The Challenges of Biomedical Waste Management During the Ongoing Coronavirus Disease-19 (COVID-19) Pandemic: The Current Scenario

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REVIEW ARTICLE

The Challenges of Biomedical Waste Management During the Ongoing Coronavirus Disease-19 (COVID-19) Pandemic: The Current Scenario

Sabitha Vadakedath[1], Venkataramana Kandi[2,*], Tarun Kumar Suvvari[3], Lakshmi Venkata Simhachalam Kutikuppala[4], Vikram Godishala[5] and Praveen R. Shahapur[6]

[1]Department of Biochemistry, Prathima Institute of Medical Sciences, Karimnagar, India; [2]Department of Microbiology, Prathima Institute of Medical Sciences, Karimnagar, India; [3]Dr. NTR University of Health Sciences, Andhra Pradesh, India; [4]Konaseema Institute of Medical Sciences and Research Foundation (KIMS&RF), Amalapuram, Andhra Pradesh, India; [5]Department of Biotechnology, Vaagdevi Degree and PG College, Telangana, India; [6]Microbiology, BLDE (Deemed to be University) Shri B.M. Patil Medical College, Vijaypur, India

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Abstract: The novel Coronavirus (SARS-CoV-2) that has emerged and spread throughout the world causing CoV disease-19 (COVID-19) has since its discovery affected not only humans and animals but also the environment. Because of the highly infectious nature of the virus, and the respiratory aerosol transmission route, face masks and personal protective equipment have become mandatory for public and healthcare workers, respectively. Also, the complex nature of the pathogenicity of the virus, wherein, it has been associated with mild, moderate, and severe life-threatening infections, has warranted increased laboratory testing and placing the infected people in isolation and under constant observation in quarantine centers or at dedicated hospitals. Some infected people, who are generally healthy, and do not show symptoms have been placed in home quarantines. At this juncture, there has been increased amount of Biomedical Waste (BMW), and infectious general waste along with plastic disposable recyclable and non-recyclable waste. The increased BMW along with the potentially hazardous plastic waste collection, segregation, transport, and disposal has assumed increased significance during the ongoing pandemic. Therefore, this review attempts to investigate the current scenario of BMW management and strategies to minimize BMW and prevent potential environmental pollution.

Keywords: Novel coronavirus, SARS-CoV-2, environment, biomedical waste (BMW), hazardous, pollution.

1. INTRODUCTION

The novel Coronavirus (CoV) named severe acute respiratory syndrome CoV-2 (SARS-CoV-2) that emerged from China and has spread to most parts of the world causing CoV disease-19 (COVID-19) has posed several challenges to mankind [1, 2]. The pandemic has been in course for over a year, and although vaccines have been recently made available, we do not yet know if the end is anywhere near [3]. Among the challenges posed by this pandemic were the increased transmission rates, morbidity, and mortality among the susceptible populations, pressure on the healthcare system, lockdowns, restricted travel within and between countries, economic losses, among others [4, 5].

Since the virus spreads through respiratory aerosols, and direct or indirect contact with mucus membranes, people are advised to use face masks, face shields, and follow strict hand and face hygiene by either using alcoholic sanitizers or by frequent hand washing to prevent the spread of infection. Healthcare Workers (HCWs), as a part of patient management, are instructed to use Personal Protective Equipment (PPE), gloves, masks, and other infection-preventing barriers while handling the patients irrespective of their COVID-19 status.

The scenario is almost the same throughout the world, and several countries have been reporting increased cases and hospitalizations after experiencing the second wave of COVID-19. This has contributed to enhanced use of both recyclable and non-recyclable consumables by the general population as well as the healthcare community. The cause of concern now is how should we manage the potentially infectious Healthcare Waste (HCW), laboratory, and community (containment zones, and quarantine homes) associated with the Biomedical Waste (BMW) that is generated as a part of novel CoV infection [6]. Also, a concern is the exponentially increased amounts of BMW generated and the insufficient infrastructure and trained personnel available for careful collection, storage, treatment, and disposal. This review summarizes the current BMW management situation because of the ongoing COVID-19 pandemic and strategies to minimize environmental impact.

*Address correspondence to this author at the Department of Microbiology, Prathima Institute of Medical Sciences, Karimnagar, India; E-mail: ramana20021@gmail.com

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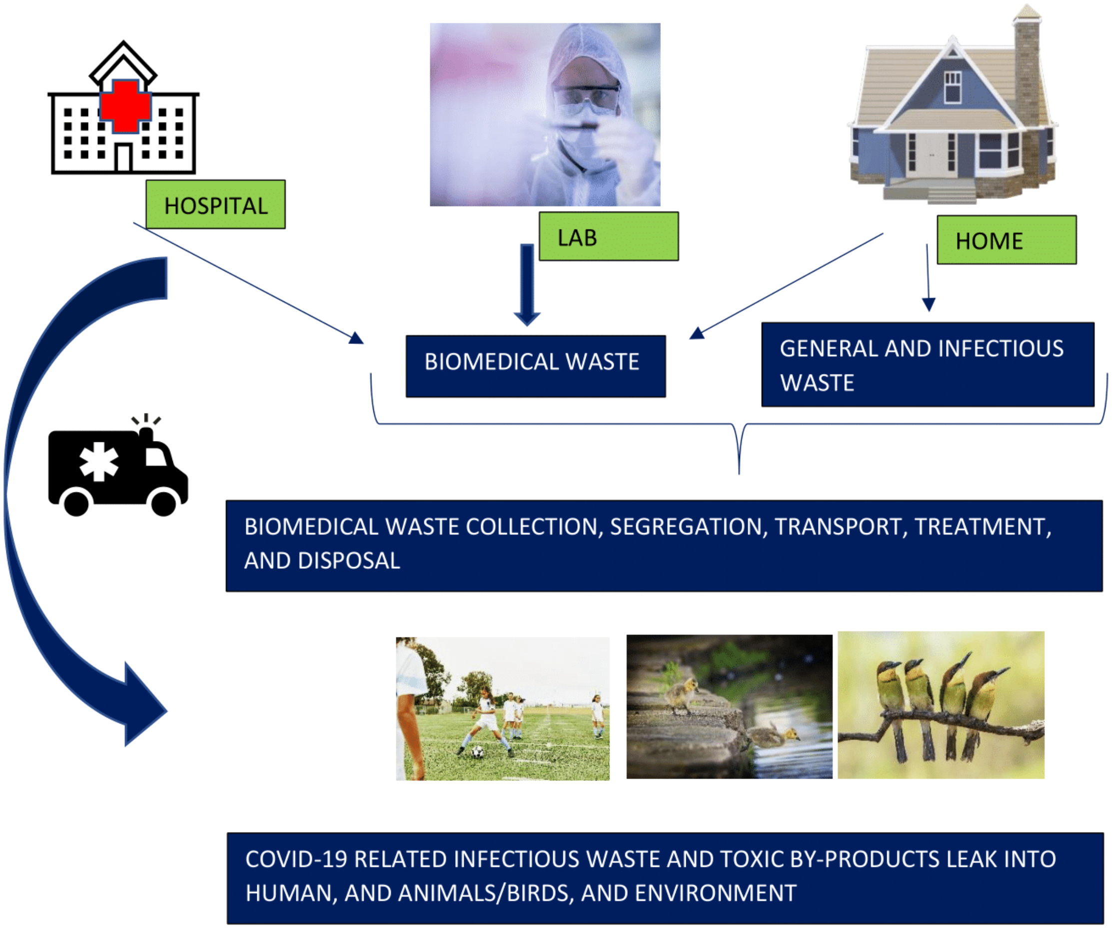

Fig. (1). Pictorial representation of sources of BMW and their leakage into the environment. *(A higher resolution / colour version of this figure is available in the electronic copy of the article).*

2. BIOMEDICAL WASTE

Biomedical wastes are any solid and liquid wastes generated in the process of patient management, animal care, and experiments. The biomedical waste generated from the hospitals and the laboratories associated with the hospitals poses an increased threat to the environment, especially in the times of Coronavirus disease-19 (COVID-19) caused by the novel severe acute respiratory syndrome Coronavirus-2 (SARS-CoV-2). During the pandemic, there is a possibility of infectious home waste being combined with the general waste and increases the threat of infection to humans and animals and causes environmental hazards when handled carelessly (Fig. **1**).

These sources can include the hospital linen (bedsheets), gloves, used cotton, wound dressings, syringes, and other material that come in direct and indirect contact with the patient and the laboratory animals. Biomedical waste can broadly be classified into hazardous (pathological, anatomical wastes, blood, and blood products) and non-hazardous types [7]. The hazardous type of biomedical waste presents a threat of infection both to the people handling it, as well as to the environment. Therefore, proper handling and disposal of biomedical wastes assume increased significance.

Because the SARS-CoV-2 is a highly infectious virus that spreads through the respiratory aerosols, handling and disposing of the COVID-19 related biomedical wastes are crucial to prevent the spread of infection both within the hospital/laboratory environments and public places surrounding the hospitals and laboratories.

3. BIOMEDICAL WASTE MANAGEMENT

Traditionally, the biomedical waste was processed in the hospital and laboratory premises by using incinerators. Incineration is the process of burning the BMWs at an extremely high temperature (>1000°C). This process although was effective in controlling and preventing the spread of infections, there is an imminent possibility of the generation of toxic substances like the products of incomplete combustion including dioxins, furans, and other metal-related toxic remnants. Also, the ash produced from the incineration of BMWs could mix with the environment and pose both public and animal health hazards. The use of incinerators with High-Efficiency Particulate Air filters (HEPA) that can filter out the hazardous and toxic wastes before being disposed of in the form of landfills was also previously practiced.

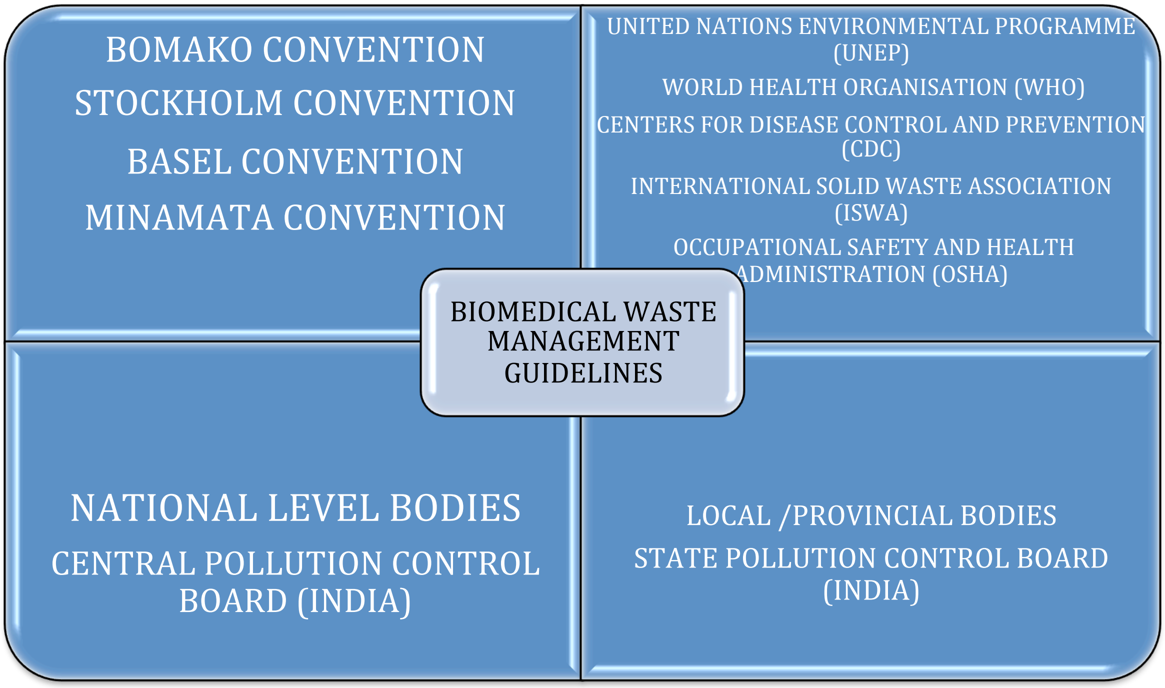

Fig. (2). The international, national, and local bodies on biomedical waste management. *(A higher resolution / colour version of this figure is available in the electronic copy of the article).*

To counter the increased generation of toxic wastes during incineration, alternative methods to treat BMWs that use autoclaves, low heat microwaves, medium heat microwaves with nitrogen environment, and high heat plasma pyrolysis techniques are currently endorsed. Other advanced methods used to treat BMWs include using chemicals, radiation, and biodegradation [8, 9].

The technological advancements although have been at the forefront in the development of improved techniques for BMW management, not much has been available for the low-, and middle-income countries. The major drawback with the advanced BMW management methods is the cost associated with them. It becomes a herculean task for developing countries to procure the instruments and provide adequate infrastructure for proper maintenance of these types of machinery.

During the ongoing COVID-19 pandemic, there is an increased BMW output generated throughout the world. Given the highly infectious nature of the SARS-CoV-2, improved BMW management techniques are required to counter the spread of infection outside the containment zones that include quarantine centers, hospitals, specialized laboratories, research centers, and residential areas.

The management of BMW in developing countries like India is complicated owing to the enormous quantities of hazardous waste generated both at the healthcare facilities and the households. Large population size, poor knowledge of infection control measures, low literacy rates among the people handling BMWs, and common people, all contribute to the complexity of BMW management [10, 11].

The guidelines, standard operating procedures, and recommendations concerning the best practices of BMW management were proposed by the Bamako Convention, the Stockholm Convention on persistent organic pollutants, the Basel Convention on hazardous waste, and the Minamata Convention on Mercury. The recommendations made at these conventions were followed in various countries to protect human health and the environment from potentially hazardous BMWs. Also, such guidelines and recommendations were proposed by the local and international bodies like the Central Pollution Control Board (CPCB) of India, the United Nations Environmental Programme (UNEP), the World Health Organization (WHO), the Centers for Disease Control and Prevention (CDC) of the United States of America (USA), the International Solid Waste Association (ISWA), and the Occupational Safety and Health Administration (OSHA) (Fig. **2**).

The WHO and the CDC have proposed to classify the COVID-19 related BMW into those that are generated within the healthcare facility compounds like the Personal Protective Equipment (PPE), the hospital linen, and others, and the ones that are generated outside such premises that include the masks, the gloves, and others.

The CPCB of India had in March 2020 proposed guidelines for effective management of BMW generated because of COVID-19, and it was later amended in April 2020. These regulations have proposed separate COVID-19 healthcare facilities, household waste, and containment facilities to manage the BMW and minimize the environmental leak of the infection [12].

4. THE CURRENT SCENARIO

Due to overcrowding, there is an increased possibility of transmission of infectious diseases, and because of low literacy levels, and inferior psychological conditions, most people do not generally follow best BMW management practices. The situation is further worsened by the presence of unqualified people working with BMW collection, transport, and disposal [13-15].

Also, in countries like India, where there is no strict surveillance and containment of the BMW dumping zones, there is a possibility of humans, domestic and wild animals wandering around the BMW disposal areas and pose an increased threat of acquiring and transmitting the infections to the community.

In India, the guidelines for handling and disposing of BMWs were formulated first in 1998 and were later amended in the year 2016, and 2018 [16]. The drawbacks with the collection and disposal of BMW management regarding 1998 guidelines included no proper recommendations on the segregation of BMWs, no pre-treatment, no recommendations on liquid waste disposal, and no training and immunization of the BMW personnel, among others. The 2016 amendments to the BMW management guidelines included systematic segregation of the biomedical waste into separate color-coded bags/bins and recommendations on the methods of pre-treatment and disposal. Specific guidelines of BMW collection and disposal were also suggested for public health camps like the blood donation camps and others. Also, an effluent treatment plant was made mandatory for the pre-treatment of liquid BMWs. Improved accident reporting mechanisms, mandatory documentation for application and renewal to collect, store, and process the BMW at the healthcare facilities (common disposal is suggested if such a facility is available within the 75 Km range), and common BMW treatment and disposal facilities are some other features of the renewed 2016 guidelines proposed by the Indian Ministry of Environment, Forest, and Climate change department [7, 17].

The CPCB of India had revised the recommendations for the fourth time and had released renewed recommendations for BMW management concerning COVID-19. These newer guidelines have been suggested after collecting and evaluating additional current information on the disease. The procedures for solid BMW collection, segregation, treatment, and disposal regarding the BMW were generated at healthcare facilities, quarantine centers, home care facilities, sample collection centers, diagnostic laboratories, and CBWTFs. Also, the revised guidelines stress the disposal of PPE. Some important guidelines included mandatory labeling of BMW as COVID-19 waste, registration of COVID-19 related facility (Quarantine facility, sample collection centers, etc.) with the CPCB, the SPCB, and informing it to the CBWTFs, the use of foot-operated bins, use of double-layered plastic bags, sodium hypochlorite disinfection sprays on the COVID-19 waste bins, among others.

Also, the revised regulations direct the CBWTFs to have COVID-19 dedicated collection and transport vehicles, use of COVID19BMW management tracking mobile application, regular sanitization of the operators working at the collection, transport, and treatment facility, provision of complete PPE kits to the BMW handlers, ensuring doorstep BMW collection, and coordinating with the local bodies [18].

In India, there is currently an increase in the number of healthcare facilities, which in turn increases the amount of BMW generated from them. It is also estimated that the amount of BMW generated by India could well be more than 750 tons/day by 2022 with an annual rise of 7% [19]. Although these numbers were projected before the COVID-19 pandemic, the present-day data shows an exponential growth (>2000 tons/day) in terms of BMW generation, especially in the COVID-19 burdened countries like the United States of America (USA), Brazil, and India and this potentially predicts public health disaster if the pandemic were not to be controlled soon [20, 21].

The environment-related effects of the COVID-19 pandemic were previously reported. It was noted that the pandemic related restricted human movements (lockdowns) although have contributed to improved environmental conditions (reduced noise pollution, nitrogen dioxide, and other toxic gas emissions water pollution, and ozone depletion), they have increased the threat of infection to the environment, the flora and fauna, attributing to the biomedical waste contaminated with COVID-19 [22].

Since the novel, SARS-CoV-2 has been noted to survive from a couple of hours and up to a week on various surfaces like the wood, plastic, and metal surfaces, the BMW collection and disposal assume increased significance to restrict environmental leak and potential flaring of infection back to the community [23].

Also, excessive use of disposable items and increased risk of infection with the non-recyclable consumables pressurise the BMW management systems throughout the world. Also, insufficient treatment of BMW could predispose handlers to infection, and release toxic by-products that contaminate the environment, and when such organic compounds accidentally enter humans and animals, they cause severe consequences related to the immune system, the endocrine system, and the nervous system, among others [24, 25].

The treatment and disposal of BMWs depend greatly on the amounts of wastes generated in the healthcare facilities, containment zones, and other regions that generate infectious wastes. It was suggested that the incinerators, steam sterilizers like the autoclaves, other thermal methods, and chemical treatment (chlorine-based chemicals like the sodium hypochlorite (NaOCl); non-chlorine-based chemicals like formaldehyde, hydrogen peroxide H_2O_2, and other alcohol-based chemicals) can be used for decontamination of BMWs both in the onsite, as well as common biomedical waste treatment and disposal facilities [26]. Application of ultraviolet irradiation as an alternative to the corrosive and potentially carcinogenic chemical disinfectants was also suggested amid potential hazards to humans on continued exposures [27].

Environmental survival capabilities of microbes combined with the improper BMW management procedures could contribute to increased survival and potential transmission of such microbes to humans and animals [28].

Because increased airborne pollution may predispose people to COVID-19, recent reports have recommended several techniques to minimize the airborne pollutants and thereby reduce the chances of SARS-CoV-2 transmission both among humans and the environment [29].

The significance of hospital infection control committees and the role played by the institutional infection control committees in training and monitoring the healthcare personnel with reference to their BMW management practices, especially during the ongoing COVID-19 pandemic were recently stressed [30, 31].

The municipal waste management (MWM) practices during the current pandemic need adequate attention to prevent the spread of infection. Several patients infected with the novel CoV remained in isolation at their homes. This has put the MWM workers at increased risk of contracting COVID-19 during the collection and transport. Also, it was noted that the workers are less educated and belong to low socioeconomic sections and mostly belong to developing and third world countries like India, Bangladesh, Philippines, and others including China, who are at increased risk of infection while handling municipal waste potentially contaminated with novel CoV [32- 36].

A previous study from India had assessed and categorized the BMW management practices of public and private sectors in Punjab, North India. This study reported that more than 80% of the public sector and over 60% of private-sector institutions lacked foolproof system of BMW management. It was observed that lack of training and inadequate infrastructure was responsible for the current situation [37].

In a recent study, it was noted that only four states (approximately 25%) out of the 29 states in India are infrastructurally equipped to efficiently manage BMW. Because of the exponentially increased BMW attributed to the COVID-19 pandemic, the local governments and health authorities must evolve strategies like capacity building with advanced technologies, scientific collaborations, and personnel training to efficiently manage BMW [38].

5. STRATEGIES TO MINIMIZE BMW GENERATION AND PREVENT ENVIRONMENTAL HAZARDS

To counter the exponential nature of BMW production during the pandemic, a recent study had proposed the reuse of PPE and stressed the potential environmental hazards of the treatment of polypropylene-containing plastic disposables, when they are incinerated as well as when they are deeply buried. These materials when disposed of could release toxic and hazardous gases/chemicals into the environment and they are not easily degradable [39].

In a recent report, the effects of the two most common types of BMW treatment and disposal that include incineration, and landfills were compared for their potential to cause environmental hazards like global warming, ozone depletion, and toxins released into the air, water, and soil that affects both humans and animals. This study had observed that incineration is the best option when it is done in smaller quantities and at the respective centers as compared to the landfills to minimize the environmental impacts of COVID-19 related BMW [40].

The application of photocatalytic reactors in the elimination of different types of microbes including the RNA viruses was recently reported. This study had suggested that healthcare-related surfaces and other equipment can be effectively removed from bacterial, fungal, and viral pathogens. Photocatalysis is a process of reacting to certain elements in the presence of light. This process causes oxidation and generation of reactive oxygen species that can kill most microorganisms by causing cell membrane damages/perforation [41]. Therefore, such mechanisms of microbial removal must be extensively researched for their activities against SARS-CoV-2. These procedures can potentially be used to decontaminate the PPEs, gloves, face guards, and others to reuse them and reduce the quantitates of BMW.

The demand for PPE and other healthcare-associated consumables is increasing, and there is a concern regarding the proper disposal, and the impact they can have on the environment. This has forced HCWs to minimize the use and encourage the reuse of such equipment by using decontamination methods like exposure to ozone, vaporized hydrogen peroxide (H_2O_2), ultraviolet radiation, humidity, microwave generated steam, and autoclaving at high humidity for at least one hour [42- 48].

Even after a year of pandemic, there is still a state of uncertainty and the public gathering related current restrictions are presumed to continue at least until most of the population is vaccinated or develops immunity. Therefore, the demand for masks and other consumables that control and prevent the spread of the virus remains the same. The cause of concern here is with the excessive BMW and the disposal-related environmental hazards. The use of recyclable masks prepared from cotton, polycotton, quilt, and quilting cotton was suggested as an efficient alternative to polypropylene masks to counter BMW-related environmental issues [49, 50].

The COVID-19 pandemic has been instrumental in creating an increased demand for PPE, thereby creating economic and environmental pressure on governments. This situation has forced healthcare management to find alternative and effective techniques to disinfect PPE and encourage reuse. The efficacy of UV radiation, heat, and chemicals to disinfect PPEs was recently evaluated. The UV radiation (260-280 nm) destabilizes the microbial nucleic acids and inactivates the virus. Varied intensities of UV light that range from 400 mJ/cm2 and 10,000 or 20,000 mJ/cm2 are used to decontaminate PPE and filtering face respirators (FFRs). An autoclave temperature of up to 100^0C for about 60 minutes

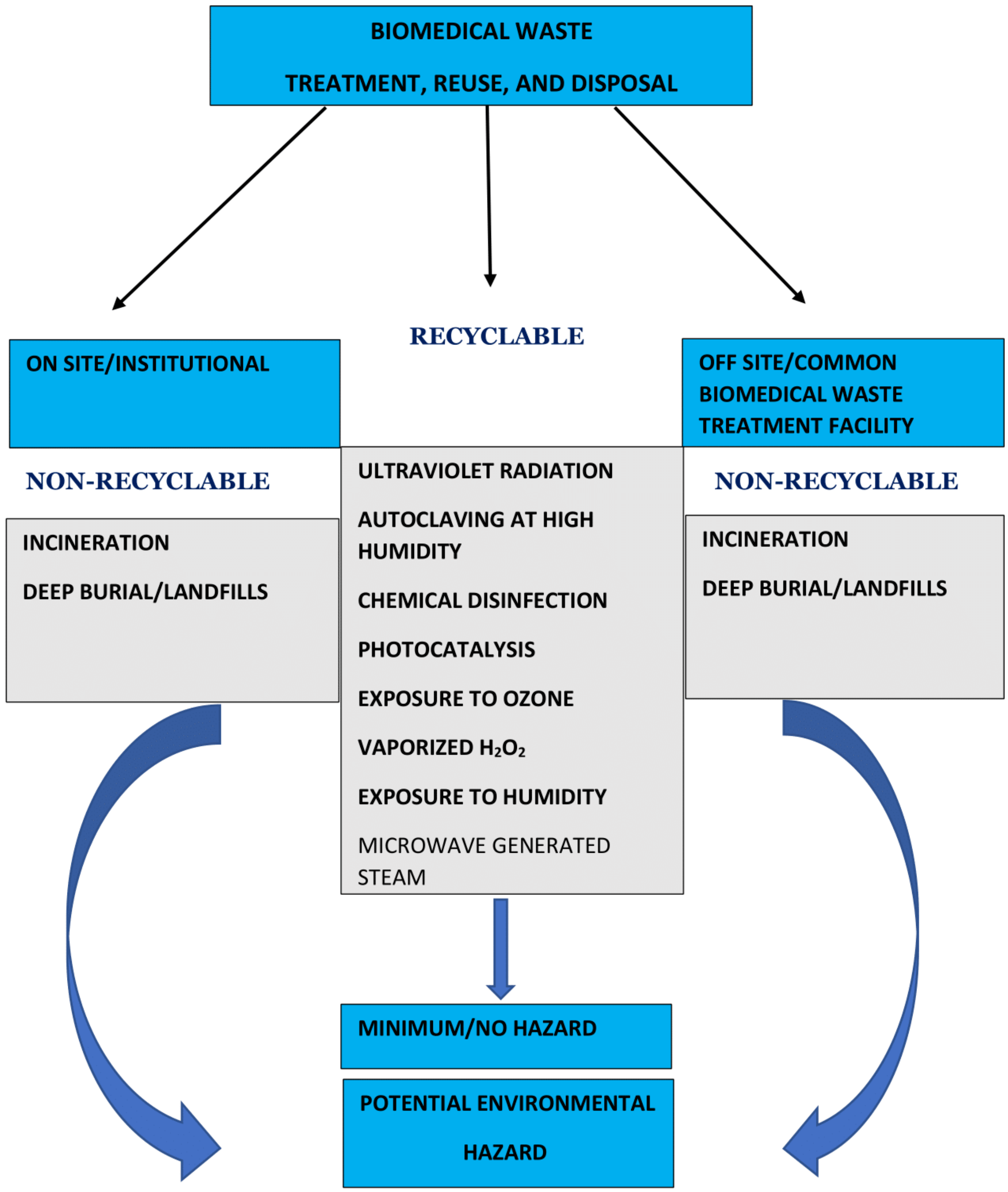

Fig. (3). Biomedical waste treatment of both recyclable and non-recyclable material.

was noted to eliminate both the SARS-CoV-1 and SARS-CoV-2. Chemical disinfection with alcohol-based chemicals, povidone-iodine, formaldehyde, and sodium hypochlorite at appropriate concentrations was found to be effective in complete removal of microorganisms and facilitating the reuse of PPE [51]. Nevertheless, the reuse of potentially contaminated PPE must be cautiously done after performing suitable decontamination procedures that consider the nature of the contamination, decontamination procedure, the material, and other factors (Fig. **3**).

The discarding procedures of used face masks, face shields, PPE, and other infection barriers should carefully be applied to prevent the spread of infection. Previous studies have reported that the SARS-CoV-2 may survive in different environmental conditions for days to weeks as aerosols and on different surfaces like paper, plastic, glass, wood, metal [52, 53].

The application of internet and social media-based technology as an alternative to the traditional poster and hoarding-based methods to publicize the waste management procedures was recently recommended [54].

Understanding the HCW management systems by utilizing the Political, Economic, Social, Technological, Environmental, and Legal (PESTEL), Total Interpretive Structural Modeling (TISM) and fuzzy- MICMAC (cross-impact matrix multiplication applied to classification) analyses will contribute to sustainable waste management practices, especially during the current COVID-19 pandemic situation. Also, the local governing bodies and health officials must enforce the environmental laws, and regularly monitor the HCW management practices [55].

To minimize the environmental pollution caused by the increased plastic waste generated during the current COVID-19 pandemic, a recent study had explored the utility of pyrolysis. Pyrolysis is a process of treating the BMW at high temperatures and chemicals in the presence of anaerobic environment. This procedure enables the breakdown of complex organic substances into simpler, environment-friendly compounds like char, coke, and other energy-efficient biofuels [56].

An innovative biodegradable material was recently discovered and was successfully tested for its eco-friendly applications. Such materials can be used in the preparation of biomedical items that include patient management-related supplies, laboratory consumables, among others [57].

6. APPLICATION OF NOVEL DECONTAMINATION PROCEDURES

Given that PPEs have become an integral part of patient and healthcare management personnel, decontamination after their use has gained increased significance. A recent study from Brazil proposed a spray disinfection technique that can instantly decontaminate the used PPEs. It was revealed that exposure of sodium hypochlorite for 30 seconds could reduce the burden of viable microbes by more than 99% [58]. Another study had suggested that PPE when exposed to Per Acetic Acid (PAA) could kill bacterial spores, which are generally very resistant in nature [59]. Although chemical disinfection appears to be instant and effective, there is an imminent danger of their toxic effects on humans and the environment as noted previously [60]. Decontamination of inanimate surfaces potentially contaminated with coronaviruses was found more effective with ethanol (>60%), hydrogen peroxide (0.5%) and sodium hypochlorite (0.1%) than with benzalkonium chloride (0.05-0.2%) and chlorhexidine digluconate (0.02%) [61].

Exposing PPEs, masks and other respirators to UV irradiation was found effective in complete decontamination and enabling them to be reused [62, 63]. Application of aerosolized PAA and H_2O_2generated in an ultrasonic room as a High-Level Disinfection System (HLDS) was effective in disinfecting N95 respirators without affecting the filtering capability of respirators [64]. A study was recently attempted regarding the efficacy of a 30 second plasma disinfection procedure on the bioburden in an intensive care unit [65]. Decontamination of various PPE including the N95 respirators potentially soiled with SARS-CoV-2 was found effective with vaporized H_2O_2, and UV irradiation as compared to other procedures that included heat, moist heat/autoclave, immediate-use steam sterilization (IUSS), using a Steris Amsco Evolution HC1500 PreVac Steam Sterilizer autoclave, dry heat/oven, thermal heat (70°C) at 50% humidity, UV-C, gamma radiation, multi-purpose high-level disinfection cabinet that generates aerosolized peracetic acid and H_2O_2, vaporized ethylene oxide, activated oxygen/ozone (O_3) treatment, 70% ethanol, isopropanol treatment (soaking/spraying), sodium hypochlorite treatment, treatment with soap/detergent, microwave generated steam, pulsed Zenon UV, and nanoparticles/nanoemulsions [66-72].

Application of the novel pulse-light technology that uses high intensity and wide spectrum light as an alternative to chemical, heat, and radiation methods in the inactivation of SARS-CoV2 was recently proposed for effective surface decontamination. This technique was proposed both for clinical and environmental surface decontamination [73].

Efficacy of visible Blue Light (BL) at a wavelength of 405 nm against antibiotic-resistant bacteria was recently demonstrated. The study revealed that the BL was able to inhibit biofilm-producing antibiotic-resistant bacteria, and therefore it can be used as a surface decontaminant for both clinical and environmental purposes [74]. Exposing steam to counter the effects of biofouling in the environment that include marine bodies was recently reported. It was suggested that since most other alternative treatment strategies are either counter-productive or not cost-effective, steam exposure may be an easy alternative, wherein the direct steam exposure causes shock and inactivation of microorganisms [75].

Performance analysis of a novel surface decontamination procedure that can be applied to surfaces like plastic, steel, food, among other was done using a combination of steam and ultrasound. This procedure was positively tested at various temperatures (85°, 90°, and 95°C) for 5 seconds, enabling instant decontamination [76].

CONCLUSION

The present literature has suggested that the amount of BMW generated has exponentially increased throughout the world. The COVID-19 pandemic resulted in increased healthcare-related hospital and laboratory wastes that are potentially contaminated with SARS-CoV-2. The BMW management practices currently followed were mostly sufficient to manage low-level waste management. Most institutions lack in-house BMW treatment facilities, especially in developing countries like India. The workers involved in the collection, segregation, transport, and disposal of BMW are not sufficiently educated. There is an increased possibility of institutional cross-contamination of infectious material. It is important to have separate facilities for the storage of COVID-19 related BMW and other hospital waste. The CBWTFs are not adequately equipped to handle the huge quantities of COVID-19 waste. The institutional infection control committees should play proactive roles in the BMW management. Frequent sensitization programs could help in educating the HCWs in the areas of BMW collection, segregation, and disposal.

CONSENT FOR PUBLICATION

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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