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REVIEW

Municipal solid waste, an overlooked route of transmission for the severe acute respiratory syndrome coronavirus 2: a review

Jie Han[1] · Shanshan He[1] · Wenyuan Shao[2] · Chaoqi Wang[1] · Longkai Qiao[1] · Jiaqi Zhang[1] · Ling Yang[3]

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Abstract

Municipal solid waste could potentially transmit human pathogens during the collection, transport, handling, and disposal of waste. Workers and residents living in the vicinity of municipal solid waste collection or disposal sites are particularly susceptible, especially unprotected workers and waste pickers. Recent evidence suggests that municipal solid waste-mediated transmission can spread the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) to humans. Such risks, however, have received little attention from public health authorities so far and may present an under-investigated transmission route for SARS-CoV-2 and other infectious agents during pandemics. In this review, we provide a retrospective analysis of the challenges, practices, and policies on municipal solid waste management during the current pandemic, and scrutinize the recent case reports on the municipal solid waste-mediated transmission of the coronavirus disease 2019 (COVID-19). We found abrupt changes in quantity and composition of municipal solid wastes during the COVID-19. We detail pathways of exposure to SARS-CoV-2 and other pathogens carried on municipal solid wastes. We disclose evidence of pathogenic transmission by municipal solid waste to humans and animals. Assessments of current policies, gaps, and voluntary actions taken on municipal solid waste handling and disposal in the current pandemic are presented. We propose risk mitigation strategies and research priorities to alleviate the risk for humans and vectors exposed to municipal solid wastes.

Keywords Novel coronavirus · Infectious agents · Waste management · Waste recycling · Waste picking · Landfill disposal

Abbreviations

COVID-19	Coronavirus disease 2019
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2
ACE-2	Angiotensin-converting enzyme 2
$PM_{2.5}$	$PM_{2.5}$ describes fine inhalable particles, with diameters that are generally 2.5 µm and smaller.
PM_{10}	PM_{10} describes inhalable particles, with diameters that are generally 10 µm and smaller.
CDC	The centers for disease control and prevention, the national public health agency of the USA
OSHA	The occupational safety and health administration, a regulatory agency of the United States department of labor

✉ Jie Han
jiehan@xjtu.edu.cn

[1] School of Human Settlements and Civil Engineering, Xi'an Jiaotong University, Xi'an 710049, People's Republic of China

[2] School of Life Sciences and Technology, Xi'an Jiaotong University, Xi'an 710049, People's Republic of China

[3] School of Engineering and Built Environment, Griffith University, Nathan, QLD 4111, Australia

Introduction

The novel coronavirus disease 2019 (COVID-19) pandemic has resulted in more than 545 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 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 wastes generated from domestic sources

have increased significantly (Nanda and Berruti 2021). In the USA, the volume of domestic wastes increased by about 30 percent through the first quarter of 2020, compared with those reported in the previous year (Helmer 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), personal use products (Han and Zhang 2020), food items and packages (Han et al. 2021; Valsamatzi-Panagiotou and Penchovsky 2022), high-touch surfaces (Chen et al. 2021a, b; Han and Zhang 2020; Wang et al. 2021), and virus-laden aerosols (He and Han 2021b; Sun et al. 2021). Many human pathogens, including fecal coliform bacteria, salmonellae, enteroviruses, protozoan parasites, noroviruses, hepatitis B virus, and antibiotic-resistant bacteria, are commonly found in municipal solid wastes 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 municipal solid wastes make workers particularly susceptible to infectious agents, of which domestic workers, custodians, waste pickers, and waste bin handlers are at heightened risk. An earlier survey revealed that municipal solid waste 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 municipal solid waste workers showed a higher seroprevalence of hepatitis than found in the general population (WHO 2004). In a cross-sectional study ($n = 545$) at the University Hospitals Birmingham NHS Foundation Trust, one of the largest hospital trusts in the UK, Shields et al. (2020) found that the housekeeping staff had higher seroprevalence rates of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) antibodies (34.5%) than healthcare workers at this facility (14.8–33.3%).

The earliest suspected case of municipal solid waste-mediated SARS-CoV-2 infection was reported in Sichuan, China, as early as December 2020 (Sichuan Daily 2020). Although there is no scientific study published to date on the municipal solid waste-mediated transmission of SARS-CoV-2, a report revealed that on September 1, 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 quarantined hotel in Guangzhou, China, which became the first known case of SARS-CoV-2 infection via contact with household wastes (CCTV 2021) (Fig. 1). In fact, only several weeks ago, a group of custodian staff at an international airport in Nanjing was infected by the Delta variant after cleaning the interiors

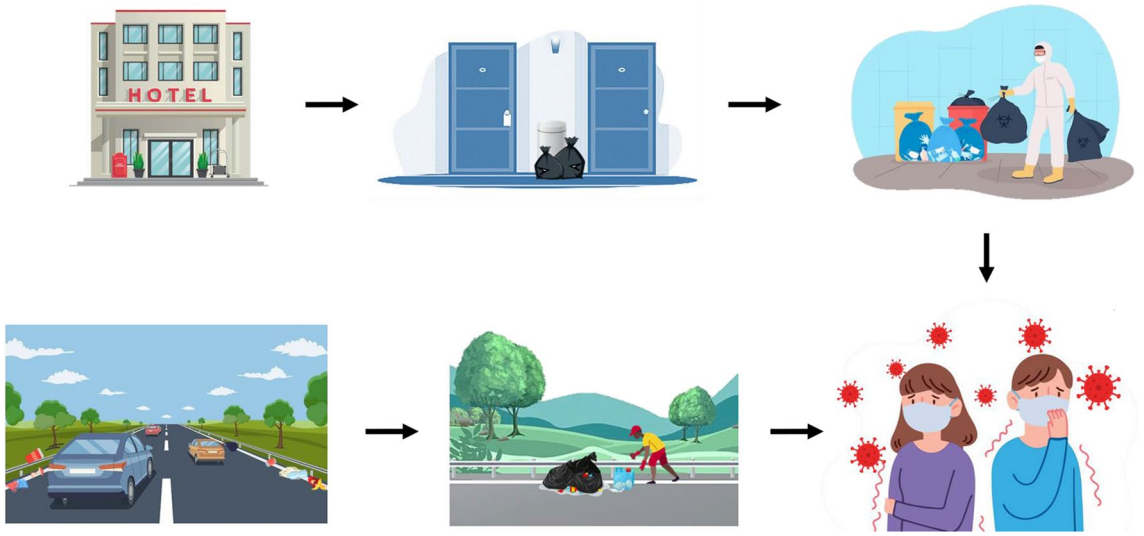

Fig. 1 Two confirmed cases of domestic infections of the coronavirus disease 2019 (COVID-19) have been recently reported in mainland China. Government investigations found that both incidents were caused by exposure to municipal solid wastes. Details of the incidents are available in various news reports (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, the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2, Suzhou 2022)

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 SARS-CoV-2 infection has been reported on a roadside waste picker with another suspected case on three municipal solid waste workers, raising further alarms on the municipal solid waste-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 municipal solid wastes (Aboubakr et al., 2021; Chin et al. 2020; EPA 2020). 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).

To date, however, there have been no studies on the persistence or infectivity of SARS-CoV-2 in simulated or real municipal solid waste-related environments such as household trash, waste bins, landfills, or open waste dumps. Meanwhile, there are no specific regulations to ensure the safe handling and disposal of municipal solid wastes during the COVID-19 pandemic. Major knowledge gaps exist in the current literature concerning the risk factors and unsafe practices in managing municipal solid wastes 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 the municipal solid waste-mediated transmission of SARS-CoV-2 and other pathogens, practices on waste recycling, policies, and voluntary actions on risk mitigation in municipal solid waste management during COVID-19, by reviewing current practices of municipal solid waste 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 municipal solid wastes in a public health crisis scenario.

Risk factors in municipal solid waste management during the COVID-19 pandemic

Human respiratory droplets, aerosols, mucus, and fecal matter residues carrying viable SARS-CoV-2 may contaminate personal items routinely being disposed of in municipal solid wastes (Fig. 2). One of the three principal ways of spreading SARS-CoV-2 is by touching the eyes, nose, or mouth with hands after contacting virus-contaminated surfaces, or 'fomites' (CDC 2021). 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., 2021). These varieties constitute nearly one-third of the solid wastes (31.3%) found in municipal solid wastes (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 municipal solid wastes. In Italy, face masks and other SARS-CoV-2 personal protection equipment accounted for up to 1.4% of the total weight of municipal solid wastes 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 communities, 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 municipal solid waste 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 municipal solid wastes, contamination and cross-contamination are likely to occur in facilities and equipment storing and handling municipal solid wastes, 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).

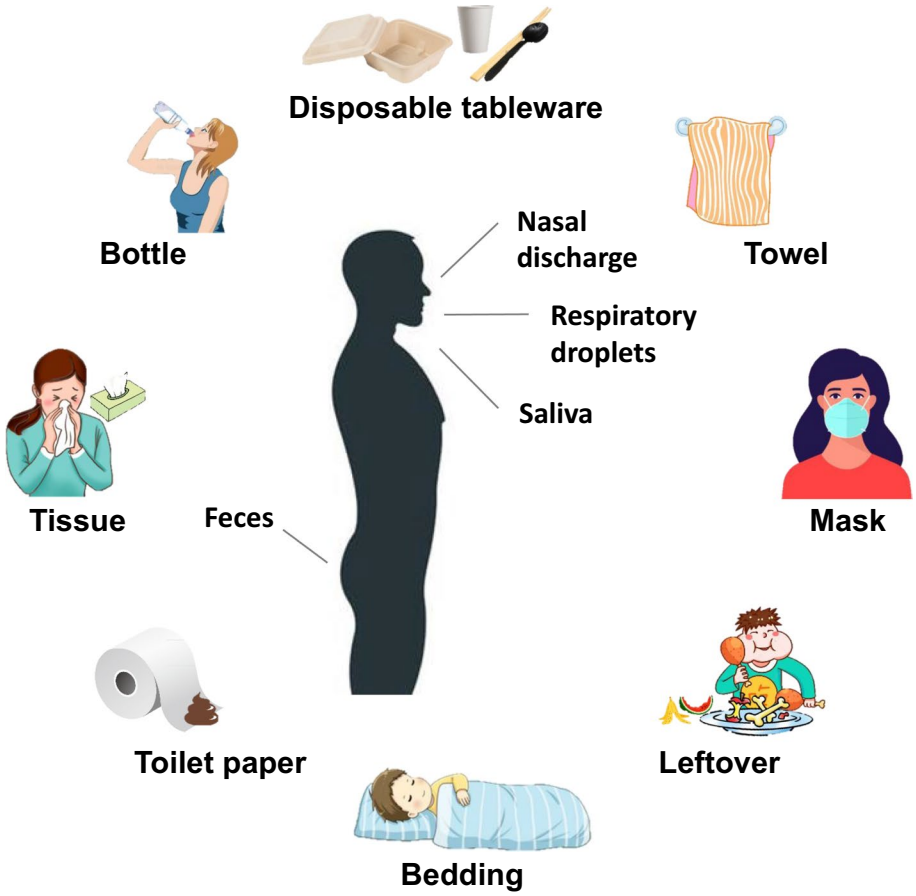

Fig. 2 Human biological matter carrying the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and common household items that are likely to be contaminated by virus-laden human biological matter after use by infected persons. The majority of these end up in household trash and are disposed of as municipal solid wastes

There are several unique risk factors for pathogenic transmissions in municipal solid waste-related environments (Fig. 3). During the bulk transport and disposal of municipal solid wastes, large quantities of dust and aerosols are generated (Anand et al. 2021a, b), which may carry viable SARS-CoV-2 and effectuate the transmission of COVID-19. In

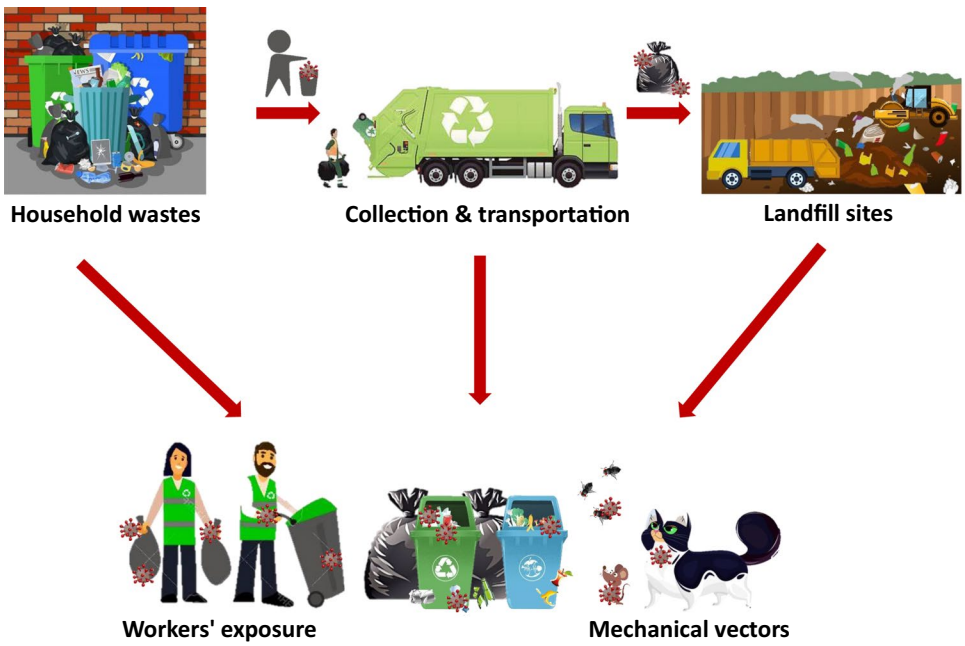

Fig. 3 Risks of exposure by workers, machinery operators, and animal and insect vectors to pathogens, including the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and other human or zoonotic pathogens, carried in solid wastes routinely collected from infected communities and households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

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. For instance, the overexpression of alveolar angiotensin-converting enzyme 2 (ACE-2) receptors on the surface of epithelial cells, i.e., the major cell entry receptor for SARS-CoV-2, and the exhaustion of Th2 immune responses facilitate viral penetration and increase host susceptibility to infections (Chen et al. 2021a, b; He and Han 2021b). Municipal solid waste transfer stations, waste dumps, and landfill sites are significant sources of atmospheric fine particulate matter, e.g., particles with an aerodynamic diameter of 2.5 µm or less ($PM_{2.5}$) and particles with an aerodynamic diameter of 10 µm or less (PM_{10}), bioaerosols, pathogenic bacteria, and antibiotic resistance genes (Anand et al. 2021a, b; 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 municipal solid waste landfill sites (Chalvatzaki et al. 2010).

Indeed, high levels of atmospheric particulate matter are often detected at municipal solid waste transfer stations and landfill sites, as well as downwind locations. Godri et al. (2010) reported that in London, the highest particulate matter 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 $\mu g \bullet m^{-3}$) 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; Ezeke 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).

Aerosol-mediated long-distance transmission of infectious agents has been well documented even before the COVID-19 pandemic. Zhao et al. (2019) reported that through airborne transmission, highly pathogenic avian influenza viruses from poultry farms could spread across states in the USA. In an earlier study, Alonso et al. (2014) found that the porcine epidemic diarrhea virus, a member of the Coronaviridae family, remained infectious after being harbored by airborne particles and transported over long distances. The genetic materials of the virus were detected at downwind locations of three swine farms at distances of 3–10 miles from the source. Recent studies confirmed the persistence of SARS-CoV-2 on aerosol particles, which maintained infectivity after 3–16 h 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 municipal solid waste 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). To summarize, pathogen-laden airborne matter is routinely released from sites and activities handling or disposing of municipal solid wastes, which can contaminate the surrounding environments and travel to downwind locations, exposing workers and others in these environments.

Since most municipal solid waste 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. A more recent laboratory study showed that, 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 after 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 (ACE-2) receptor, a diverse range of vertebrates can be 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 municipal solid waste-dwelling insects, animals can act as mechanical vectors for spreading human and zoonotic pathogens. In fact, reports on animal vectors of municipal solid waste-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 municipal solid waste facilities make them particularly susceptible to infection or contamination by SARS-CoV-2 and other pathogens carried in municipal solid wastes, 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).

During the COVID-19 pandemic, these risks may have been exacerbated by the enormous quantities of municipal solid wastes and the inefficient—often inappropriate—handling and disposal of municipal solid wastes (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 municipal solid waste 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

Fig. 4 Mounting domestic wastes overwhelming household waste bins and collection facilities during the coronavirus disease 2019 (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 the severe acute respiratory syndrome coronavirus 2 (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

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, the municipal solid waste-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. Overall, the increased amount of household wastes and challenges in the timely handling and disposal of municipal solid wastes during COVID-19 could exacerbate the risk of pathogenic transmission by insect and animal vectors.

Waste recycling during the COVID-19 pandemic

Waste recycling constitutes an essential part of the sustainable management of municipal solid wastes. The sorting and handling process, however, often 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 municipal solid waste handling and recycling (Nithya et al. 2021; Reuters 2021; Samson 2020). However, they lack both personal protection and training on the safe handling of municipal solid wastes in the current pandemic. Thus, they are at high risk of contracting pathogens, including SARS-CoV-2, via municipal solid wastes collected from infected communities (Aqil 2020; Reuters 2021).

Recognizing these 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 municipal solid wastes, all collected municipal solid wastes were disposed of in landfills as recycling and composting were banned during COVID-19, which caused a drastic escalation in municipal solid waste landfilling volumes by 360% (Zand and Heir 2021). Some municipalities in India, Mexico, Colombia, and the USA deliberately chose not to completely ban recycling programs to relieve the escalating pressure on municipal solid waste 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 municipal solid waste workers in developing countries. In Brazil, there are about 3000 unregistered dumps and landfills, which impact the quality of life of 77 million people (Cruvinel et al. 2019). The majority of waste recycling centers in Brazil rely on manual sorting (Fidelis et al. 2020). Waste pickers, mobile vendors, middlemen, and other informal workers constitute a major part of the municipal solid waste 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). To conclude, some regulators are facing the dilemma of COVID-19 transmission in workers sorting and handling of municipal solid wastes for recycling, especially in unprotected workers and those under informal employment, and the ongoing need for waste sorting and recycling. In some countries, there exists a significant workforce who informally handles such work to make their living and income.

Policies and voluntary actions for municipal solid waste management during the COVID-19 pandemic

Public health authorities such as the World Health Organization, the Centers for Disease Control and Prevention (CDC) in the USA, and the Occupational Safety and Health Administration (OSHA) in the USA have so far *not* issued specific regulations for the safe handling and disposal of municipal solid wastes during the COVID-19 pandemic (NWRA 2022; WM 2022). In the interim guidance for water and sanitation practitioners and providers, the World Health Organization and the United Nations Children's Fund issued a joint statement that there was no evidence showing that direct, unprotected human contact during the handling of healthcare waste had resulted in the transmission of COVID-19 (WHO & UNICEF 2020). However, the interim guidance advised on careful packaging of waste generated at home while caring for a sick family member by putting these wastes into strong bags and completely closing the bags before their disposal and collection by municipal waste services. Government organizations recommended general precautions to be taken for municipal waste operations during COVID-19 (CDC 2020; Das et al. 2021; EC 2020; OSHA 2021). In earlier guidance issued by the OSHA, the work safety agency advised that management of wastes suspected or known to contain or be contaminated with SARS-CoV-2 does not require special precautions beyond those already in place for solid waste and wastewater management, and that workers and employers should manage municipal, e.g., household or business solid waste with potential or known SARS-CoV-2

Table 1 Evidence and risk assessments on municipal solid waste-mediated pathogenic transmission to humans and animals

Pathogen type	Routes of transmission	Evidence or perceived risks	References
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 municipal solid waste workers compared with those not exposed to municipal solid wastes, due to a lack of personal protective equipment and proper training	Dounias et al. (2006); Gutberlet and Uddin (2017); Rachiotis et al. (2012a, b)
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); Mol et al. (2015); Rachiotis et al. (2012a, b)
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	Mol 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. (2020); 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)

Table 1 (continued)

Pathogen type	Routes of transmission	Evidence or perceived risks	References
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); Tabue 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 municipal solid waste workers is associated with increased risks of infection	Chen et al (1998); Kassir et al (2019); Kuijer et al (2010); Tabue et al. (2015); Rozman et al (2008)

contamination like other non-contaminated municipal waste (OSHA 2021). No specific recommendations or updates are given for municipal solid waste workers in its current set of guidance (OSHA 2022a, b).

The National Waste & Recycling Association, a coalition of private-sector waste recycling companies in the USA, also stated that household wastes should not be considered regulated medical wastes, even if the person in the home has an infectious disease, such as COVID-19 (NWRA 2022). Waste Management, a major waste management service provider operating in North America, stated on its support page that management of waste suspected or known to contain or be contaminated with COVID-19 does not require special precautions beyond those already used to protect workers from wastes they encounter during routine job tasks (WM 2022). The service provider cited guidelines issued by the OSHA, the CDC, and the Public Health Agency of Canada in making such recommendations. 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 municipal solid waste-mediated transmission of COVID-19 and other infectious diseases, especially for those living in the vicinity of municipal solid waste handling or disposal sites or having regular exposure to municipal solid wastes, 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, 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 municipal solid wastes during COVID-19. Meanwhile, some nongovernment organizations have made efforts in raising awareness among workers in the municipal solid waste sector to mitigate their risks of exposure to SARS-CoV-2. In its current guide, the National Waste & Recycling Association offered role-specific guidance for drivers, helpers, sorters, and post-collection operators in the USA during COVID-19 (NWRA 2022). 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 municipal solid waste sector. To summarize, although there is a lack of mandatory requirements from public health authorities on preventing municipal solid waste-mediated transmission of SARS-CoV-2 for workers, some industrial associations and humanitarian organizations have issued specific guidance that could be adopted to mitigate such risks during COVID-19.

Conclusion

Municipal solid wastes contain large varieties of domestic wastes including personal products that are contaminated with human biological matter. Services and management of municipal solid wastes 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 municipal solid waste 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 municipal solid waste 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 municipal solid wastes, 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 municipal solid waste-related environments, numerous types of infectious agents have been found in municipal solid wastes and there is ample evidence of municipal solid waste-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 municipal solid waste 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 municipal solid waste sector have been made by coalitions and humanitarian organizations, although no mandate or public notice has been issued to date. Under the current practices, municipal solid wastes 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 municipal solid wastes 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 municipal solid waste 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 municipal solid waste 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 municipal solid wastes from infected households and those exposed to municipal solid waste-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 municipal solid wastes. 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 (SWANA 2020). They stressed 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 waste generated in the current pandemic. 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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Declarations

Conflict of interest The authors declare no conflict of interest in this work.

References

Aboubakr HA, Sharafeldin TA, Goyal SM (2021) Stability of SARS-CoV-2 and other coronaviruses in the environment and on common touch surfaces and the influence of climatic conditions: a review. Transbound Emerg Dis 68:296–312. https://doi.org/10.1111/tbed.13707

Alm EW, Daniels-Witt QR, Learman DR et al (2018) Potential for gulls to transport bacteria from human waste sites to beaches. Sci Total Environ 615:123–130. https://doi.org/10.1016/j.scitotenv.2017.09.232

Alonso C, Goede DP, Morrison RB et al (2014) Evidence of infectivity of airborne porcine epidemic diarrhea virus and detection of airborne viral RNA at long distances from infected herds. Vet Res 45:1–5. https://doi.org/10.1186/s13567-014-0073-z

Anand U, Li X, Sunita K et al (2021a) SARS-CoV-2 and other pathogens in municipal wastewater, landfill leachate, and solid waste: a review about virus surveillance, infectivity, and inactivation. Environ Res 203:111839. https://doi.org/10.1016/j.envres.2021.111839

Anand U, Reddy B, Singh VK et al (2021b) Potential environmental and human health risks caused by antibiotic-resistant bacteria (ARB), antibiotic resistance genes (ARGs) and emerging contaminants (ECs) from municipal solid waste (MSW) landfill. Antibiotics 10:374. https://doi.org/10.3390/antibiotics10040374

Aoustin T (2012) Chikungunya and urban sprawl on Reunion Island (Le chikungunya et l'habitat informel à La Réunion). Médecine Tropicale 72:51–59. https://www.jle.com/en/MedSanteTrop/2012/72.1/051-059%20Chikungunya%20et%20habitat%20informel%20(Aoustin).pdf Accessed 10 August 2022

Aqil AMI (2020) Jakarta's trash output down during COVID-19 but environmentalists warn of possible increase. https://www.thejakartapost.com/news/2020/05/01/jakartas-trash-output-down-during-covid-19-but-environmentalists-warn-of-possible-increase.html Accessed 10 August 2022

ARC (American Red Cross) (2020) How to social distance during COVID-19. https://www.redcross.org/about-us/news-and-events/news/2020/coronavirus-what-social-distancing-means.html. Accessed 10 August 2022

Balaraman V, Drolet BS, Mitzel DN et al (2021) Mechanical transmission of SARS-CoV-2 by house flies. Parasite Vector 14:1–9. https://doi.org/10.1186/s13071-021-04703-8

Benitez ADN, Martins FDC, Mareze M et al (2017) Spatial and simultaneous representative seroprevalence of anti-Toxoplasma gondii antibodies in owners and their domiciled dogs in a major city of southern Brazil. PLoS ONE 12:e0180906. https://doi.org/10.1371/journal.pone.0180906

Bittel J (2016) The lure of landfills: how garbage changes animal behavior. https://www.nrdc.org/onearth/lure-landfills-how-garbage-changes-animal-behavior. Accessed 10 August 2022

Boisier P, Rahalison L, Rasolomaharo M et al (2002) Epidemiologic features of four successive annual outbreaks of bubonic plague in Mahajanga, Madagascar. Emerg Infect Dis 8:311–316. https://doi.org/10.3201/eid0803.010250

Bonfante-Cabarcas R, Rodríguez-Bonfante C, Oviol-Vielma B et al (2011) Seroprevalence for Trypanosoma cruzi infection and associated factors in an endemic area of Venezuela. Cad Saude Publica 27:1917–1929. https://doi.org/10.1590/s0102-311x2011001000005

Bosco-Lauth AM, Root JJ, Porter SM et al (2021) Peridomestic mammal susceptibility to severe acute respiratory syndrome Coronavirus 2 infection. Emerg Infect Dis 27:2073–2080. https://doi.org/10.3201/eid2708.210180

Brock J (2020) COVID-19 has hit plastic recycling, just as big oil firms are investing hundreds of billions of dollars to make new plastic. These investments massively exceed the industry's spending to tackle plastic waste. https://www.reuters.com/investigates/special-report/health-coronavirus-plastic-recycling/. Accessed 10 August 2022

Cai M, Guy C, Héroux M et al (2021) The impact of successive COVID-19 lockdowns on people mobility, lockdown efficiency, and municipal solid waste. Environ Chem Lett 19:3959–3965. https://doi.org/10.1007/s10311-021-01290-z

CCTV (2021) Guangzhou: New confirmed case of COVID-19 was infected by handling domestic wastes. https://news.cctv.com/2021/09/05/ARTIjVAoG26Yts12aB2Oi0ZX210905.shtml (in Chinese) Accessed 10 August 2022

CDC (Centers for Disease Control and Prevention) (2020) Waste Collectors & Recyclers. https://www.cdc.gov/coronavirus/2019-ncov/community/organizations/waste-collection-recycling-workers.html. Accessed 10 August 2022

CDC (Centers for Disease Control and Prevention) (2021) How COVID-19 spreads. https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html. Accessed 10 August 2022

CDC (Centers for Disease Control and Prevention) (2022) How to Protect Yourself & Others. https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/prevention.html Accessed 10 August 2022

Cevik M, Tate M, Lloyd O et al (2021) SARS-CoV-2, SARS-CoV, and MERS-CoV viral load dynamics, duration of viral shedding, and infectiousness: a systematic review and meta-analysis. The Lancet Microbe 2:e13–e22. https://doi.org/10.1016/S2666-5247(20)30172-5

Chakraborty S, Sarma N (2017) Scrub typhus: an emerging threat. Indian J Dermatol 62:478–485. https://doi.org/10.4103/ijd.ijd_388_17

Chalvatzaki E, Kopanakis I, Kontaksakis M et al (2010) Measurements of particulate matter concentrations at a landfill site (Crete, Greece). Waste Managa 30(11):2058–2064. https://doi.org/10.1016/j.wasman.2010.05.025

Chen HL, Yang JY, Chen HY et al (1998) Surveillance of anti-hantavirus antibodies among certain high-risk groups in Taiwan. J Formos Med Assoc 97:69–72

Chen B, Han J, Dai H, Jia P (2021a) Biocide-tolerance and antibiotic-resistance in community environments and risk of direct transfers to humans: unintended consequences of community-wide surface disinfecting during COVID-19? Environ Pollut 283:117074. https://doi.org/10.1016/j.envpol.2021.117074

Chen B, Jia P, Han J (2021b) Role of indoor aerosols for COVID-19 viral transmission: a review. Environ Chem Lett 19:1953–1970. https://doi.org/10.1007/s10311-020-01174-8

Chin AWH, Chu JTS, Perera MRA et al (2020) Stability of SARS-CoV-2 in different environmental conditions. The Lancet Microbe 1:e10. https://doi.org/10.1016/S2666-5247(20)30003-3

Collectors (2020) New guidelines on effective practices and instruments for a high-quality recycling take into account the COVID-19 impact on municipal waste collection systems. https://www.collectors2020.eu/library/press-releases/new-guidelines-on-effective-practices-and-instruments-for-a-high-quality-recycling-take-into-account-the-covid-19-impact-on-municipal-waste-collection-systems/. Accessed 10 August 2022

Conde-Cid M, Arias-Estévez M, Núñez-Delgado A (2021) SARS-CoV-2 and other pathogens could be determined in liquid samples from soils. Environ Pollut 273:116445. https://doi.org/10.1016/j.envpol.2021.116445

Corrao CR, Del Cimmuto A, Marzuillo C et al (2013) Association between waste management and HBV among solid municipal waste workers: a systematic review and meta-analysis of observational studies. Sci World J 2013:692083. https://doi.org/10.1155/2013/692083

Cruvinel VRN, Marques CP, Cardoso V et al (2019) Health conditions and occupational risks in a novel group: waste pickers in the largest open garbage dump in Latin America. BMC Public Health 19:581. https://doi.org/10.1186/s12889-019-6879-x

Sichuan Daily (2020) The origin of the outbreak in Chengdu's Pidu district: one may be infected by contact with the garbage at a quarantine facility. https://china.huanqiu.com/article/41KK7ESXMMp (in Chinese) Accessed 10 August 2022

Das AK, Islam MN, Billah MM et al (2021) COVID-19 and Municipal Solid Waste (MSW) management: a review. Environ Sci Pollut Res 28:28993–29008. https://doi.org/10.1007/s11356-021-13914-6

Di Maria F, Beccaloni E, Bonadonna L et al (2020) Minimization of spreading of SARS-CoV-2 via household waste produced by subjects affected by COVID-19 or in quarantine. Sci Total Environ 743:140803. https://doi.org/10.1016/j.scitotenv.2020.140803

Dounias G, Rachiotis G (2006) Prevalence of hepatitis A virus infection among municipal solid-waste workers. Int J Clin Pract 60:1432–1436. https://doi.org/10.1111/j.1742-1241.2006.00845.x

Dounias G, Kypraiou E, Rachiotis G et al (2005) Prevalence of hepatitis B virus markers in municipal solid waste workers in Keratsini (Greece). Occup Med 55:60–63. https://doi.org/10.1093/occmed/kqi007

Dutta D, Arya S, Kumar S et al (2021) Electronic waste pollution and the COVID-19 pandemic. Environ Chem Lett. https://doi.org/10.1007/s10311-021-01286-9

EC (European Commission) (2020) Waste management in the context of the coronavirus crisis. https://ec.europa.eu/info/sites/info/files/waste_management_guidance_dg-env.pdf. Accessed 10 August 2022

EPA (United States Environmental Protection Agency) (2020) National overview: facts and figures on materials, wastes and recycling. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials. Accessed 10 August 2022

Ezeke CI, Agbakogba A, Igbagara PW (2016) Source Gas Emission and Ambient Air Quality around The Eneka Co-disposal Landfill in Port Harcourt. Nigeria Int J Appl Chem Ind Sci 2(1):11–23

Fan YV, Jiang P, Hemzal M et al (2021) An update of COVID-19 influence on waste management. Sci Total Environ 754:142014. https://doi.org/10.1016/j.scitotenv.2020.142014

Fears AC, Klimstra WB, Duprex PN et al (2020) Persistence of Severe Acute Respiratory Syndrome Coronavirus 2 in Aerosol Suspensions. Emerg Infect Dis 26(9):2168–2171. https://doi.org/10.3201/eid2609.201806

Fidelis R, Marco-Ferreira A, Antunes LC (2020) Socio-productive inclusion of scavengers in municipal solid waste management in Brazil: Practices, paradigms and future prospects. Resour Conserv Recy 154:104594. https://doi.org/10.1016/j.resconrec.2019.104594

Foladori P, Cutrupi F, Segata N et al (2020) SARS-CoV-2 from faeces to wastewater treatment: what do we know? a review. Sci Total Environ 743:140444. https://doi.org/10.1016/j.scitotenv.2020.140444

Garcia-Jordan N, Berrizbeitia M, Rodriguez J et al (2017) Seroprevalence of Trypanosoma cruzi infection in the rural population of Sucre State. Venezuela Cad Saude Publica 33:e00050216. https://doi.org/10.1590/0102-311X00050216

GAWP (Global Alliance of Waste Pickers) (2020) Coronavirus (COVID-19) and waste pickers. https://globalrec.org/covid19/. Accessed 10 August 2022

Godri KJ, Duggan ST, Fuller GW et al (2010) Particulate matter oxidative potential from waste transfer station activity. Environ Health Perspect 118(4):493–498. https://doi.org/10.1289/ehp.0901303

Gutberlet J, Uddin SMN (2017) Household waste and health risks affecting waste pickers and the environment in low- and middle-income countries. Int J Occup Env Heal 23:299–310. https://doi.org/10.1080/10773525.2018.1484996

Han J, He S (2021) Urban flooding events pose risks of virus spread during the novel coronavirus (COVID-19) pandemic. Sci Total Environ 755:142491. https://doi.org/10.1016/j.scitotenv.2020.142491

Han J, Zhang Y (2020) Microfiber pillow as a potential harbor and environmental medium transmitting respiratory pathogens during the COVID-19 pandemic. Ecotoxicol Environ Saf 205:111177. https://doi.org/10.1016/j.ecoenv.2020.111177

Han J, Zhang J, He S, Jia P (2021) Can the coronavirus disease be transmitted from food? a review of evidence, risks, policies and knowledge gaps. Environ Chem Lett 19:5–16. https://doi.org/10.1007/s10311-020-01101-x

He S, Han J (2021a) Biorepositories (biobanks) of human body fluids and materials as archives for tracing early infections of COVID-19. Environ Pollut 274:116525. https://doi.org/10.1016/j.envpol.2021.116525

He S, Han J (2021b) Electrostatic fine particles emitted from laser printers as potential vectors for airborne transmission of COVID-19. Environ Chem Lett 19(1):17–24. https://doi.org/10.1007/s10311-020-01069-8

He S, Han J, Lichtfouse E (2021) Backward transmission of COVID-19 from humans to animals may propagate reinfections and induce vaccine failure. Environ Chem Lett 19:763–768. https://doi.org/10.1007/s10311-020-01140-4

Helmer J (2020) During the pandemic, residential waste has increased significantly. So why are composting programs on hold? https://thecounter.org/covid-19-coronavirus-food-waste-landfills-compost/. Accessed 10 August 2022

Islam A, Kalam M, Sayeed M et al (2021) Escalating SARS-CoV-2 circulation in environment and tracking waste management in South Asia. Environ Sci Pollut Res 28:61951–61968. https://doi.org/10.1007/s11356-021-16396-8

Jones DL, Baluja MQ, Graham DW et al (2020) Shedding of SARS-CoV-2 in feces and urine and its potential role in person-to-person transmission and the environment-based spread of COVID-19. Sci Total Environ 749:141364. https://doi.org/10.1016/j.scitotenv.2020.141364

Kassir MF, El Zarif T, Kassir G et al (2019) Human rabies control in Lebanon: a call for action. Epidemiol Infect 147:e46. https://doi.org/10.1017/S095026881800300X

Krystosik A, Njoroge G, Odhiambo L et al (2020) Solid wastes provide breeding sites, burrows, and food for biological disease vectors, and urban zoonotic reservoirs: a call to action for solutions-based research. Front Public Health. https://doi.org/10.3389/fpubh.2019.00405

Kuijer PP, Sluiter JK, Frings-Dresen MH (2010) Health and safety in waste collection: towards evidence-based worker health surveillance. Am J Ind Med 53:1040–1064. https://doi.org/10.1002/ajim.20870

Kumar B (2020) Are insects the future vectors of COVID-19? https://www.researchgate.net/publication/347646769_Are_insects_the_future_vectors_of_COVID-19. Accessed 10 August 2022

Li L, Wang Q, Bi W et al (2020) Municipal solid waste treatment system increases ambient airborne bacteria and antibiotic resistance genes. Environ Sci Technol 54:3900–3908. https://doi.org/10.1021/acs.est.9b07641

Lima ID, Lima ALM, Mendes-Aguiar CO et al (2018) Changing demographics of visceral leishmaniasis in northeast Brazil: lessons for the future. PLOS Neglect Trop D. https://doi.org/10.1371/journal.pntd.0006164

Liu Q, Schauer J (2021) Airborne microplastics from waste as a transmission vector for COVID-19. Aerosol Air Qual Res 21:200439. https://doi.org/10.4209/aaqr.2020.07.0439

Milke M (2004) Plague in Sydney and its solid waste lessons. Waste Manag 24:321–323. https://doi.org/10.1016/j.wasman.2004.02.006

Mol MPG, Greco DB, Cairncross S et al (2015) Hepatitis B and C in household and health services solid waste workers. Cad Saude Publica 31:295–300. https://doi.org/10.1590/0102-311X00083814

Morawska L, Milton DK (2020) It is time to address airborne transmission of coronavirus disease 2019 (COVID-19). Clin Infect Dis 71(9):2311–2313. https://doi.org/10.1093/cid/ciaa939

Muñoz-Zanzi C, Mason MR, Encina C et al (2014) Leptospira contamination in household and environmental water in rural communities in Southern Chile. Int J Env Res Pub He 11(7):6666–6680. https://doi.org/10.3390/ijerph110706666

Nanda S, Berruti F (2021) Municipal solid waste management and landfilling technologies: a review. Environ Chem Lett 19:1433–1456. https://doi.org/10.1007/s10311-020-01100-y

Hebei News (2022) The source of the outbreak in Qian'an, Hebei: a villager picked up virus-contaminated garbage on the roadside of a highway. http://m.hebnews.cn/hebei/2022-04/26/content_8779815.htm (in Chinese) Accessed 10 August 2022

Nithya R, Sivasankari C, Thirunavukkarasu A (2021) Electronic waste generation, regulation and metal recovery: a review. Environ Chem Lett 19:1347–1368. https://doi.org/10.1007/s10311-020-01111-9

NWRA (National Waste & Recycling Association) (2022) COVID-19 guide for waste operations. https://wasterecycling.org/covid-19-work-practices/ Accessed 10 August 2022

OSHA (Occupational Safety and Health Administration) (2021) Solid waste wastewater. http://web.archive.org/web/20210902215827/https://www.osha.gov/coronavirus/control-prevention/solid-waste-wastewater-mgmt Accessed 10 August 2022

OSHA (Occupational Safety and Health Administration) (2022b) Guidance by Industry. https://www.osha.gov/coronavirus/guidance/industry Accessed 10 August 2022

OSHA (Occupational Safety and Health Administration) (2022a) Control and Prevention https://www.osha.gov/coronavirus/control-prevention#solidwaste Accessed 10 August 2022

Ouigmane A, Boudouch O, Hasib A et al (2021) Effect of COVID-19 on the generation of waste in Marrakech. Morocco J Air Pollut Health 11:210606. https://doi.org/10.5696/2156-9614-11.30.210606

Peccia J, Zulli A, Brackney DE et al (2020) Measurement of SARS-CoV-2 RNA in wastewater tracks community infection dynamics. Nat Biotechnol 38:1164–1167. https://doi.org/10.1038/s41587-020-0684-z

Penteado CSG, de Castro MAS (2020) Covid-19 effects on municipal solid waste management: what can effectively be done in the Brazilian scenario? Res Con Recy 164:105152. https://doi.org/10.1016/j.resconrec.2020.105152

People' Daily (2022a) Decisions by the Supreme People's Procuratorate of China, investigations on COVID-19 related cases (the 16th batch), five people arrested amid outbreaks originated from the Nanjing Lukou International Airport (in Chinese). http://js.people.com.cn/n2/2022/0331/c360303-35202598.html Accessed 10 August 2022

People's Daily (2022b) Three cases of Covid-19 infections reported in Hohhot, Inner Mongolia, all of them were workers at a waste transfer station http://nm.people.com.cn/n2/2022b/0216/c196689-35136576.html (in Chinese) Accessed 10 August 2022b

Poulsen OM, Breum NO, Ebbehoj N et al (1995) Collection of domestic waste. review of occupational health problems and their possible causes. Sci Total Environ 170:1–19. https://doi.org/10.1016/0048-9697(95)04524-5

Rachiotis G, Papagiannis D, Markas D et al (2012a) Hepatitis B virus infection and waste collection: prevalence, risk factors, and infection pathway. Am J Ind Med 55:650–655. https://doi.org/10.1002/ajim.22057

Rachiotis G, Papagiannis D, Thanasias E et al (2012b) Hepatitis A virus infection and the waste handling industry: a Seroprevalence study. Int J Environ Res Public Health 9:4498–4503. https://doi.org/10.3390/ijerph9124498

Ragazzi M, Rada EC, Schiavon M (2020) Municipal solid waste management during the SARS-COV-2 outbreak and lockdown ease: Lessons from Italy. Sci Total Environ 745:141159. https://doi.org/10.1016/j.scitotenv.2020.141159

Rahman MM, Bodrud-Doza M, Griffiths MD et al (2020) Biomedical waste amid COVID-19: perspectives from Bangladesh. Lancet Glob Health 8:e1262. https://doi.org/10.1016/S2214-109X(20)30349-1

Ramos M, Mohammed H, Zielinski-Gutierrez E et al (2005) Epidemic dengue and dengue hemorrhagic fever at the Texas-Mexico border: results of a household-based Seroepidemiologic survey. Am J Trop Med Hyg 78:364–369. https://doi.org/10.4269/ajtmh.2008.78.364

Raza ST, Hafeez S, Ali Z et al (2021) An assessment of air quality within facilities of municipal solid waste management (MSWM) sites in Lahore. Pakistan Processes 9(9):1604. https://doi.org/10.3390/pr9091604

Renninger N, Nastasi N, Bope A, et al. (2021) Indoor Dust as a Matrix for Surveillance of COVID-19. mSystems. https://doi.org/10.1128/mSystems.01350-20

Reuters (2021) Millions in Brazil thrown back into poverty as pandemic aid dries up. https://www.reuters.com/news/picture/millions-in-brazil-thrown-back-into-pove-idUSKBN2BI2OE Accessed 10 August 2022

Roberts K, Stringfellow AM, Williams LD (2020) Rubbish is piling up and recycling has stalled—waste systems must adapt. https://www.strawlesschallenge.com/rubbish-is-piling-up-and-recycling-has-stalled-waste-systems-must-adapt-the-conversation-uk/ Accessed 10 August 2022

Rozman MA, Alves IS, Porto MA et al (2008) HIV infection and related risk behaviors in a community of recyclable waste collectors of Santos. Brazil Rev Saude Publica 42:838–843. https://doi.org/10.1590/s0034-89102008005000042

Samson M (2020) SAs response to COVID-19 worsens the plight of waste reclaimers. https://www.wits.ac.za/news/latest-news/opinion/2020/2020-04/sas-response-to-covid-19-worsens-the-plight-of-waste-reclaimers.html Accessed 10 August 2022

Semuels A (2021) 'Garbage Freaking Everywhere' as Americans Venture Outdoors After a Year of Lockdowns. https://time.com/5949983/trash-pandemic/ Accessed 10 August 2022

Setti L, Passarini F, Gennaro GD et al (2020) SARS-Cov-2RNA found on particulate matter of Bergamo in Northern Italy: first evidence. Environ Res 188:109754. https://doi.org/10.1016/j.envres.2020.109754

Shields A, Faustini SE, Perez-Toledo M et al (2020) SARS-CoV-2 seroprevalence and asymptomatic viral carriage in healthcare workers: a cross-sectional study. Thorax 75:1089–1094. https://doi.org/10.1136/thoraxjnl-2020-215414

SHLW (Sound Health Lasting Wealth) (2020) Coronavirus fly-tipping soars as recycling centres close with staff wanting key worker status. https://www.soundhealthandlastingwealth.com/health-news/coronavirus-fly-tipping-soars-as-recycling-centres-close-with-staff-wanting-key-worker-status/ Accessed 10 August 2022

Singh SP, Reddy DC, Mishra RN et al (2006) attitude, and practices related to Kala-azar in a rural area of Bihar state, India. Am J Trop Med Hyg 75:505–508. https://doi.org/10.4269/ajtmh.2006.75.505

Soltani A, Jamalidoust M, Hosseinpour A et al (2021) First molecular-based detection of SARS-CoV-2 virus in the field-collected houseflies. Sci Rep 11:13884. https://doi.org/10.1038/s41598-021-93439-7

Sun S, Han J (2021a) Unflushable or missing toilet paper, the dilemma for developing communities during the COVID-19 episode. Environ Chem Lett 19:711–717. https://doi.org/10.1007/s10311-020-01064-z

Sun S, Han J (2021b) Open defecation and squat toilets, an overlooked risk of fecal transmission of COVID-19 and other pathogens in developing communities. Environ Chem Lett 19:787–795. https://doi.org/10.1007/s10311-020-01143-1

Sun S, Li J, Han J (2021) How human thermal plume influences near-human transport of respiratory droplets and airborne particles: a review. Environ Chem Lett 19:1971–1982. https://doi.org/10.1007/s10311-020-01178-4

Suwannapong N, Tipayamongkholgul M, Bhumiratana A et al (2014) Effect of community participation on household environment to mitigate dengue transmission in Thailand. Trop Biomed 31:149–158

Suzhou (2022) Suzhou: Some samples of highway roadside wastes found positive for COVID-19 https://wap.peopleapp.com/article/6647807/6522726 (in Chinese) Accessed 10 August 2022

SWANA (Solid Waste Association of North America) (2020) Waste industry must be included in coronavirus emergency response. https://waste-management-world.com/artikel/swana-waste-industry-must-be-included-in-coronavirus-emergency-response/ Accessed 10 August 2022

Tabue NR, Madgan ER, Kenfack MMF et al (2015) Do open garbage dumps play a role in canine rabies transmission in Biyem-Assi health district in Cameroon? Infect Ecol Epidemiol 5:26055. https://doi.org/10.3402/iee.v5.26055

Tanakasempipat P (2020) Plastic piles up in Thailand as pandemic efforts sideline pollution fight. https://www.reuters.com/article/us-health-coronavirus-thailand-plastic-idUSKBN22N12W Accessed 10 August 2022

Tyko (2022) Grocery stores still have empty shelves amid supply chain disruptions, omicron and winter storms. https://www.usatoday.com/story/money/shopping/2022/01/12/shortage-grocery-store-empty-shelves/9178100002/ Accessed 10 August 2022

Urbana RC, Nakadab LYK (2021) COVID-19 pandemic: solid waste and environmental impacts in Brazil. Sci Total Environ 755:142471. https://doi.org/10.1016/j.scitotenv.2020.142471

Vallee J, Thaojaikong T, Moore CE et al (2010) Contrasting spatial distribution and risk factors for past infection with scrub typhus and murine typhus in Vientiane City. Lao PDR Plos Negl Trop Dis 4:e909. https://doi.org/10.1371/journal.pntd.0000909

Valsamatzi-Panagiotou A, Penchovsky R (2022) Environmental factors influencing the transmission of the coronavirus 2019: a review. Environ Chem Lett 20:1603–1610. https://doi.org/10.1007/s10311-022-01418-9

van Aart AE, Velkers FC, Fischer EAJ et al (2021) SARS-CoV-2 infection in cats and dogs in infected mink farms. Transbound Emerg Dis. https://doi.org/10.1111/tbed.14173

van Doremalen N, Bushmaker T, Morris DH et al (2020) Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. N Engl J Med 382:1564–1567. https://doi.org/10.1056/NEJMc2004973

Vaverková MD, Paleologos EK, Dominijanni A et al (2020) Municipal solid waste management under Covid-19: challenges and recommendations. Environ Geotech 8:217–232. https://doi.org/10.1680/jenge.20.00082

Wang CQ, Han J (2022) Will the COVID-19 pandemic end with the delta and omicron variants? Environ Chem Lett. https://doi.org/10.1007/s10311-021-01369-7

Wang X, Sun S, Zhang B, Han J (2021) Solar heating to inactivate thermal-sensitive pathogenic microorganisms in vehicles: application to COVID-19. Environ Chem Lett 19:1765–1772. https://doi.org/10.1007/s10311-020-01132-4

Werneck GL, Rodrigues L, Santos MV et al (2005) Household structure and urban services: neglected targets in the control of visceral leishmaniasis. Ann Trop Med Parasitol 99:229–236. https://doi.org/10.1179/136485905X28018

WHO (World Health Organization) (2004) Review of Health Impacts from Microbiological Hazards in Health-Care Wastes. http://web.archive.org/web/20220308151132/https://www.who.int/water_sanitation_health/medicalwaste/en/microbhazards0306.pdf Accessed 10 August 2022

WHO (World Health Organization) (2021) Advice for the public: Coronavirus disease (COVID-19). https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public Accessed 10 August 2022

WHO (World Health Organization) (2022a) Coronavirus (COVID-19) Dashboard. https://covid19.who.int/ Accessed 10 August 2022a

WHO (World Health Organization) (2022b) Coronavirus disease (COVID-19) Weekly Epidemiological Update and Weekly Operational Update https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports Accessed 10 August 2022b

WIEGO (Women in Informal Employment: Globalizing and Organizing) (2020) Waste pickers: Essential Service Providers at Risk. https://www.wiego.org/waste-pickers-essential-service-providers-risk Accessed 10 August 2022

WM (Waste Management) (2022) What special precautions is WM taking during the pandemic. https://www.wm.com/us/en/support/faqs/what-special-precautions-is-wm-taking-during-the-pandemic Accessed 10 August 2022

World Health Organization (WHO) & United Nations Children's Fund (UNICEF) (2020). Water, sanitation, hygiene, and waste management for SARS-CoV-2, the virus that causes COVID-19: interim guidance, 29 July 2020. https://apps.who.int/iris/handle/10665/333560 Accessed 10 August 2022

Wright N, Subedi D, Pantha S et al (2021) The role of waste management in control of rabies: a neglected issue. Viruses 13:225. https://doi.org/10.3390/v13020225

Yousefi M, Oskoei V, Jonidi Jafari A et al (2021) Municipal solid waste management during COVID-19 pandemic: effects and repercussions. Environ Sci Pollut Res 28:32200–32209. https://doi.org/10.1007/s11356-021-14214-9

Zambrano-Monserrate MA, Ruano MA, Sanchez-Alcalde L (2020) Indirect effects of COVID-19 on the environment. Sci Total Environ 728:138813. https://doi.org/10.1016/j.scitotenv.2020.138813

Zand AD, Heir AV (2021) Emanating challenges in urban and healthcare waste management in Isfahan, Iran after the outbreak of COVID-19. Environ Technol Innov 42:329–336. https://doi.org/10.1080/09593330.2020.1866082

Zhao Y, Richardson B, Takle E et al (2019) Airborne transmission may have played a role in the spread of 2015 highly pathogenic avian influenza outbreaks in the United States. Sci Rep 9:11755. https://doi.org/10.1038/s41598-019-47788-z