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REVIEW ARTICLE

The influence of COVID-19 pandemic on biomedical waste management, the impact beyond infection

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Abstract

Excessive population outbursts and associated xenobiotic interventions contribute overproduction of waste materials across the world. Among these waste materials biomedical wastes (BMW) make a significant contribution. The huge accumulation of BMW is not only meant for successive environmental pollution but increases health hazards by cross-contamination and reoccurrence of different fatal infections. The management of BMW gaining continuous attention to the scientific communities for their intriguing potentiality towards public health concerns. Although, world health organization (WHO) and other public health and environmental societies formulate different guidelines for the disposal machinery of BMW but the proper implementation of those rules in public sectors in developing countries is very difficult. In this situation, the sudden prevalence of pandemic like, COVID-19 further worsen such conditions. Huge disposition of medical wastes during COVID-19 detection, treatment, and precautionary measures not only increases the risk of reoccurrence of infection but puts us also in front of a huge challenge of efficient management of these BMW. In this respect, the present review focus on an overview of BMW, existing BMW management, probable consequences of COVID-19 pandemic on the waste management system, and future perspectives.

Keywords Biomedical waste · COVID-19 · Environmental risk · Pandemic · Waste management

Introduction

Corona viral disease outbreak has been considered a major threat to human life in the recent past. This viral disease had started its journey from Wuhan, China in late 2019. Hence, the disease is called coronavirus disease 2019 (COVID-19). Although China was the primary epicenter of the disease, later this virus spread all over the world at a rapid irruption rate. On 30th January 2020, World Health Organization (WHO) has officially declared COVID-19 as an international public health emergency. This new disease has changed every equation of normal human life and put the most evolved advanced human life in front of many questions. Coronaviruses (CoVs) are the group of positive-sense RNA viruses which cause respiratory tract infections in humans. This respiratory illness ranges from mild common cold-like symptoms to severe respiratory pneumonic symptoms. The recent COVID-19 has caused by SARS-CoV-2 (severe acute respiratory syndrome corona virus-2) which followed the infection path of SARS-CoV during 2002 and the emergence of Middle East Respiratory Syndrome Coronavirus (MERS-CoV) during 2012 (Meo et al., 2020). Present SARS-CoV-2 is far more infectious than previous SARS-CoV but mortality is low (2%-3%) as compared to the previous one (Petersen et al., 2020). It has been noted that genomic variations in SARS CoV-2 are associated with infection rate and mortality of the same (Toyoshima et al., 2020). Recently emerging variants are showing alarming infectivity and community transmission (Davies et al., 2021).

Different work starting from genomic dissection to structural studies has been continuously carried out to uncover

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puzzles behind this disease. Again, scientists and healthcare professionals throughout the world are trying their level best to uncover effective drugs and vaccines to contain the disease in the fastest possible way. Besides the health issues, COVID-19 has also a huge long-term effect on our environment which in turn will affect all the life forms diversely. Although, at present health issues are our primary concern but broad ignorance on environmental issues will return to many future fatalities. Among much other xenobiotic waste, biomedical wastes (BMWs) possess acute concerns in their management and risks. The waste management system particularly the BMW management system is not up to the mark in many developing countries (Shammi et al., 2021). The improper disposal and management system leads to major environmental and health-associated risks to mankind. The COVID-19 pandemic have worsened the situation far ahead. The generation of BMWs has increased manifold across the globe. According to the world health organization (WHO), 85% of the total health care waste is non-toxic and only 15% are toxic (https://www.who.int/news-room/fact-sheets/detail/health-care-waste), but the present pandemic has changed the scenario completely. Highly populous countries exhibited more strenuous situations. Hubei province in China alone possesses a 600% increase in BMWs (Haque et al., 2021). India possesses a 46% gross increase in BMWs across the country in past two months in previous year (April and May 2021) and the number is still increasing (https://www.indiatoday.in/coronavirus-outbreak/story/46-increase-in-covid-biomedical-waste-april-bihar-karnataka-1813935-2021-06-12). In this context, the present review focus on general concepts of BMW, their management strategies along with impact of COVID-19 pandemic on BMW management system, their potential risk and future perspective.

Biomedical waste

According to the world health organization (WHO), biomedical wastes are the collective materials generated during treatment, diagnosis, pathological laboratories, operation theatres, or immunization events in humans and animals. The waste materials accumulated in research laboratories during biomedical research are also included in this category. Different health care equipment including personal protective equipment (PPE), gloves, masks, and other wearables used by patients as well as any healthcare professionals during regular or public community health services are also included in this category (Govt. of India. Ministry of Environment and Forests Gazette notification no 460 dated July 27, New Delhi. 1998:10–20). WHO has given the guidelines to segregate different BMWs into different categories e.g. human anatomical waste, animal waste, microbiological waste, sharp object waste, pharmaceutical waste, solid waste, liquid waste, incineration waste, and cytotoxic chemical waste (Singh et al., 2001). The recent COVID-19 pandemic has accelerated BMW drastically across the globe. Although, WHO have specific guidelines for waste management in normal health situations and as well as during pandemic but in this present situation of emergency it becomes very difficult to follow the existing rule accordingly. On the other hand, developed countries have well-designed existing waste management systems but it creating huge problems for developing countries (Matete and Trois, 2008). In India, BMWs are broadly classified into two categories, infected and non-infected categories. Non-infected categories mainly included cytotoxic chemicals and pharmaceutical products. Among infected wastes are segregated into four major groups and each group having a specific color code i.e., red, yellow, blue, and white. Red bin deals with infected materials that belong to the direct contact with the patient, wound, or infected part e.g. dressings, POP casts. Yellow color includes anatomical wastes and pathological waste materials including the placenta. Blue and white colors include syringes, gloves, plastic materials, and sharp objects respectively (https://www.aiims.edu/en/departments-and-centers/central-facilities/265-biomedical/7346-bio-medical-waste-management.html, Biomedical Waste Management Rules 2016, notified by the Ministry of Environment, Forest and Climate Change, Government of India as per the gazette notification dated 28th March 2016.). Details about types of BMWs and their guided disposal categories have been discussed later.

Biomedical waste management system

Incineration

This is a method of the waste management system that utilizes heat to destruct BMWs. This method of waste management requires incinerators that are meant for the combustion of solid waste into the mixture of byproducts. Rapid incineration converts toxic materials into non-toxic ions in presence of heat and continuous flow of oxygen. This process has been considered being the safest scientific procedure to dispose of medical wastes (MW) across the globe and more than 90% of MW has been disposed of by this technique in most of the developed countries. India has observed the application of incineration during the early 1990s after the first implication of BMW rules (Datta et al., 2018). Although, this is the most popular and effective means of BMW management but this method of management has been noticed to produce several toxic substances due to incomplete combustion, called products of incomplete combustion (PIC). Besides, dioxins are another group of chemicals known to produce during the incineration process (Datta et al., 2018). Dioxins and dioxin-like compounds are a group of toxic substances that have profound health hazardous effects on humans. They are known to activate Aryl hydrocarbon Receptor (AhR) in human and expresses AhR mediated effects like immunological disorders, hormonal disorders, reproductive problems and neurological disorders (White and Birnbaum, 2009). It also has potential carcinogenic effects. These dioxins are also sometimes associated with furans another harmful chemical that originated through incineration (Schuhmacher and Domingo, 2006). Many MW contains polyvinyl chloride (PVC) and are the major source of dioxins in the environment (Datta et al., 2018). Recently several studies have shown an increase in dioxin concentration in humans and have threatened the use of this technology for future waste management (Subramanian et al., 2007; Datta et al., 2018). The recently massive technological revolution has modified the grate combustion system and introduced modular combustion of BMW which utilized starved air basis that reduces PIC dramatically (Rogoff and Screve, 2019). It was investigated that dioxin generation was significantly dropped to even 0.02 ng/ Nm3 of stack gas i.e. equivalent to 0.1 toxic equivalents (TEQ) gram per million tons of MSW (medical solid waste) combusted in WTE (Waste-to-Energy) plants (Themelis, 2012).

Chemical disinfection

Chemical disinfection has been done mainly on the surfaces and to the equipment, those are impossible to dispose off. Sometimes MWs which are difficult to move to an incinerator or landfill facility are also recommended for chemical disinfection. Most of the liquid medical wastes are mandatorily disinfected with chemical agents. The major chemical to be used for chemical disinfectants is chlorine compounds. Sodium hypochlorite is a customary chemical used for chemical disinfection (https://www.lenntech.com/processes/disinfection/chemical/disinfectants-sodium-hypochlorite.htm). Ethylene oxide is also used as an effective chemical disinfectant agent. Generally, 1–10% sodium hypochlorite is used to disinfect BMW but the high concentration of sodium hypochlorite can cause serious human ailments (Slaughter et al., 2019). Treatment with NaOCl causes a serial reaction with an organic compound in wastewater to produce organic chlorine compounds such as AOX (halogenated chlorine compounds readily absorbed by activated carbon). These AOX are also very much toxic for aquatic animals (Emmanuel et al., 2004). Although, 0.5% NaOCl concentration was found to be effective antibacterial effect and safe for direct human administration (Byström and Sundqvist, 1983) but 1% NaOCl was found to be inefficient in disinfecting medical instruments with blood and hypodermic needles (Chitnis et al., 2002). So, for disinfecting any surface 3–5% solution of NaOCl can be used to effectively decontaminate them. WHO also have formulated guidelines for use of NaOCl as disinfection agents for surfaces concerning the COVID-19 pandemic (WHO/2019-nCoV/Disinfection/2020).

Steam and thermal treatment

Autoclaving is an age-old technique in sterilizing different MWs. This technique is also used for the decontamination of different reusable medical instruments. Thermal treatment has been used in some developing countries as a possible alternative to incineration. In a study, three different temperatures 111 °C, 121 °C, and 131 °C were analyzed to check the effectiveness of different bacteria. 121 °C for 15 min were used for Gram-negative bacteria and 131 °C for 30 and 60 min were tested for Gram-positive bacteria but in each of those cases, re-growth of the bacterial population was observed after two days (Hossain et al., 2012). It indicates thermal treatment cannot be used as an alternative technique of incineration specifically for highly infectious viral diseases like COVID-19.

Microwave irradiation

Microwaves can be used in BMW management without producing any pollutants. Application of microwave technology in biomedical waste management gaining popularity because of its green nature of disposal. Microwave irradiation technology was successfully used in sludge and wastewater treatment (Mudhoo and Sharma, 2011). The application of this technique is also increasing in hospital waste management in India (Thakur and Katocha, 2012). In food industries, microwave treatment is also coupled with electron beam irradiation and proved to be very effective than single microwave irradiation (Martin et al., 2005). This method can also be used in the medical waste management system. Although the application of this technique in BMW is rare but the possibility of this technique in the future management of different hazardous waste including wastes from healthcare sectors is emerging (Zimmermann, 2017).

Land disposal

Land disposal or burial has been used to dispose of the large amount of BMW effectively. Along with some biodegradable hospital wastes, the ash generated in incinerators is also buried in the landfill. Landfilling of pretreated BMW is a sustainable option for the toxic waste management system. Now-a-days bioreactor simulators are used to efficiently dispose of the BMWs. Leachate recirculation has greater carbon reduction capability than dry simulators (Lakshmikanthan et al., 2017) This method of waste disposal has a great significance on hospital waste management. (Latha and Rajasekhar, 2021; Bhardwaj and Kumar, 2021).

Inertization

Inertization has been carried out for incinerator ashes and also for pharmaceutical components. Firstly the materials are crushed into small pieces and then encapsulated under non-reactive, non-toxic containers and disposed of in safe places. This method is gaining popularity because of its easy operation and low-cost nature. Presently, nano-photocatalysis has also been employed in various BMWs for the risk-free disposal of harmful waste materials (Hooshmand et al., 2020). This technique can also have an enormous possibility for the COVID-19 BMW disposal as well.

The impact of COVID-19 pandemic on BMW management

COVID-19 pandemic enhances the generation of BMWs manifold in different countries across the world. The situation is quiet alarming in densely populated country like India. According to the central pollution control board (CPCB, India) in 2017 a total of 557 tonnes/day BMW was generated in India, out of which 517 tonnes/day was remained untreated. The country possesses 198 approved BMW treatment plants and another 28 were under construction (Chand et al., 2021). As per annual report of CPCB, 2019, the total 233 incinerators are in working status in different states of India (https://cpcb.nic.in/list-of-common-bmw-treatment-facilities, last accessed 15th August, 2021). It has been also directed to use industrial incinerators in case of emergency with special permission (https://cpcb.nic.in/uploads/Projects/Bio-Medical-Waste/BMW-GUIDELINES-COVID_1.pdf). In such a situation, COVID-19 pandemic not only increases the annual BMW but uplift untreated pollutants also in the environment. Due to the pandemic situation annual, BMW escalates 850 tonnes/ day during 2020 in India. The existing facilities can dispose of 700 tonnes/ day of BMW if the incinerators work in their full swing. The remaining 150 tonnes/day of toxic wastes increases potential environmental as well as healthcare risks (https://swachhindia.ndtv.com/coronavirus-pandemic-exposes-broken-system-of-bio-medical-waste-management-experts-discuss-the-issue-and-solutions-49427, Accessed 7th August 2021; Chand et al., 2021) (Fig. 1). The public-Government sectors are trying their best to improve the infrastructure and contain such situations to reduce the environmental contamination as well as quick disposal of the BMW particularly the covid wastes (more than100 tonnes/ day). In this context, a single method of disposal cannot reach the huge requirement of waste removal. A synergistic approach in waste management and ground-level separation of BMW can only successfully diminish the danger from toxic medical wastes. Judicial use of healthcare and single-use personal protective elements

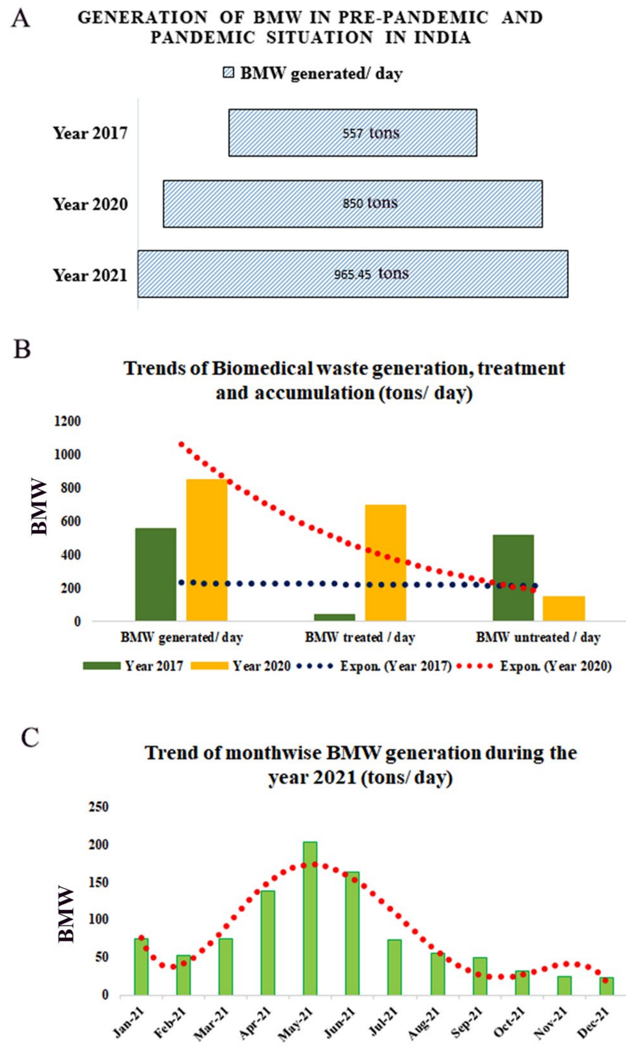

Fig. 1 Graphical representation depicting biomedical waste (BMW) generation during pre-pandemic and pandemic situation in India, **A**. Pyramid histogram indicating significant increase in BMW production during pandemic condition, **B**. Graph represents BMW generation/day, BMW treated/ day, and BMW accumulated/ day during pandemics, **C**. Graphical representation of trend of month wise BMW generation during the year 2021 (data procured from CPCB, India https://cpcb.nic.in/)

(PPE), face masks, and other small disposable medical devices can further reduce huge toxic plastic wastes. Simultaneously, proper awareness in mass, as well as healthcare workers, are required to sustainable management of the BMWs in this challenging situation. Studies have shown that disposable surgical and other types of N95 masks are made up of polypropylene, polyurethane, polyester, polyacrylonitrile, etc. (Shen et al., 2021) which are potential sources of microplastics. The burning of such masks can also release tremendous toxic gases from the combustion of polypropylene, polyethylene, nylon, Fe, Si, etc. For the environment, safe valorization CO_2 is now used to incinerate such masks as a reaction medium in many countries. Still, carbon monoxide (CO) and methane (CH_4) are produced significantly in these cases (Jung et al., 2021). Although, several attempts have been made to standardize the decontamination process to re-use masks and other protective elements for the reduction of BMW burden to the Earth. Recently active hydroxyl radical-based decontamination of surgical and N95 masks had been carried out through photo degeneration of hydrogen peroxide and ozone by UV-C. This process is also called "gas-phase Advanced Oxidation Process (gAOP)" (Hasani et al., 2021). Another study showed that moist heat and chemical treatment with salt (NaCl) and N-halamide can dramatically reduce pathogenic contaminants from used masks (Zorko et al., 2020). Recently, carbon nanotubes are also used to generate face masks with self-sterilizing capability (Soni et al., 2021).

The global market of face masks is projected to grow up from 737 million in 2019 to 22,143 million in 2021. It has been anticipated that these markets will further reduce to some extent to 3021 million in 2025, but still, the number is dramatically higher than any annual consumption before 2019 (https://www.marketsandmarkets.com/ResearchInsight/face-mask-market.asp, on 7th August 2021). This increasing habit of using face masks (particularly surgical and other face masks containing water repellent layer) and improper disposal of the same would put the environment into a new challenge in the future (Huang and Morawska, 2019). A BBC report on 4th May 2021 has documented that improper disposal of surgical masks could release chemical pollutants like heavy metals and also increases microplastic contamination in the environment (https://www.bbc.com/news/uk-wales-56972074). Water bodies are potential sinks for these microplastics pollutants from surgical face masks, especially during the rainy season. The polymeric substances released from the face masks can deteriorate aquatic life tremendously. The microplastic accumulation can affect the food chain and further hamper human health as many of these aquatic organisms are readily consumed as food by the human. The detailed study of the effect of microplastics on human health is still unknown, but studies are continued in its full swing to delineate as well as solve this potential risk as early as possible (Aragaw, 2020). Hydrolytic bacteria are known to hydrolyze toxic products and bioconvert them into several non-toxic elements. Hence, these types of bacteria are utilized earlier in wastewater treatment (Ethica and Sabdono, 2017). These properties tend to the use of these bacteria in treating liquid BMWs (Ethica et al., 2018). Recently, Ethica et al., has again documented the use of a consortium of hydrolytic enzyme-producing bacteria that can be successfully utilized for BMW management and microencapsulation (Ethica et al., 2021). Identification and characterization of many plastic degrading bacteria may also provide future solutions for BMW-associated microplastic pollution (Caruso, 2015; Purohit et al., 2020). Proper formulations of disposal guidelines and further progress in microplastic pollution research urgently necessitate mitigating any future undesirable situation (Figs. 2, 3).

Environmental footprint vis à vis COVID-19 pandemic

The COVID-19 pandemic has changed the environmental footprint precariously. Although, global lockdown, controlled transportation, and associated effect had significantly reduced global carbon (C) footprint initially but excessive use of single-use plastic (SUPs) reverses all the efforts made previously to curtail plastic pollution on Earth. Plastic pollution particularly microplastic (~ 1 μM to 5 μM) and nano plastics (~ 1 nm to 100 nm) are supposed to affect the environment in the recent future due to the gap between generation and disposition of plastic pollutants. Besides existing plastic pollution, the aggressive accumulation due to pandemic completely reversed the concept of global plastic waste footprint. Benson et al., 2021 have estimated the probable SUPs use and waste generation across the world. African subcontinent was estimated to be the highest contributor on this followed by Asia, Europe, South, and North America and Oceania. Among the countries, China is the highest contributor of daily use of face masks as well as plastic waste generation (702,390,002 face masks; 107,949,283.20 tons). India ranks second in this category, with 386,401,228 daily face mask use and 103,500,328.90 tons of plastic waste generation (Bensen et al., 2021).

The effect of COVID-19 on Indian coastal areas

A small remote sensing-based study has been performed along with two Indian coastal locations i) coastal area of the Bay of Bengal and ii) Arabian sea coast (Table 1). The remote sensed data were downloaded from NASA (National Aeronautics and Space Administration) Ocean Color web server (https://oceancolor.gsfc.nasa.gov/). In this particular study Level, 3 SMI data of Chlorophyll a (Chla), particulate inorganic carbon (PIC), particulate organic carbon (POC), and total reflectance (RRS) were downloaded from the above server which relies on MODIS (Moderate Resolution Imaging Spectroradiometer) aqua satellite ["Terra" (EOS AM) and "Aqua" (EOS PM)]. These two satellites look over the entire Earth's surface every two days and acquire data in 36 spectral bands (https://oceancolor.gsfc.nasa.gov/data/aqua/). The analysis was performed by NASA SeaDAS (Version 7.5.3) (https://seadas.gsfc.nasa.gov/) software. Satellite images of different periods, as well as the statistical data

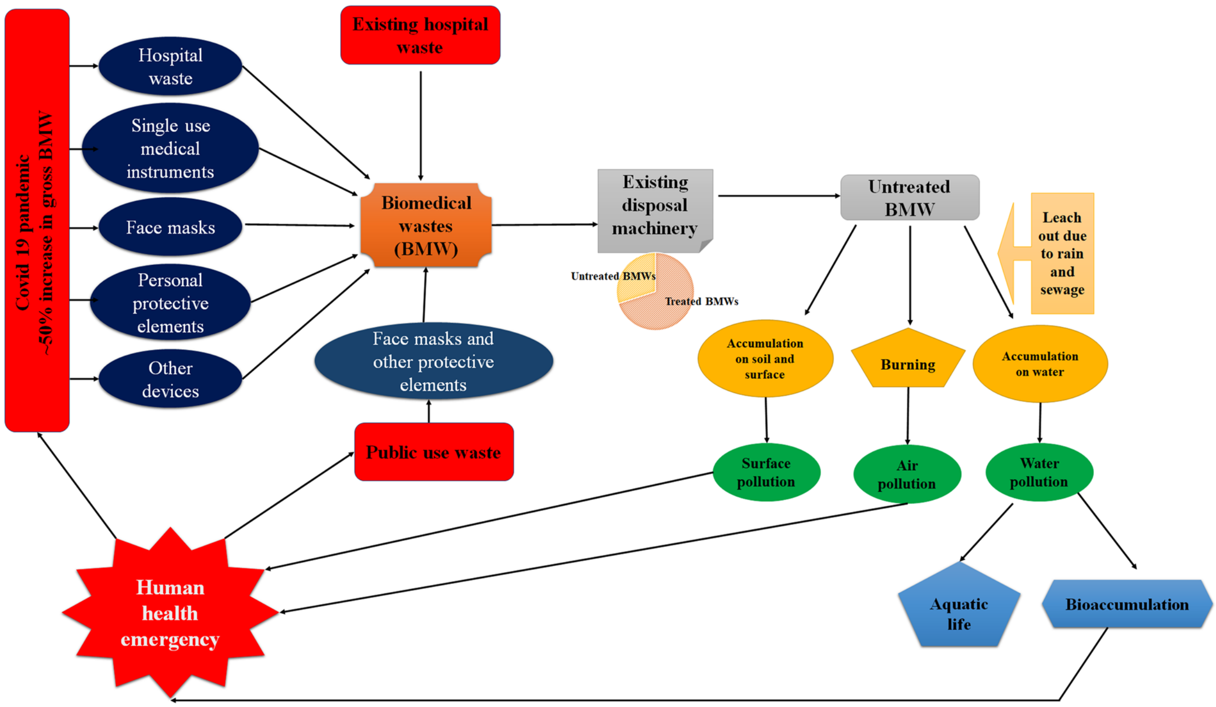

Fig. 2 Schematic representation of Covid-19 pandemic on biomedical waste (BMW) generation and impact on the environment. Insufficient facilities of BMW disposal led to the generation of untreated BMWs which turn out to be potential soil, air, and water pollutants, affecting aquatic as well as human life

of particular parameters, were obtained from NASA SeaDAS during the entire analysis. The location of map areas is snapped from Earthexplorer (https://earthexplorer.usgs.gov/) server (Fig. 4).

Coastal areas lining the Bay of Bengal

Carbon compounds in the ocean can be categorized as inorganic and organic compounds, and they can be dissolved or particulate. The main contributors of dissolved inorganic carbon (DIC) are bicarbonate and carbonate that are the byproducts of inorganic carbon availability in the habitat. DIC gets dissolved in the water to form particulate inorganic carbon (PIC) which is used by autotrophic marine organisms as the carbon source for photosynthesis that forms particulate organic carbon (POC). POC is contributed by protein, lipids, carbohydrates, and nucleic acids. So along with photosynthetic products, marine non-photosynthetic organisms also contribute to POC.

The rapid fall of PIC during the lockdown season indicates that the availability of inorganic carbon compounds was low. It may be an effect of closing all the factories and industries that produce PIC. The ocean system is the largest sink for global PIC showing greater solubility in marine water as compared to freshwater due to higher specific gravity. Thus, as lockdown prevented CO_2 emission from both industrial and vehicular sources, it accounted for low PIC levels in the Bay of Bengal as well. This hypothesis is also supported by the fact that, as the lockdown protocols were removed and all the industries were running again, the PIC levels went upward again. The fall of the chlorophyll-a level was probably due to the Amphan cyclone (May 2020). The pre-cyclone water disturbances resulted in an unstable water column that would have subsequently affected stratification which in turn may have impacted the green autotrophic community which may be a possible reason for the fall of chlorophyll fluorescence levels during that period. As the lockdown period was over, as shipping activities and fishing started over, the water column became disturbed and less stratified that inhibited marine flora to flourish, and rendered low chlorophyll concentration of the habitat. Moreover, microplastic pollution due to biomedical waste discharge may also affect the photosynthetic efficiency of the autotrophic community that in turn may have lowered the POC levels. This imposes an indication of the deleterious effects of microplastic pollution due to the COVID-19 pandemic and required further in-depth study to reconfirm the fact. (Figs. 5, 6).

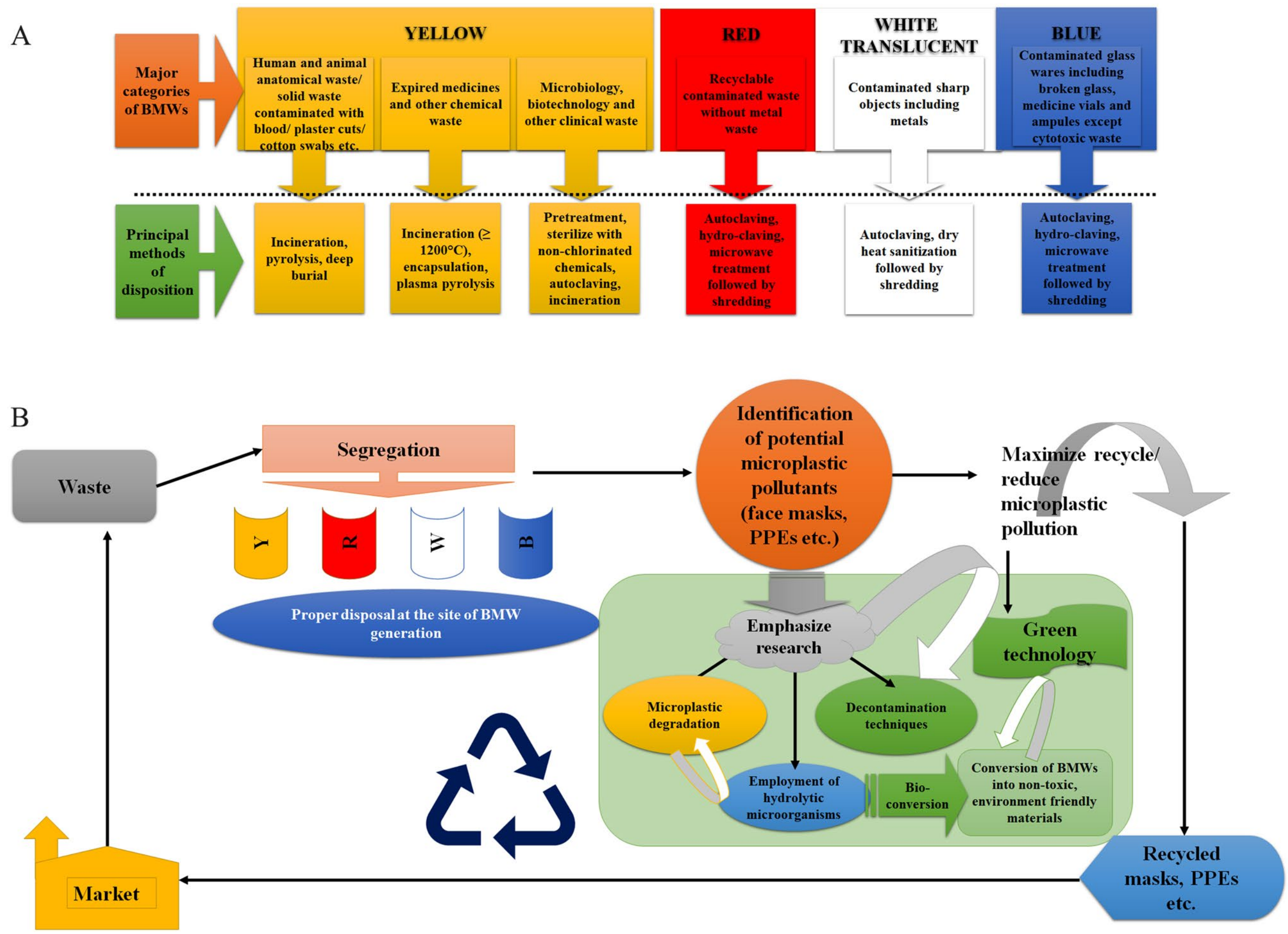

Fig. 3 Biomedical waste management system, **A**. Schematic representation of major BMWs categories and their respective disposal guidelines, **B**. Proposed BMW management system to emphasize primary segregation of BMWs and subsequent technology enhancement in decontamination techniques to enhance re-use. Technology enhancement for microplastic degradation and bio-conversion of BMWs by employing different hydrolytic microorganisms can also help to solve this problem

Table 1 Coordinates of the study area

Coordinates stations		Latitude	Longitude
Study area I (Bay of Bengal)	Near Pakokku (Myanmar)	21.4320	94.7570
	Near Chhattisgarh (India)	21.4320	82.1890
	Near Karapa (India)	16.8990	82.1890
	Bassein (Now, Pathein) (Mayanmar)	16.8990	94.7570
Study area II (Arabian sea)	Gujarat	23.0660	73.7470
	Gujarat	23.0660	68.9610
	Open ocean	18.7860	68.9610
	Near Shirota Lake, Maharastra	18.7860	73.7470

Coastal areas lining the Arabian sea

Before the lockdown which initiated in March 2020, the variation in chlorophyll fluorescence was similar and complemented well with that of PIC levels of the habitat. This would indicate that available PIC was utilized by chlorophyll to perform photosynthetic carbon assimilation. However, in December 2020 a different pattern was observed where even though PIC levels were low whereas chlorophyll concentrations were much higher which deviated from the pattern shown in the previous samples. This may be an outcome of the lockdown period and subsequent restrictions that were

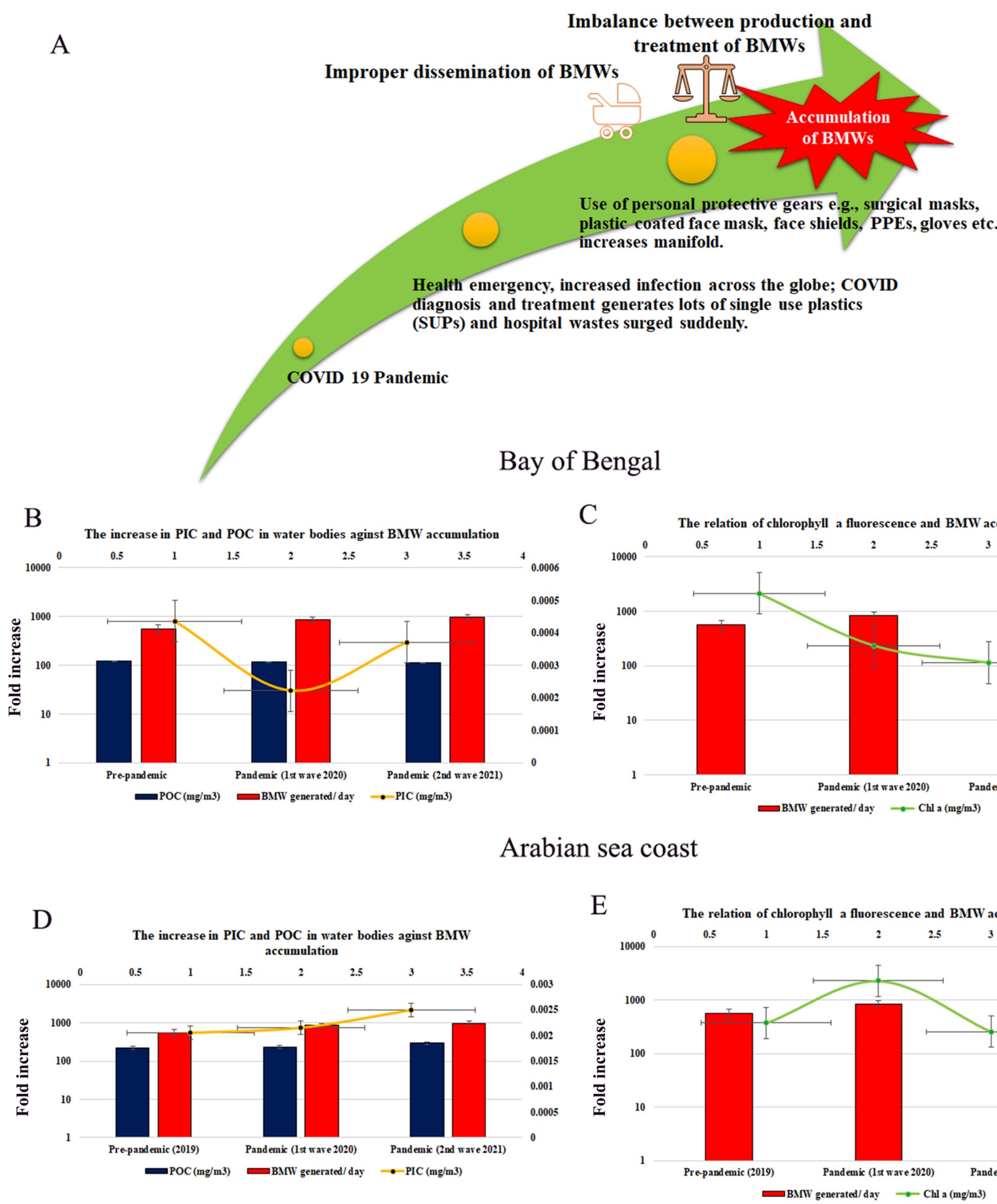

Fig. 4 Graphical representation depicting changes of water ecosystem in Bay of Bengal and Arabian sea coast of India during pre-pandemic and pandemic situation, **A**. COVID-19 imposes huge BMW pressure on existing waste management system, **B**. The changing parameters of POC, PIC against BMW generation in Bay of Bengal, **C**. The effect of BMW accumulation on Chlorophyll a fluorescence in Bay of Bengal, **D**. The changing parameters of POC, PIC against BMW generation in Arabian sea coast, **E**. The effect of BMW accumulation on Chlorophyll a fluorescence in Arabian sea coast. The graph represents fold increase/ decrease of all the parameters (logarithmic values with base 10, $\log_{10}$). The data represented as mean value ± SD

implemented all over the country. During this period as both recreational and fishing activities in the open ocean were restricted and highly reduced, it accounted for a less disturbed and well-stratified habitat. Such a stable condition of the habitat was very well suited for the proliferation of planktonic autotrophic protists that largely remain buoyant in the habitat and contributed to enhanced chlorophyll-specific reflectance. However, the opposite pattern was observed for April 2021where PIC was high in the habitat although chlorophyll fluorescence was recorded at any other sampling time. This was possible because when the lockdown period was over after the first wave of COVID-19, there was a

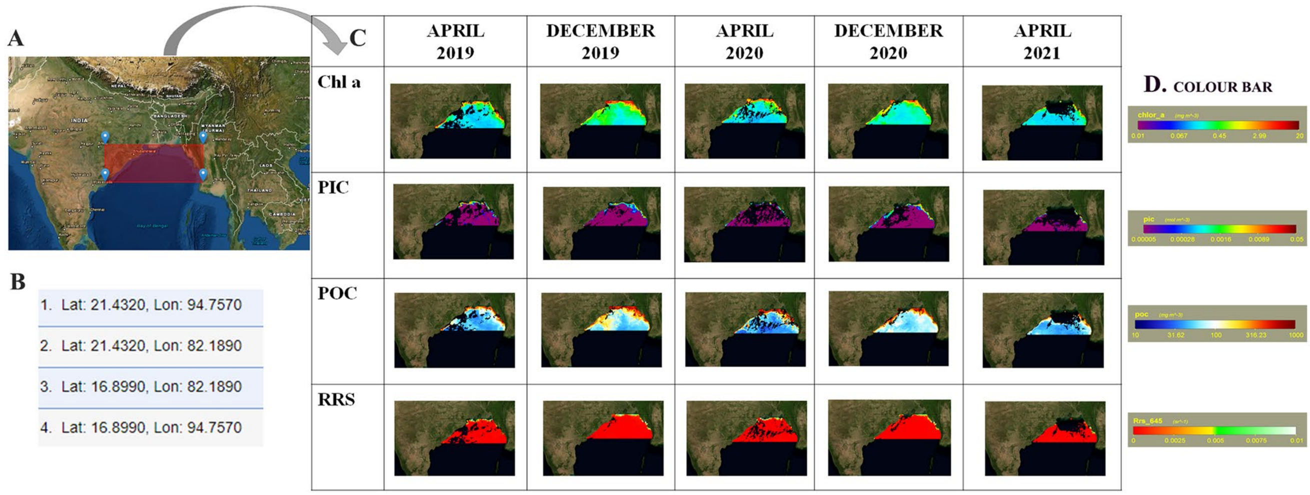

Fig. 5 Representation of study area and remote sensing data of Bay of Bengal region with satellite images. **A**. Study area. **B**. Latitude (Lat) and Longitude (Long) of four corners of the rectangular study area. **C**. Satellite images showing different concentrations of different parameters (Chlorophyll a—Chla, Particulate Inorganic Carbon—PIC, Particulate Organic Carbon—POC, Remote Sensing Reflectance (645 nm)—RRS) of different months (April-2019, December-2019, April-2020, December-2020, April-2021). **D**. Colour Bar

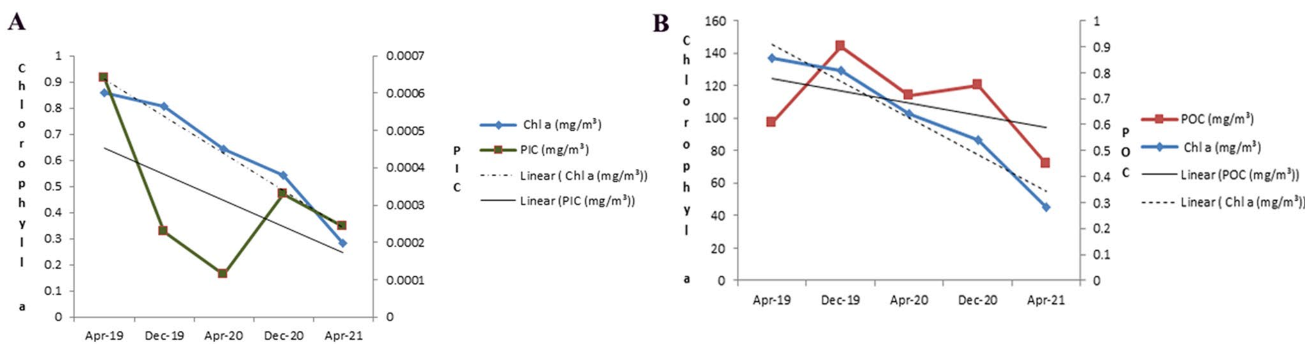

Fig. 6 Graphical representation of accumulated data of Chlorophyll a (Chla), particulate inorganic carbon (PIC), particulate organic carbon (POC) concentration from satellite images of Bay of Bengal region, and correlation of the Chla concentration data with **A**. PIC concentration and **B**. POC concentration

buildup of biomedical wastes in the habitat including microplastic. Such low specific gravity and buoyant biomedical wastes tend to make the water column lose transparency thereby inhibiting light availability in the water column. As light attenuation takes place, the chlorophyll biosynthesis process is expected to be hampered which was possibly the reason for the low chlorophyll concentrations even though PIC was comparatively high.

POC tended to be more consistent even though chlorophyll concentrations varied from April 2019 till December 2020. So, the basic pattern shows that the POC levels were not entirely dependent on chlorophyll-dependent carbon fixation with heterotrophic populations may be an important contributor. After December 2020 as the pandemic situation improved, most of the restrictions imposed during lockdown were withdrawn that allowed both recreational and economical exploitation of marine habitats which consequently created a sudden surge in anthropogenic pressure in the habitat thereby inhibiting buoyant autotrophic community and concomitant chlorophyll availability. Furthermore, by April 2021 more than a year had passed in the pandemic situation which is expected to account for a significant amount of biomedical waste discharge in these habitats. Unlike the east coast of India, the Arabian Sea is not inundated with freshwater inflow from perennial sources. Thus, an increase in biomedical waste discharge in the water column will have a further cumulative negative effect on both autotrophic and heterotrophic communities of the habitat that may have resulted in the low POC levels in the habitat (Figs. 7, 8).

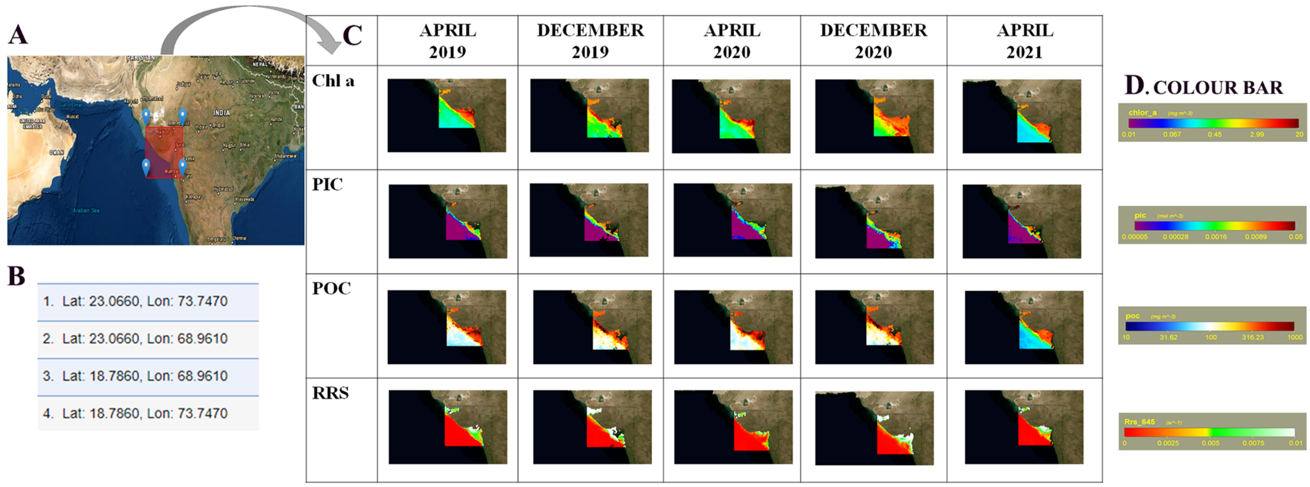

Fig. 7 Representation of study area and remote sensing data of Arabian Sea region with satellite images. **A**. Study area. **B**. Latitude (Lat) and Longitude (Long) of four corners of the rectangular study area. **C**. Satellite images showing different concentrations of different parameters (Chlorophyll a—Chla, Particulate Inorganic Carbon—PIC, Particulate Organic Carbon—POC, Remote Sensing Reflectance (645 nm)—RRS) of different months (April-2019, December-2019, April-2020, December-2020, April-2021). **D**. Colour Bar

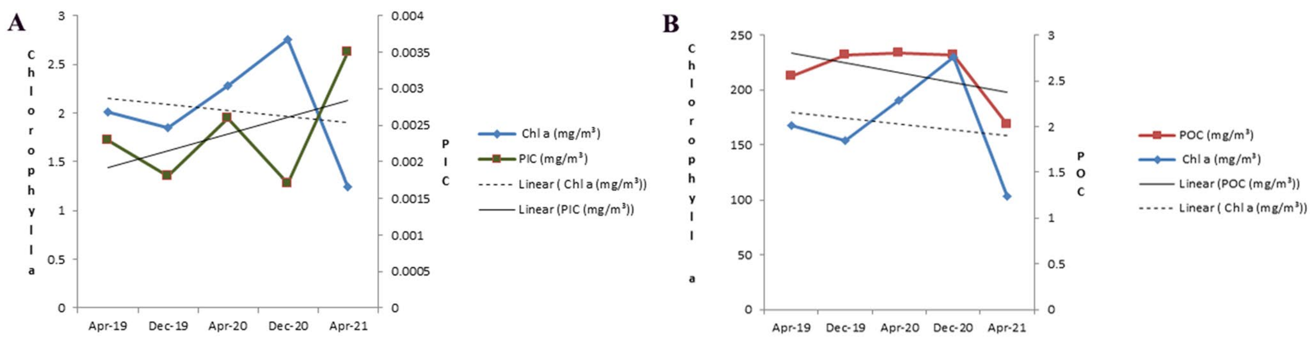

Fig. 8 Graphical representation of accumulated data of Chlorophyll a (Chla), particulate inorganic carbon (PIC), particulate organic carbon (POC) concentration from satellite images of Arabian sea region, and correlation of the Chla concentration data with **A**. PIC concentration and **B**. POC concentration

Conclusion and future perspective

Growing population density and associated pollution threaten the environment across the world. Among these biomedical waste management demand more attention because it not only affects the environment in varied ways but increases also the potential risks of infections and associated health hazards. Insufficient waste management system along with improper waste littering of BMWs mixed with other garbage make the situation more critical in highly populous countries like India. According to the biomedical waste management rule, 2016, all the BMWs are to be segregated into four categories with respective color-coded bins e.g., yellow bins are for human and other animals anatomical waste, solid waste. Expired medicines and other chemicals are also incorporated in this bin, which specifically incorporates antibiotics and cytotoxic drugs and containers of the same. Different microbiological, biotechnological, and clinical wastes are also targeted towards the yellow bin. Red bins are meant for any contaminated recyclable waste without metal wastes. White translucent bags are specifically encompassing contaminated sharp objects and blue bags are for glass wastes. This primary segregation at source is the vital requirement for successful reduction in toxicity through BMWs. The major concern concentrated towards microplastic pollution due to elevated use of single-use medical instruments particularly face masks and personal protective elements due to pandemic situations. The present scenario of the COVID-19 pandemic ensures multifold regular use of such potential sources of microplastic pollutants and will continue surging in the future. The use of face masks and other personal protective elements and essential single-use plastic devices are inevitable to contain the pandemic from further spread and maintenance of public health. On the other hand, potential, environmental risks out of such enormous use of BMW generators should not be overlooked. The harmful effect of microplastic on the environment and human health is well documented but the specific hazardous effect is still elusive (Campanale et al., 2020). Much research is now necessary to unveil the specific effect of microplastic pollution as well as finding a solution for such notorious micropollutants. The emphasis on proper segregation and re-use of single-use BMWs may only be the easiest solution for such a huge crisis. Much research is now conducted to finding out decontamination techniques for medical devices as well as masks and personal protective elements to maximize re-use and minimize pollution (Fig. 3). Although it is very easy to postulate but very difficult to perform in mass implication. On the other hand, standardization and formulation of decontamination technique maintaining its original performance and other properties is another big challenge. Concentrating more research in this field along with mass awareness regarding the effects and proper disposal of BMWs would only save us from many future predicaments.

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Declarations

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