haddara *et al.,* 2018). Weighing sensors would be installed in the bins where these bags are placed; this will alert the trucks transporting the waste to CBMWTF. **Fig. 7** gives a clear idea about this system. After the bins are filled with the bags, the weight sensor will

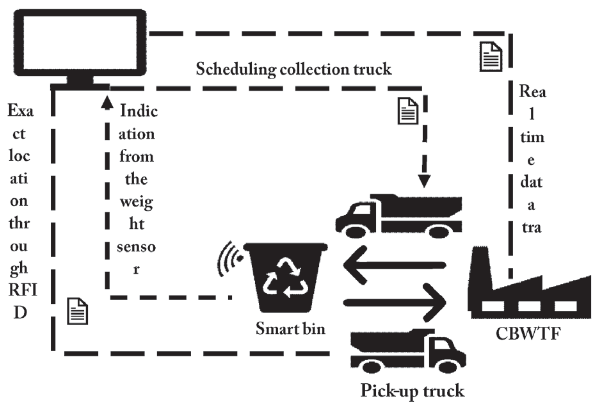

Fig. 7. Schematic for the system proposed by Raundale *et al.*, 2018

deliver a message to the public authority, and authorities will set a pick-up time. These bags are then carried to the CBWTF. The exact weight of each bag, as well as its position and disposal time, may be tracked at any time by the local government authority using an IoT-based microcomputer. This system tackles most BMW management issues by reducing human intervention, increasing collection truck efficiency, and assisting in the tracking and recording of the BMW generated using RFID tags. This system also reduces transportation costs by scheduling pick up times. However, this system still has room for improvement, as it does not address the significant problem of the segregation of waste into colour-coded bags. This system mainly focuses on BMW's transportation, tracking, and transparency aspects (Karnan *et al.*, 2021) researchers have addressed this issue and proposed a prototype model called smart arm, which segregates the wastes into respective colour-coded bags. The proposed system, consisting of direct current (DC) motors and gear drives, is intended to pick up waste mechanically and arrange it on a platform. This system can recognise the type of material and dispatch it to the appropriate container. To determine the type of waste, the prototype model employs a variety of sensors such as ultrasonic sensors, voltage sensors, moisture sensors, inductive proximity sensors, and glass sensors. Table 2 explains the functions of each sensor. The ultrasonic sensor is used initially to identify the waste that has been generated. The inductive proximity sensor then analyses the waste. This sensor detects metals, and if there is any evidence that metal is present, the garbage is disposed of in the white colour bin. If there is no metal, waste is directed to the moisture sensor, where it is disposed of in the yellow bin if there is enough moisture; if there is no moisture, waste is directed to the next sensor, the glass sensor, where all glass objects are sorted and disposed of in the blue bin. Finally, the voltage sensor detects waste, segregating all infectious wastes. This model's sensor network is illustrated in **Fig. 8.** This model also has some limitations. The robotic arm cannot distinguish if two objects are found together, so it dumps them into a separate bin. The research to develop this model for segregating multiple parametric wastes remains ongoing.

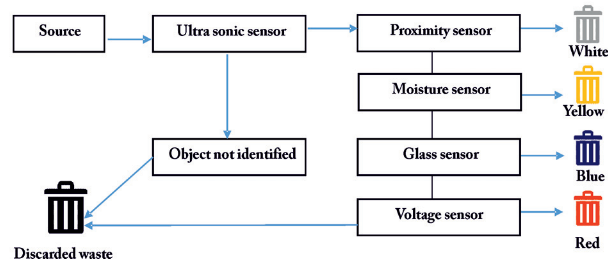

Fig. 8. Robotic arm sensor network

Several studies have also been conducted on segregating waste using various image-processing techniques (Hantoko, *et al.*, 2021; Karnan *et al.*, 2021; Munirathinam, 2019). Image processing is a skill of smearing operations on an image to extract relevant information. It is a form of signal processing in which the input is an image, and the result is either that image or its features. Pre-processing the image is considered the first and the most important step of image processing. Pre-processing is obligatory to convert the images to the format required by the machine learning algorithms (Kumar *et al.*, 2021; Singh *et al.*, 2012a). It comprises of removing background noise, removing reflections and blocking parts of the image. After pre-processing, the next step is feature extraction. The goal of feature extraction is to minimise the raw image to make decision-making processes like pattern classification easier. To get a high classification rate, feature extraction is a necessary step.

Methods like texture analysis are normally used for feature extraction. Texture analysis aims to evaluate instinctive properties of images, defined as a property of pixel intensity. The distribution of grey levels determines the BMW region in the image (Achuthan and Madangopal, 2016). To assess the greyscale of the image, (Soni and Singh, 2021) adopted methods like Histogram of Greyscale (HoG) and Local Binary Pattern (LBP). They found that the histogram of the COVID-19 waste was on the dimmer side of the greyscale. This indicates the closeness of the texture. The next step is to input the features extracted from a COVID-19 image into the proper classification system, keeping in mind the final classification result/decision (Verma *et al.,* 2008b). Because the study involves a variety of wastes, including COVID-19 related medical waste streams, plastics, metal, and paper, a focus on applying a classification algorithm to recognise the different waste kinds is made. Any features collected from the waste image are utilised to classify waste into COVID-19 and other classifications using a multi-label classification system. Better alternatives, such as feature selection and fusion approaches and classifiers, are used to improve classification outcomes (Benson *et al.,* 2021b; Bhakta *et al*., 2020; Singh *et al.,* 2012).

Secondary Application of BMW

The incineration process is considered the best process for the disposal of biomedical waste. The incineration process reduces the volume of BMW up to 75% and kills 90% of the pathogens, but the product of the incineration process produces incinerated biomedical waste ash, also called IBWA, along with some harmful gases. Even though the volume has been reduced by 75%, IBWA still contains toxic metals and inorganic compounds. When this ash is disposed of in a landfill, leaching occurs, leading to air and water pollution (Kaur *et al*., 2019). Instead of dumping IBWA in a landfill, it can be used in a variety of industries to lessen the environmental effect. Several studies have been conducted on the alternative application of IBWA in various sectors. (Kaur *et al*., 2019) have studied the effect of IBWA on the properties of concrete. It was reported that IBWA could be used up to 10% as a partial replacement for fine aggregate in concrete (Goutam *et al*., 2021). The slump test showed a decrease in workability, but the addition of IBWA to concrete resulted in an improvement in compressive strength. This is due to the calcium and silica content of IBWA and the filler effect of IBWA. IBWA can also be used to replace ground granulated blast furnace slag (GGBS) in making geopolymer concrete. Results showed that 7% replacement to GGBS has increased the compressive strength of concrete (Kanhai *et al*., 2021). IBWA can also be used in asphalt layers, and nearly half of the incinerated ash produced in Germany is used in making soundproofing walls and pavement layers. About 72% of the incinerated ash produced in Denmark is used to develop parking spaces and cycle tracks (Rajor *et al.,* 2012). Some studies suggest that BA containing mixtures have similar properties as asphalt containing mixtures. (Toraldo *et al*., 2013) studied the use of stabilised bottom ash for bound layers of road pavement. They have reported that under high traffic conditions, stabilised bottom ash of 10% composition can be used in making asphalt and concrete pavements. Biomedical waste ash can also be used in the agricultural sector. It consists of almost all the nutrients essential for crop growth. IBWA can act as a chemical fertiliser studies showed that incinerated ash as a chemical fertiliser has increased the yield of mustard and fenugreek plants by 35% and 50%, respectively (Ansari *et al.,* 2021; C. Sharma and Bhardwaj, 2019). One of the most successful hazardous waste disposal technologies is heat treatment and gasification. Studies show that Plasma gasification produces clean syngas, which can be converted into various energy sources, including electricity, through gas turbines. The plasma gasifier is connected to an internal combustion engine (ICE) for power generation. BMW drives the plasma gasifier, and a plasma torch converts BMW into slag and syngas, internal combustion engine burns this gas to generate electricity (Mikhailovich and Franci, 2020).

CONCLUSION

The COVID-19 pandemic has led to a substantial increase in the generation of biomedical waste (BMW). The unanticipated nature and the enormous expanse of the pandemic, has highlighted the inadequate capacity of municipalities, for the collection, storage, treatment and disposal of BMW. The problem is further exacerbated in developing countries with large populations, such as India, where a vast amount of BMW is generated. In general, the poor management of the BMW lifecycle is complemented by a lack of awareness of standard operating protocols and guidelines. In particular, during the ongoing COVID pandemic, a lack of clarity and consensus on the BMW waste management techniques have often led to the ad-hoc implementation of guidelines. Overall, the inadequate waste management capacity, the multiplicity of guidelines and regulations from both the government and private organisations, and the lack of readiness to adopt the latest technological solutions for processing BMW lead to increased health hazards and pose a challenge to the health care and municipal systems. In this paper, a detailed classification of the various hazardous and non-hazardous wastes is presented with a critique of the current techniques for the collection and segregation of BMW. Guidelines issued by various organisations, such as the Central Pollution Control Board (CPCB) of India, the World Health Organization (WHO), for effective management of BMW are highlighted to indicate the best practices. The new challenges presented by the increased variety of BMW generated due to the COVID-19 pandemic are presented and discussed. The enormous scale of the pandemic has led to an increased focus on the incorporation of novel technologies for segregation, identification, treatment and disposal of BMW. The adoption of IoT based technological solutions is particularly emphasised. New technological devices, which use a variety of sensors and employ image-processing methods are addressed. The various options available for the secondary application of BMW are discussed with particular focus on the reuse of the certain non-hazardous BMW, which could be used as input material for other industries. Finally, novel ideas from recent research, which could improve the future practice of BMW management are presented with perspectives on the opportunities and challenges that lie ahead.

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