Review

Municipal solid wastes: An under-investigated route of transmission for SARS-CoV-2 and other pathogens in the Covid-19 pandemic

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Abstract. The novel coronavirus disease 2019 (COVID-19) pandemic has brought major challenges to the management of municipal solid wastes (MSWs), which may present an under-investigated route of transmission for SARS-CoV-2 and other infectious agents. Food wastes, personal care products (e.g., toothbrushes, first aids, feminine hygiene products), disposable products (e.g., tissues and wipes, face masks, plastic utensils), and other personal items (e.g., pillows, napkins, razor blades) are easily contaminated with human biological matter that carries infectious agents from infected households. The management of MSWs involves complex logistics with a range of facilities and personnel involved, from their collection, bulk transport, handling, and final disposal. The process often requires manual operations with risks of inhalation of virus-laden aerosols or inadvertent contact with virus-contaminated objects or surfaces. Further, unrestrained access to waste bins in public settings or open landfills can expose certain individuals (*e.g.*, waste pickers, custodial staff, machinery operators) and mechanical vectors (*e.g.*, animals, insects) to SARS-CoV-2 and other infectious agents carried on MSWs. In developing communities, unsanitary practices of MSW handling and disposal such as fly-tipping, waste picking, and unprotected workers with informal employment can exacerbate the risk of MSW-mediated transmission of SARS-CoV-2 and other pathogens among MSW workers and residents near waste collection and disposal sites. This review scrutinizes the practices of MSW management in the Covid-19 context and articulates the key risk factors by assessing current evidence, policies, gaps, and voluntary actions taken on MSW handling and disposal in the pandemic. We highlight the main knowledge gaps on MSW-mediated transmission of SARS-CoV-2 and other infectious agents and propose several risk mitigation strategies and research priorities to alleviate the risk for humans and vectors exposed to MSWs and to understand the role of MSWs in spreading infectious agents including novel pathogens to humans and animal hosts.

Keywords*:* Coronavirus; infectious disease; household waste; fomite; waste management; disposal

1. Introduction

The novel coronavirus disease 2019 (Covid-19) pandemic has resulted in more than 500 million confirmed cases around the globe, including over six million deaths (WHO 2022a). With the recent emergence of variants and re-emergent outbreaks, large numbers of new infections are set to continue in most countries and regions (Wang and Han 2022; WHO 2022b). Recent surveys showed that both the quantities and compositions of municipal solid wastes (MSWs) have been impacted by the current pandemic (Cai et al. 2021; Dutta et al. 2021; Fan et al. 2021; Ouigmane et al. 2021; Zambrano-Monserrate et al. 2020). In particular, the amounts of solid waste generated from domestic sources have increased significantly (Nanda and Berruti 2021). In the United States, the volume of domestic wastes increased by about 30 percent through the first quarter of 2020, compared with those reported in the previous year (Jodi 2020). Main factors contributing to these changes include extended lockdowns, prevalent work-from-home regimes, reduced trips with most people spending more time at home, and an enormous amount of personal protective equipment (*e.g.*, face masks) and single-use products being routinely used and disposed of in households (Tanakasempipat 2020).

Municipal solid wastes constitute a ubiquitous class of carriers for infectious agents and human pathogens, posing known risks of disease transmission during epidemics or pandemics, along with other types of carriers, such as sanitary wastes (Han and He 2021; Peccia et al. 2020; Sun and Han 2021a; 2021b), human biological matter (He and Han 2021a), and personal use products (Han and Zhang 2020). Many human pathogens, including fecal coliform bacteria, salmonellae, enteroviruses, protozoan parasites, noroviruses, hepatitis B virus, and antibiotic-resistant bacteria are commonly found in MSWs and can spread to different hosts (Vaverková et al. 2020). The likelihood of contacting domestic wastes contaminated by human biological matter and inhaling aerosols during the collection and handling of MSWs make workers particularly susceptible to infectious agents, of which domestic workers, custodians, waste pickers, and waste bin handlers are at heightened risks. An earlier survey revealed that MSW workers in Denmark were six times more likely to contract infectious diseases than the average workforce in the country due to their exposure to higher levels of airborne pathogens (Poulsen et al. 1995; WHO 2004). Similar results were reported in Genoa, Italy where the city's MSW workers showed a higher seroprevalence of hepatitis than found in the general population (WHO 2004). In a cross-sectional study (n = 545) at University Hospitals Birmingham NHS Foundation Trust, one of the largest hospital trusts in the UK delivering care to 2.2 million people per annum, Shields et al. (2020) found that housekeeping staff had higher seroprevalence rates of SARS-CoV-2 antibodies (34.5%) than healthcare workers at this facility (14.8%–33.3%). The earliest suspected case of MSW-mediated Covid-19 infection was reported in Sichuan, China as early as December 2020 (Sichuan Daily 2020). Although there is no scientific study published to date on MSW-mediated transmission of SARS-CoV-2, a recent report revealed that on 1 September 2021, a custodial worker was infected with the B.1.617.2 (Delta) variant of the novel coronavirus when collecting garbage from hotel rooms at a quarantine hotel in Guangzhou, China, which became the first known case of Covid-19 infection via contact with household wastes (CCTV 2021) (**Fig. 1**). Several weeks ago, a group of custodian staff at an international airport in Nanjing was infected by the Delta variant after cleaning the interiors of an international flight that arrived from Moscow and was inadequately disinfected prior to cleaning. Later investigations found that infections were caused by inappropriate undressing of protective clothing, improper wearing of rubber gloves and touching face and skin with rubber gloves at work (People's Daily 2022a). Since February 2022, one confirmed case of Covid-19 infection has been reported on a roadside waste picker with another suspected case on three MSW workers, raising further alarms on MSW-mediated transmission of Covid-19 in the country (Hebei News 2022; People's Daily 2022b).

During the Covid-19 pandemic, household wastes contaminated with human biological matter may carry viable SARS-CoV-2 and other infectious agents, and transmit these to workers or others in the vicinity during their collection, transport, bulk handling, and disposal. Previous studies showed that viable SARS-CoV-2 was found in a variety of human biological matter including respiratory tract secretions, saliva, other body fluids, and feces from symptomatic and asymptomatic individuals (He and Han 2021a). Under room temperatures, SARS-CoV-2 could survive for several hours or even a few days on the surface of plastics, metals, paper, and

cloth, all of which are commonly found in MSWs (Aboubakr et al. 2020; Chin et al. 2020; EPA 2020). To date, there have been no studies on the persistence or infectivity of SARS-CoV-2 in simulated or real MSW-related environments such as household trash, waste bins, landfills, or open waste dumps, although a recent government report found SARS-CoV-2 on roadside wastes discarded by drivers and passengers along highways in Suzhou, China (Suzhou 2022). Recent discussions revolving around this issue focused on reducing workers' contact with virus-laden wastes (Ragazzi et al. 2020; Vaverková et al. 2020; Yousefi et al. 2021) or techniques for analyzing SARS-CoV-2 in soil runoff and leachates (Conde-Cid et al. 2021). Meanwhile, there are no specific regulations to ensure the safe handling and disposal of MSWs during the Covid-19 pandemic. Major knowledge gaps exist in the current literature concerning the risk factors and unsafe practices in managing MSWs in an epidemic or pandemic scenario, which may present an under-investigated route of transmission for SARS-CoV-2 and other infectious agents in. In this article, we address these gaps by articulating the main risk factors in MSW-mediated transmission of SARS-CoV-2 and other pathogens, including their transmission via airborne and contact routes by exposed individuals and vectors, by reviewing current practices of MSW management and the specific challenges confronted in the Covid-19 pandemic. We highlight the need for emergency protocols and risk mitigation strategies for the safe handling and disposal of MSWs in a public health crisis scenario.

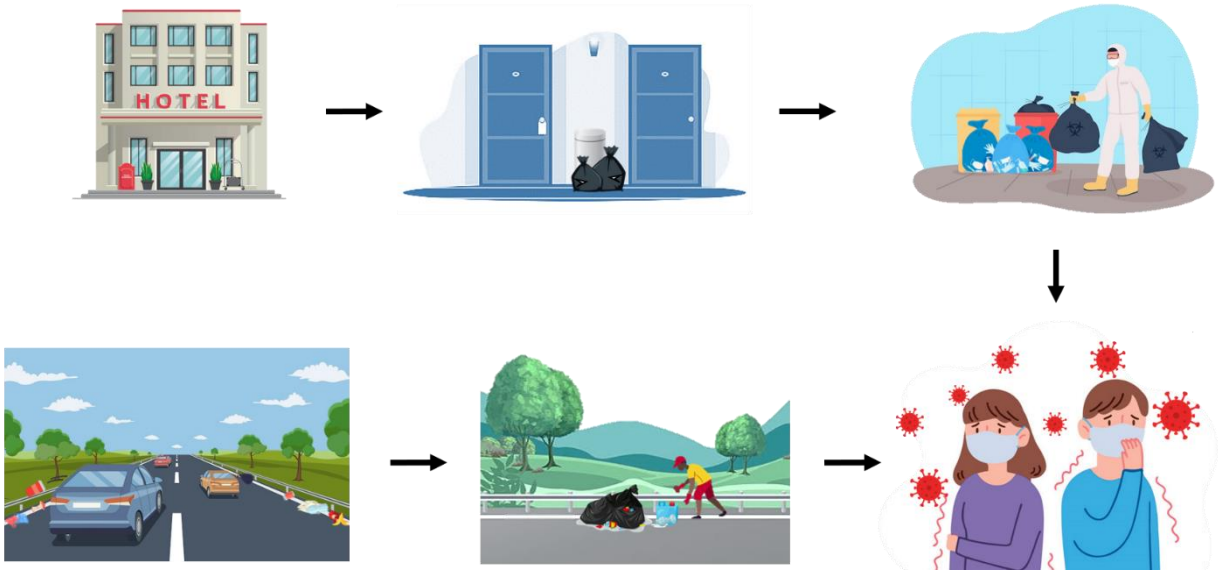

Fig. 1 Two confirmed cases of domestic Covid-19 infections have been recently reported in mainland China. Government investigations found that both incidents were caused by exposure to municipal solid wastes. Details of the incidents are available in various news reports (CCTV 2021; Hebei News 2022). The Suzhou municipality recently issued a warning that some roadside garbage samples collected along highways showed positive results in nucleic acid testing for the novel coronavirus, SARS-CoV-2 (Suzhou 2022).

2. Risk factors in MSW management during Covid-19

Human respiratory droplets, aerosols, mucus, and fecal matter residues carrying viable SARS-CoV-2 may contaminate personal items routinely being disposed of in MSWs (**Fig. 2)**. One of the three principal ways of spreading Covid-19 is by touching the eyes, nose, or mouth with hands after contacting virus-contaminated surfaces, or 'fomites' (CDC 2021a). Studies showed that SARS-CoV-2 survived for 2–7 days on the surface of wood, glass, stainless steel, and plastic under room temperatures (21–23 °C) (Aboubakr et al. 2020). These varieties constitute nearly one-third of the solid wastes (31.3%) found in MSWs (EPA 2020). During the Covid-

19 pandemic, the prevalent use of personal protective equipment (e.g., face masks) and disposable products has resulted in significant increases in plastic waste in MSWs. In Italy, face masks and other Covid-19 personal protection equipment accounted for up to 1.4% of the total weight of MSWs due to their extensive use and disposal by the general public throughout the current pandemic (Ragazzi et al. 2020). A recent study showed that infectious SARS-CoV-2 virus could still be detected on the outer layer of a surgical mask on day 7 at room temperature (22 °C) (Chin et al. 2020). In some areas, shortages of tissues and wipes were intermittently reported due to their persistently high demand by stay-at-home patients (Islam et al. 2021; Penteado and de Castro 2020; Tyko 2022), which are mostly disposed of in household trash. Meanwhile, the increased use of online purchases and food delivery services during Covid-19 lockdowns resulted in mounting wastes of packaging materials, food containers, and plastic utensils (Vaverková et al. 2020; Zambrano-Monserrate et al. 2020), creating enormous amounts of additional domestic wastes that are destined to MSW collection and handling facilities. Since many of these products are designed for personal use, they are easily contaminated by human biological matter (e.g., respiratory droplets, mucus, or saliva) after use. During the bulk collection and handling of MSWs, contamination and cross-contamination are likely to occur in facilities and equipment storing and handling MSWs, posing direct risks to workers who may come into contact with contaminated objects and surfaces and others exposed to the immediate surrounding environment (Vaverková et al. 2020).

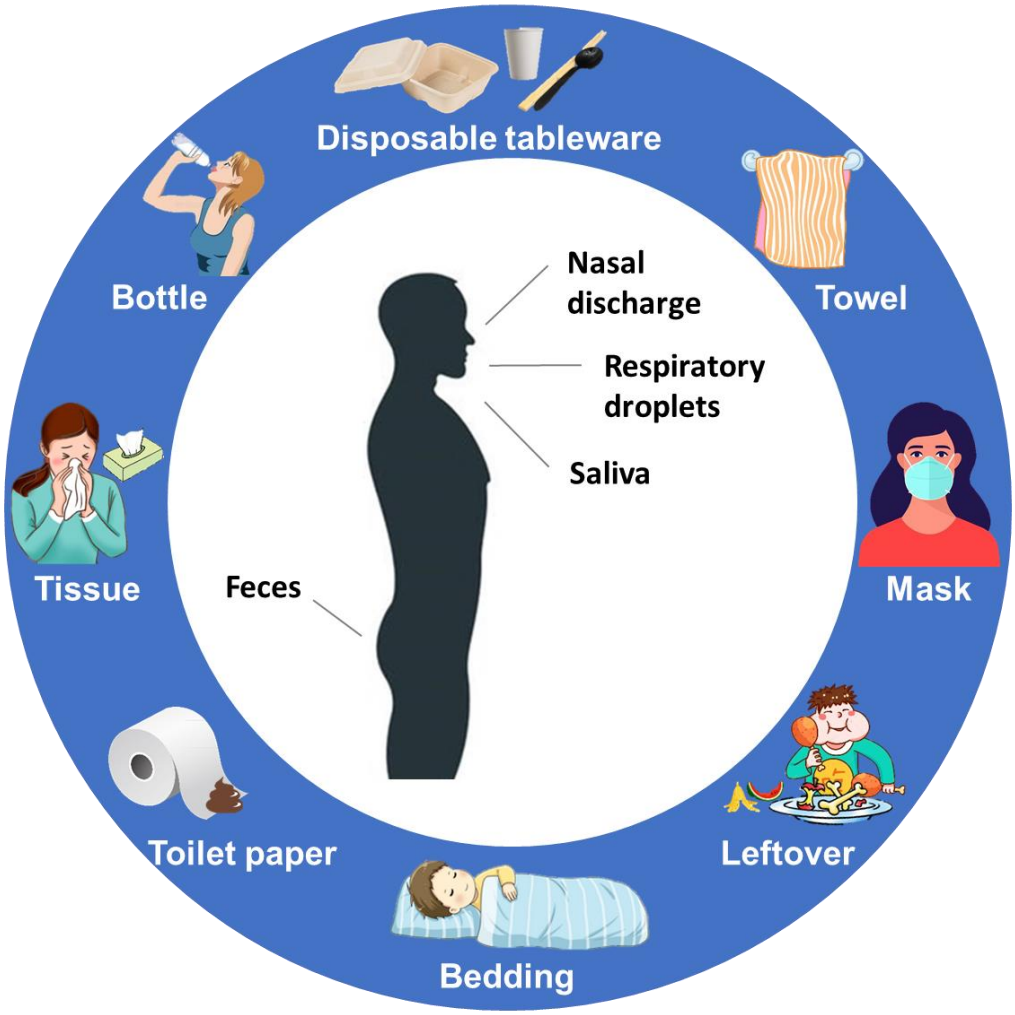

Fig. 2 (Inner circle) Human biological matter carrying SARS-CoV-2; (outer circle) common household products that are likely to be contaminated by virus-laden human biological matter after use by infected persons. The majority of these end up in household trash and are disposed of as municipal solid wastes.

There are several unique risk factors for pathogenic transmissions in MSW-related environments (**Fig. 3**). During the bulk transport and disposal of MSWs, large quantities of dust and aerosols are generated (Anand et al. 2021), which may carry viable SARS-CoV-2 and effectuate the transmission of Covid-19. In addition, short- and long-term exposure to elevated levels of airborne particulate matter and other air pollutants can exacerbate the risk of respiratory infections by SARS-CoV-2 and other pathogens by inducing specific vulnerabilities in the human respiratory tract, such as the overexpression of alveolar angiotensin-converting enzyme 2 (ACE-2) receptors on the surface of epithelial cells, the major cell entry receptor for SARS-CoV-2, and the exhaustion of Th2 immune responses, which facilitates viral penetration and increases host susceptibility to infections (Chen et al. 2021; He and Han 2021b). MSW transfer stations, waste dumps, and landfill sites are significant sources of atmospheric fine particulate matter (e.g., PM_{10} and $PM_{2.5}$), bioaerosols, pathogenic bacteria, and antibiotic resistance genes (Anand et al. 2021; Li et al. 2020). For instance, the movements of heavy dustcarts and site vehicles, the action of tipping garbage, waste compaction by bulldozers and crushers, and stockpiling of soil and rubble all generate large amounts of dust and aerosols at MSW landfill sites (Chalvatzaki et al. 2010). High levels of atmospheric particulate matter are often detected at MSW transfer stations and landfill sites, as well as downwind locations. Godri et al. (2010) reported that in London, the highest particulate matter (PM) concentrations were found in proximity to waste transfer stations experiencing large numbers of vehicles transporting industrial and household wastes. Measurements in solid waste disposal sites and transfer stations in Lahore, Pakistan also showed high $PM_{2.5}$ levels (127.1–403.8 $\mu g/m^3$) at both sources and downwind (50 m) locations, with the latter consistently showing higher $PM_{2.5}$ levels (Raza et al. 2021). The re-suspension of wastes from truck unloading, waste sorting, and mechanical equipment operating during landfill operations resulted in elevated levels of particulate matter emissions at landfill sites and downwind school and residential areas (Chalvatzaki et al. 2010; Ezekwe et al. 2016). It is noteworthy that inhalable fine particulate matter can act as airborne carriers spreading SARS-CoV-2 to long distances far exceeding the social distances advised by public health authorities (ARC 2020; CDC 2022; Morawska and Milton 2020; WHO 2021). In fact, aerosol-mediated long-distance transmission of infectious agents has been well documented even before the Covid-19 pandemic. Zhao et al. (2019) reported that highly pathogenic avian influenza viruses from poultry farms could spread across different states in the U.S. through airborne transmission. In an earlier study, Alonso et al. (2014) found that the porcine epidemic diarrhea virus (a member of the Coronaviridae family) harbored by airborne particles remained infectious after being transported over long distances, where the genetic materials of the virus were detected at the downwind locations of three swine farms at distances of 3–10 miles. Recent studies confirmed the persistence of SARS-CoV-2 on aerosol particles, which maintained infectivity after 3–16 hours under room temperatures (van Doremalen et al. 2020; Fears et al. 2020). SARS-CoV-2 RNAs have also been detected on indoor dust and outdoor atmospheric particulate matter (Renninger et al. 2021; Setti et al. 2020). It is, however, currently unknown whether dust and aerosols generated from MSW handling and disposal sites could carry infectious doses of SARS-CoV-2 and pose the risk of airborne transmission to workers and others in the vicinity or at downwind locations (Liu and Schauer 2021).

Since most MSW collection and disposal sites remain open, animals and insects can be easily exposed to infectious agents carried by those wastes and become mechanical vectors (**Fig. 3**). In a recent discussion, Kumar et al. (2020) speculated that insects such as houseflies and cockroaches could be potential vectors of SARS-CoV-2 during the current pandemic. A more recent laboratory study by Balaraman et al. (2021) supported this hypothesis. After being exposed to SARS-CoV-2-spiked medium or milk, houseflies were able to acquire live SARS-CoV-2 mechanically and transmit genomic RNAs to the surrounding environment up to 24 h post-exposure (Balaraman et al. 2021). This was confirmed in another study where researchers collected 156 houseflies from two hospitals and found that 75% of the body washout samples and 37% of the homogenized specimens were tested positive for SARS-CoV-2, suggesting that houseflies indeed acted as mechanical vectors for SARS-CoV-2 (Soltani et al. 2021). In addition to household insects, wild animals such as storks, gulls, bears, and baboons are often sighted near waste dumps and open landfill sites searching for human scraps (Bittel 2016). Since Covid-19 infection is effectuated by SARS-CoV-2 spike receptor-binding domain and angiotensin-converting enzyme 2 (ACE2) receptor, a diverse range of vertebrates can be potentially infected by SARS-CoV-2 (He et al. 2021). Among the species frequently sighted near waste bins, feral cats and dogs have been tested

positive for SARS-CoV-2 whereas a number of other wild animals are susceptible (van Aart et al. 2021; Bosco-Lauth et al. 2021). Like MSW-dwelling insects, animals can act as mechanical vectors for spreading human and zoonotic pathogens. In fact, reports on animal vectors of MSW-borne infectious diseases were common before the current pandemic. Gulls, for instance, are known as common vectors of fecal pathogens in human excreta (Alm et al. 2018). Adding to the risks, studies showed that the feces of infected persons contained high viral loads of SARS-CoV-2, from symptomatic and asymptomatic individuals as well as recovered patients several weeks after their symptoms cleared (Cevik et al. 2021; Foladori et al. 2020; Jones et al. 2020). The foraging activities of these animals near human scraps and open MSW facilities make them particularly susceptible to infection or contamination by SARS-CoV-2 and other pathogens carried in MSWs, which may become hosts and/or vectors spreading infectious agents to long distances and other species through predation or mating. Without human intervention, which is often the case for pathogenic transmission in wild animals, the reverse zoonosis of SARS-CoV-2 may lead to rapid transmission in animals and, since SARS-CoV-2 is a recombinant virus, the cross-species transmission may facilitate its mutation and the emergence of novel strains (He et al. 2021).

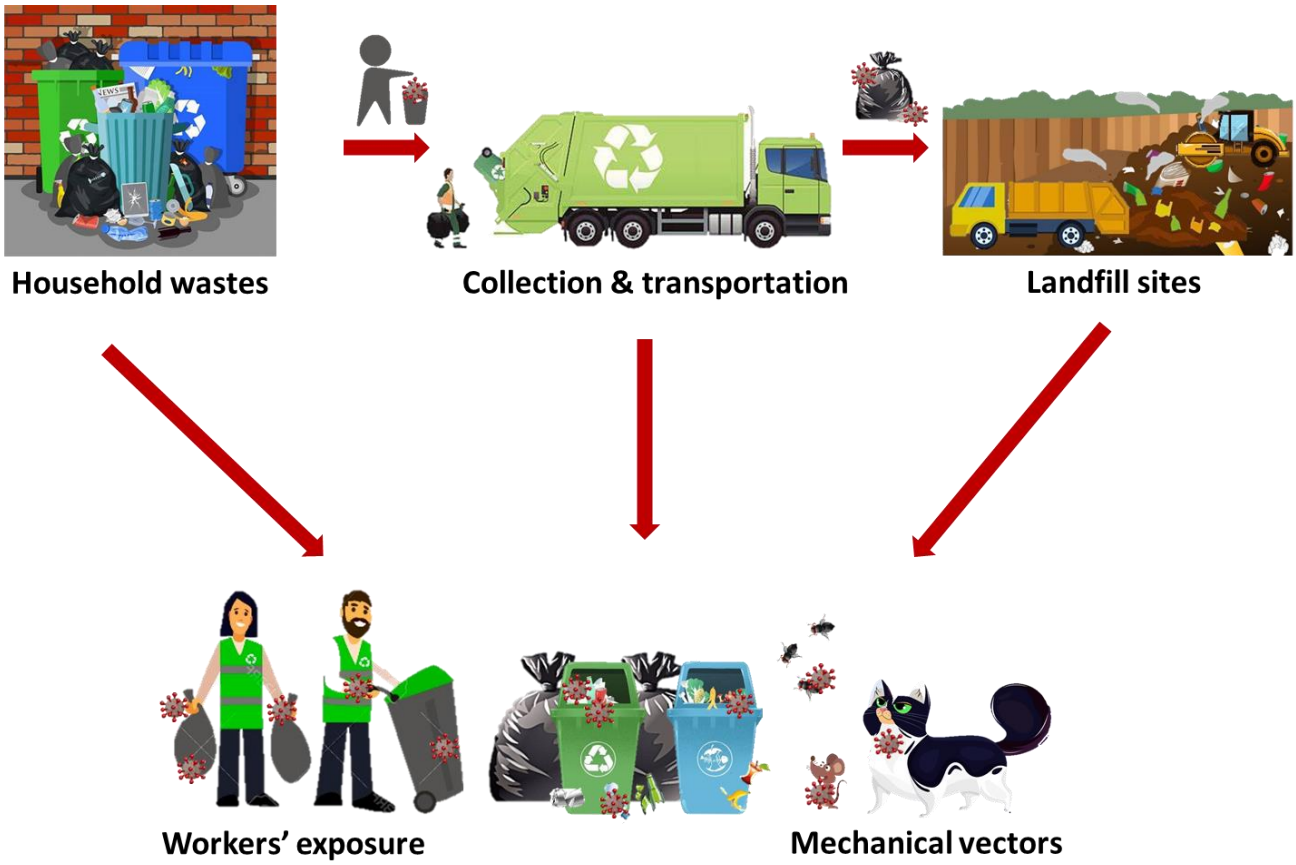

Fig. 3 Risks of exposure by workers, machinery operators, and animal and insect vectors to pathogens, including the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and other human or zoonotic pathogens, carried in solid wastes routinely collected from infected communities and households in the current pandemic.

These risks may have been exacerbated by the enormous quantities of MSWs and the inefficient—often inappropriate—handling and disposal of MSWs throughout the Covid-19 pandemic (Aqil 2020; Brock 2020; CDT 2020; Semuels 2021; SHLW 2020, Tanakasempipat 2020). The massive numbers of stay-at-home patients, extended lockdowns, work-from-home regimes, reduced trips and outdoor activities, and stalled waste recycling

programs have all contributed to mounting domestic waste generated in communities in the Covid-19 pandemic. Meanwhile, there is a dearth of sanitary service workers under the impact of the pandemic (Collectors 2020). Many MSW facilities are operating on reduced services due to a persisting shortage of staff, resulting in service disruptions, long turnover times, and overwhelmed facilities in residential communities (**Fig. 4**). In the UK, disrupted services of waste management led to a 300% increase in fly-tipping in some rural communities (Roberts et al. 2020). A widely overlooked risk factor from overwhelmed waste collection facilities, however, is that the large amounts of domestic waste exposed openly in community environments can facilitate the spread of Covid-19 and other infectious diseases. While this issue received little attention from public health authorities and research communities, MSW-mediated transmission of human infectious diseases has been well documented prior to the Covid-19 pandemic (**Table 1**). Surface runoff, leachates, dust, bioaerosols, and animal and insect vectors near exposed domestic wastes could all exacerbate such risks in community environments.

Fig. 4 Mounting domestic wastes overwhelming household waste bins and collection facilities during the novel coronavirus (Covid-19) pandemic. As more people stay and work from home and more single-use products were used during Covid-19, volumes of domestic waste increased substantially in residential communities. Stalled waste recycling programs and a shortage of staff in the waste sector also contributed to the situation. Inappropriate disposal of household wastes (e.g., fly-tipping) was sighted in communities all around the world, exacerbating the risks of municipal solid waste-mediated transmission of SARS-CoV-2 and other pathogens to workers and others in the vicinity, including animals and insects. Workers under informal employment and with inadequate personal protection, which are common in developing communities, are at heightened risks of contracting infectious diseases, such as Covid-19, from household wastes collected from infected communities. Pictures are adapted from various sources on the Internet.

Table 1. Evidence and risk assessments on MSW-mediated pathogenic transmission to humans and animals

Pathogen type	Routes of transmission	Evidence or perceived risks	Reference
Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2)	Fecal-oral, aerosol, respiratory droplets	Viable SARS-CoV-2 on tissues and papers after 3 h, cloths after 2 days, glass and banknote after 4 days, and a surgical mask (outer layer) after 7 days	Chin et al. (2020)
Leptospira interrogans, Leptospira icterohaemorrhagiae	Exposure to urine or tissue of an infected animal	Dogs and rats near garbage sites and open plastic containers in peri-domestic areas	Gutberlet and Uddin (2017); Muñoz-Zanzi et al. (2014); Krystosik et al. (2020)
Hepatitis A virus	Fecal-oral, contact, sexual, sharps (e.g., syringe needles)	Higher prevalence of antibodies in MSW workers compared with those not exposed to MSWs, due to a lack of personal protective equipment and proper training	Dounias et al. (2006); Gutberlet and Uddin (2017); Rachiotis et al. (2012)
Hepatitis B virus	Sexual, vertical (mother-to-child), blood, organ, sharps	The prevalence of antibodies differed significantly among workers exposed and non-exposed to municipal solid wastes, mainly due to occupational exposure to improperly discharged sharps, usually needles.	Corrao et al. (2013); Dounias et al. (2005); Marcos et al. (2015); Rachiotis et al. (2012)
Hepatitis C virus	Sexual, vertical (mother-to-child), blood, organ, sharps	Increased risk of infection in workers collecting household wastes compared with those non-exposed, mainly from needlestick accidents due to deficient sharps management.	Marcos et al. (2015)
Chikungunya virus; Dengue virus; Yellow fever virus; Zika virus;	Vector (mosquito), sexual, vertical	Aedes species prefer to breed in solid wastes and containers (e.g., cans, plastic containers, tires). Lack of consistent garbage collection, garbage accumulation, and lack of sanitary facilities increase the risk of vector-borne transmission.	Aoustin (2012); Krystosik et al. (2019); Ramos et al. (2005); Suwannapong et al. (2014)
Leishmania genus (parasitic protozoa)	Vector (sandfly), blood	Sandflies breeding in the trash can spread these pathogens to humans. The risk of acquiring the disease was found to be significantly higher for those who had no regular rubbish collection and those living in houses with inadequate sewage systems.	Lima et al. (2018); Singh et al. (2006); Werneck et al. (2005)
Trypanosoma cruzi (parasitic protozoa)	Vector (insects, rats), vertical	Infection seroprevalence was associated with garbage accumulation and insect and animal vectors (tsetse flies, rats, and other insects)	Bonfante-Cabarcas et al. (2011); Garcia-Jordan et al. (2017)
Orientia tsutsugamushi (Rickettsia tsutsugamushi) bacterium	Vector (Trombiculidae, flea)	Garbage accumulation and vectors (fleas, chiggers, rats) increase the risk of transmission.	Chakraborty et al. (2017); Vallee et al. (2010)
Toxoplasma Gondii (parasitic protozoan)	Foodborne, zoonotic (animal-to-human), vertical	Normally a foodborne disease. Trash-filled yards with leaves and rubble impact dog seroprevalence. Infrequent yard cleaning and dirt accumulation are positively associated with seropositivity in households.	Benitez et al. (2017)

Bubonic plague bacterium	Vectors (flea, rats); contact with body fluid or tissue of an infected person	Informal solid waste storage sites (e.g., basements) and unsanitary operations with little solid waste management led to a large rat population in an urban area and close contact of rats with workers and residents, transmitting the bacteria to humans.	Boisier et al. (2002); Milke (2004)
Rabies virus	Bites by infected animals, primarily dogs, or contact with their tissues or body fluids via mucous membranes or fresh breaks in human skin	Open garbage dumps in proximity to households increase the likelihood of man-stray dog contact and the risk of transmission of rabies.	Kassir et al. (2019); Raymond et al. (2015); Wright et al. (2021)
Treponema pallidum bacterium, human immunodeficiency virus (HIV)	Blood, sharps, sexual, vertical	Lack of personal protection equipment and training for MSW workers is associated with increased risks of infection	Chen et al (1998); Kassir et al (2019); Kuijer et al (2010); Raymond et al (2015); Rozman et al (2008)

3. Waste recycling during Covid-19

Waste recycling constitutes an essential part of the sustainable management of municipal solid wastes. The sorting and handling process, however, requires laborious manual work with workers easily exposed to virus-contaminated wastes or aerosols, especially for unprotected workers under informal employment (**Fig. 4**). In some countries, informal waste reclaimers represent a substantial portion of the workforce in MSW handling and recycling (Nithya et al. 2021; Reuters 2021; Samson 2020). However, they lack both personal protection and training on the safe handling of MSWs in the current pandemic. Thus, they are at high risk of contracting pathogens, including SARS-CoV-2, via MSWs collected from infected communities (Aqil 2020; Reuters 2021).

Recognizing such risks, some municipalities suspended their recycling programs during the Covid-19 pandemic (Fan et al. 2021; Urban and Nakada 2021; WEIGO 2020; Zand and Heir 2021). These emergency responses, however, created new challenges by adding significant quantities of recyclable wastes for disposal, with the unintended consequence of putting numerous waste reclaimers out of work and income. In Isfahan, the third-largest city in Iran where composting was used as the main disposal method accounting for 60%–70% of MSWs, all collected MSWs were disposed of in landfills as recycling and composting were banned during Covid-19, which caused a drastic escalation in MSW landfilling volumes by 360% (Zand and Heir 2021). Some municipalities in India, Mexico, Colombia, and the U.S. deliberately chose not to completely ban recycling programs to relieve the escalating pressure on MSW landfills and incineration facilities while at the same time, ensuring the income of poverty-stricken population who rely on waste picking and sorting to make their living (WEIGO 2020). There exists a large population of waste pickers and informal MSW workers in developing countries. In Brazil, there are about 3,000 unregistered dumps and landfills, which impact the quality of life of 77 million people (Cruvinel et al. 2019). The majority of recycling centers in Brazil rely on manual waste sorting (Fidelis et al. 2020). Waste pickers, mobile vendors, middlemen, and other informal workers constitute a major part of the MSW management system (Urban and Nakada 2021). In Bangladesh, approximately 40,000 informal waste pickers did much of the manual work required for waste sorting before recycling and further processing (Rahman et al. 2020).

4. Policies and voluntary actions on MSW management during Covid-19

Public health authorities including the World Health Organization (WHO), U.S. Centers for Disease Control and Prevention (CDC), and Occupational Safety and Health Administration (OSHA) have so far not issued any specific regulations for the safe handling and disposal of municipal solid wastes during the Covid-19 pandemic (NWRA 2022; WM 2022). In an interim guidance intended for water and sanitation practitioners and providers, the World Health Organization and United Nations Children's Fund stated that "there is no evidence that direct, unprotected human contact during the handling of health-care waste has resulted in the transmission of the COVID-19 virus." (WHO & UNICEF 2020). However, the interim guidance advised on careful packaging of waste generated at home during quarantine while caring for a sick family member or during the recovery period into strong bags and completely closing the bags before disposal and collection by municipal waste services. Government organizations recommended general precautions to be taken during Covid-19 for municipal waste operations (CDC 2020; Das et al. 2021; EC 2020; OSHA 2021). In an earlier guidance, the OSHA advised that "management of waste that is suspected or known to contain or be contaminated with Covid-19 does not require special precautions beyond those already used to protect workers from the hazards they encounter during their routine job tasks in solid waste and wastewater management. Workers and employers should manage municipal (e.g., household, business) solid waste with potential or known COVID-19 contamination like any other non-contaminated municipal waste." (OSHA 2021). No specific recommendations for workers in the MSW sector, however, are given in its current set of guidance for Covid-19 (OSHA 2022a; 2022b). The National Waste & Recycling Association, a coalition of private-sector waste recycling companies in the United States, stated that "household waste is not to be considered as regulated medical wastes, even if the person in the home on your route has an infectious disease, such as Covid-19." (NWRA 2022) Citing guidelines by OSHA, CDC, and the Public Health Agency of Canada (PHAC), Waste Management, a major waste management service provider in North America, stated on its support page that "management of waste that is suspected or known to contain or be contaminated with COVID-19 does not require special precautions beyond those already used to protect workers from the materials they encounter during their routine waste management job tasks." (WM 2022) Except for the adoption of personal protective equipment and precautions already being imposed prior to the current pandemic, no additional safety regulation was introduced for workers handling domestic wastes suspected to be contaminated by SARS-CoV-2 (Di Maria et al. 2020). The lax regulations created gaps in infection prevention and control of MSW-mediated transmission of Covid-19 and other infectious diseases, especially for those living in the vicinity of MSW handling or disposal sites or having regular exposure to MSWs (e.g., waste pickers, domestic workers, custodians, truck loaders, and machinery operators) with inadequate personal protection and safety training.

The European Agency for Safety and Health at Work provided a brief list of good practices communicated by stakeholders in the waste management sector, which included social distancing, the use of personal protective equipment (PPE), including masks, and disinfectant products, and following protocols when put on and take off PPE to avoid incidental contact and contamination —a real risk factor as demonstrated in the Nanjing Covid-19 outbreak in China in July 2021 (EC 2020). It is currently unknown whether other public or occupational health authorities will issue guidance or mandates to mitigate risks associated with MSWs during Covid-19. Meanwhile, some non-government organizations have made efforts in raising awareness among workers in the MSW sector to mitigate their risks of exposure to Covid-19. In its current guide, the National Waste & Recycling Association offered role-specific guidance for drivers, helpers, sorters, and post-collection operators in the United States during Covid-19 (NWRA 2021). Women in Informal Employment Globalizing and Organizing, a humanitarian organization focusing on improving the livelihood of women in informal employment, provided guidelines on personal protective equipment that workers or trained volunteers involved in waste picking and handling have to wear in the current pandemic (WIEGO 2022). The Global Alliance of Waste Pickers advocated for safer working conditions and provided recommendations for waste pickers to protect themselves from Covid-19 (GAWP 2021). In general, wearing personal protective equipment in workplaces and following the protocols of ensuring good personal hygiene are advocated as the most effective approach for preventing viruses from spreading to and among workers in the MSW sector.

5. Conclusion and recommendation

Municipal solid wastes (MSWs) contain large varieties of domestic wastes including personal products that are contaminated with human biological matter. Services and management of MSWs have been widely impacted by the Covid-19 pandemic. Surging volumes of domestic wastes, long collection intervals, disrupted services and suspended operations of waste recycling programs have overwhelmed MSW facilities during Covid-19, with inappropriate disposal (e.g., fly-tipping) being frequently sighted in communities. The inevitable manual work and complex procedures required for MSW handling and disposal may expose workers and others in the vicinity to virus-contaminated wastes or aerosols. Moreover, cross-contamination is likely in facilities and equipment handling the collection, bulk transport, and disposal of MSWs, where workers may contact surfaces or objects contaminated with viable SARS-CoV-2 or other pathogens. Specifically, dust, aerosols, and airborne particulates generated by machinery operations may carry infectious agents, which can travel long distances to surrounding environments and downwind locations. Cases of Covid-19 infections have been recently reported in domestic and custodial workers, although they have not attracted widespread attention or regulatory concerns from public health authorities. Although there has been no study to date on the persistence of SARS-CoV-2 in MSW-related environments, numerous types of infectious agents have been found in MSWs and there is ample evidence of MSW-mediated transmission of human infectious diseases by insects or animal vectors even before the current pandemic. Further, the widespread human infections of SARS-CoV-2 and the open, unrestricted nature of many MSW collection and disposal sites may exacerbate the risk of reverse zoonosis (i.e., spillover of human pathogens to animals). Advisories on the safety of waste pickers and other informal workers in the MSW sector have been made by coalitions and humanitarian organizations, although no mandate or public notice has been issued to date. Under the current practices, MSWs represent an under-investigated route of transmission of SARS-CoV-2 and other infectious agents in the current pandemic. In light of these risks, we propose the following actions to be considered by workers, public health authorities, and the general public to mitigate the source-specific risks and ensure the safe handling of MSWs in an epidemic or pandemic scenario.

1. Line household trash bins with bags. Tie the bags before placing them into waste bins.
2. Use lidded waste bins and keep bins closed after throwing trash in them. Do not overload waste bins.
3. Provide additional waste bins in communities experiencing long service intervals or service disruptions.
4. Prohibit illegal dumping (e.g., fly-tipping) of domestic wastes by erecting warning signs near waste bins and landfill sites. Install electrical fences around open landfill sites to reduce animal break-ins.
5. Suspend waste recycling programs in areas reporting active community transmission of Covid-19 or other infectious diseases. Control pests and insects in these areas.
6. Set up safety perimeters or working zones with restricted access to minimize exposure to leachates, dust, and aerosols from MSW handling and disposal sites by pedestrians or residents in the vicinity.
7. Require mandatory personal protective equipment for domestic workers, custodians, and other workers in the MSW sector who may have direct contact with domestic wastes. As a minimum, face masks, face shields, and rubber gloves must be worn at work. Coveralls are recommended for workers exposed to MSWs from infected households and those exposed to MSW-contaminated environments, such as truck loaders, drivers, and machinery operators at transfer or disposal sites. All workers must maintain good hygiene after work.
8. Where practical, issue temporary bans on waste picking, sorting, and other manual work on MSWs. Provide living subsidies for individuals whose incomes are severely affected by these restrictions.

Since the outbreak of the Covid-19 pandemic, the waste management sector has been tackling challenges while trying to mitigate the risks for its workers and facilities. The Solid Waste Association of North America recently called for the inclusion of the waste industry in coronavirus emergency response by government authorities, stressing that solid waste management is an essential part of public services which itself needs to respond to the unprecedented situation and significant changes in volumes and sources of solid wastes generated in the current pandemic (SWANA 2022). There is an essential role that citizens need to take to help public service providers overcome these challenges in this difficult time, that is, by minimizing the use of disposable products in households, recycling and reusing where possible, minimizing food wastes, putting needles and sharps in safe

containers before disposal, and adopting good practices by properly bagging and disposing of household wastes into collection bins.

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