Environmental Impacts of Medical Waste

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INTRODUCTION

The topic of waste production and disposal and the resulting environmental consequences has been an essential topic of recent research. Single-use plastics are often used for convenience and sanitary purposes in a variety of applications varying from daily consumer use to medical settings.

In the last year, the Coronavirus Disease of 2019 (COVID-19) pandemic has amplified the negative impacts of human waste on the environment. Two major contributors are the increased use and improper disposal of single-use medical equipment such as masks and gloves (Prata et al., 2020) and the increased use of cleaning compounds that lead to antimicrobial resistance (AMR) through the wastewater treatment system (Bengoechea et al., 2020).

While the environmental impacts of the pandemic are still being observed, they draw attention to documented ecological issues and how the public and scientific communities interact. The continued study of single-use medical waste production and disposal as a result of COVID-19, as well as the increased use of cleaning supplies and antibiotics, will provide further context to the social and environmental consequences of the pandemic. This paper will examine the environmental impacts of the COVID-19 epidemic resulting from the disposal of medical waste, the resulting changes to waste management industries, and recommendations for how to limit future consequences to the environment as a result of increased consumption.

DISCUSSION

Industrial waste, plastics, and chemicals are major contributors to waste production and have well-documented environmental impacts. The applications of these products and the processes that create them have impacted and often benefited the public through improved construction processes, fuel production, reductions in product costs, and the convenience of single-use products in daily life (Jambeck et al., 2015).

As a result of lockdowns from COVID-19, the worldwide demand for petroleum experienced declines and collapsed. This made the production of plastics cheaper than ever before (Adyel, 2020). Increases in the production of plastics were a necessity to battle the viral pandemic. An estimated 129 billion face masks and 65 billion gloves are produced and used each month globally during the COVID-19 epidemic (Prata et al., 2020). Increases in medical waste production in major cities are shown in Figure 1. These production increases have had significant negative impacts on the environment.

City	Population (World Population Review)	healthcare waste generated (tonnes/day before COVID-19)	Estimated additional healthcare waste generation (tonnes/day during COVID-19)	Percentage of increase due to COVID-19
Manila	14 million	47	280	496
Jakarta	10.6 million	35	212	506
Kuala Lampur	10.5 million	35	210	500
Bangkok	8 million	27	160	493
Ha Noi	7.7 million	26	154	492

Figure 1: Estimated additional amount of healthcare waste in each city due to the COVID-19 pandemic. (ADB, 2020)

Many countries have required face coverings outside of private homes or in public buildings, and a commonly used type of covering is the disposable medical face mask. Readily available to the public and businesses, these inexpensive, single-use masks provide the benefit of a decreased chance of contamination and virus transmission through the establishment of a physical barrier between the nose and mouth and the outside environment (Sunjaya et al., 2020). They are made of layers of non-woven polyurethane, polypropylene, or polyacrylonitrile fabric, with elastic ear loops or plastic ties. As a result, they do not decompose readily but instead break down into progressively smaller pieces to eventually become microplastics (Talvitie et al., 2017). Their improper disposal can have severe and far-reaching negative consequences ranging from reduced water quality, pollution, lower aesthetic value, and the increased use of landfills. Latex or plastic gloves are used by many people in public and businesses to reduce the amount of contact they have with potentially contaminated surfaces. They are not recyclable, and due to the composition of plastics and other additives, do not decompose. So, like masks, they contribute to plastic waste and pollution when improperly disposed of (Prata et al., 2020).

COVID-19 has increased the production and use of single-use medical personal protective equipment (PPE) that accumulate in landfills, or when improperly disposed of, in the environment. The broader detrimental impacts of this waste production are pollution, ecosystem damage, and the increased potential for people to come into contact with contaminated PPE. Research is ongoing regarding the actual COVID-19 related environmental consequences, but the current events highlight waste disposal and pollution issues that have been studied for an extended time period before the pandemic. Previous research has shown that large amounts of plastic waste enter the marine environment from pollution on land, mostly from landfills and coastal populations (Jambeck et al., 2015). This has significant detrimental effects on marine life and coral reefs ranging from animals ingesting plastics to the plastic waste sorbing chemicals from surrounding ocean water, which can disrupt chemical communication (Figure 2) (Trotter et al., 2019).

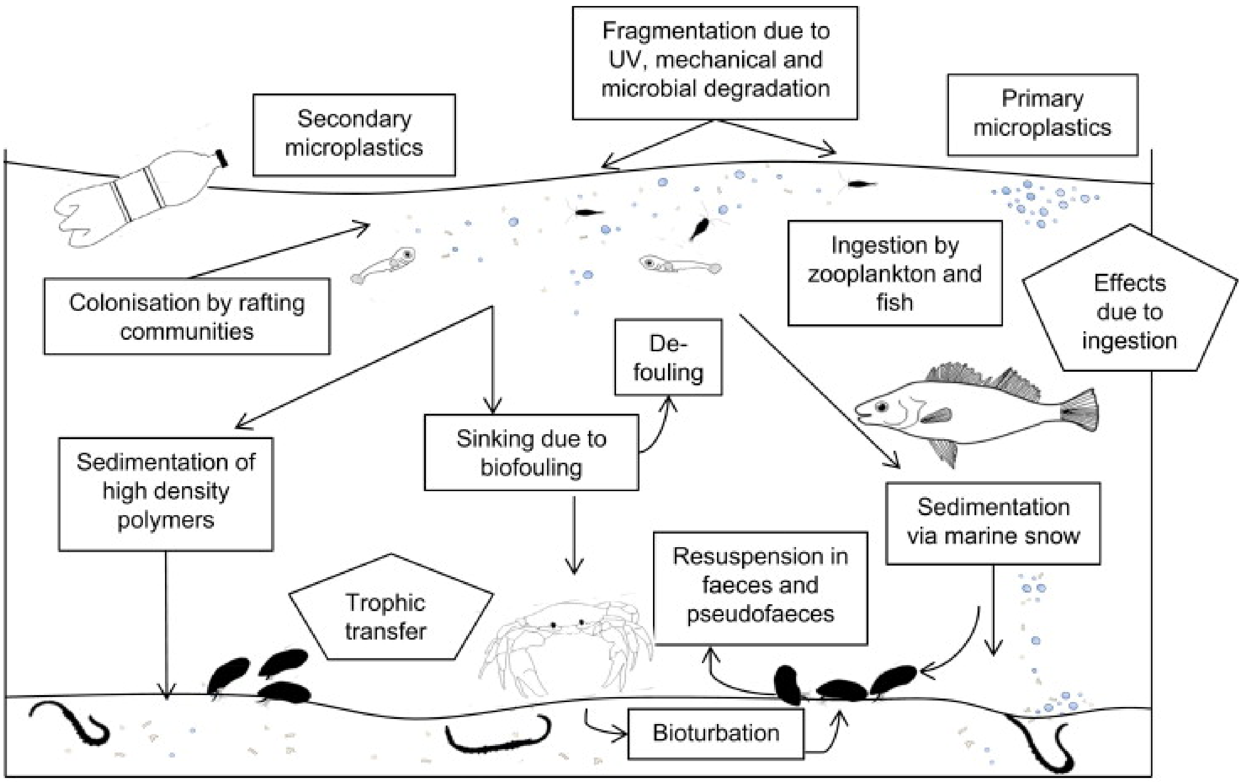

Figure 2: The physical impacts of microplastics on marine organisms (Wright et al., 2013)

Single-use face masks and gloves are among this plastic pollution, as they are disposed of in landfills and as litter in the environment. They then enter the freshwater system or the marine system, where they become a source of microplastic particles as they degrade and form increasingly smaller fragments (Aragaw, 2020).

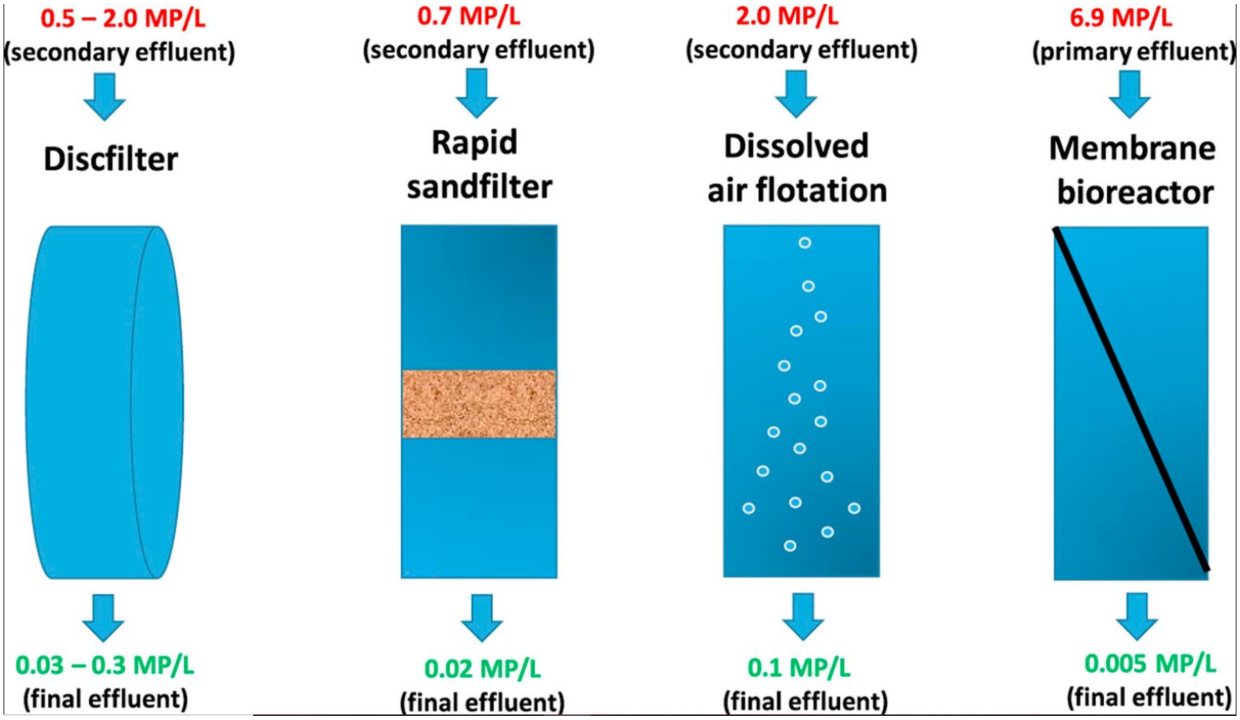

Figure 3: Removal of microplastics from wastewater effluent with advanced wastewater treatment technologies (Talvitie et al., 2017)

The treatment of wastewater through filtration and dissolved air flotation and skimming can remove plastic waste and microplastics before the water is discharged into aquatic environments, which assists in reducing the amount of improperly disposed of plastic waste entering the environment (Talvitie et al., 2017). Wastewater treatment plants use a variety of filtration and removal methods to reduce or eliminate the number of microplastics in water before it reenters the environment. Water containing microplastics is typically passed through progressively finer filters before being subjected to float and membrane removal methods, after which it can be released back to the water system (Figure 3).

As a direct result of increased use of disposable PPE as a consequence of Covid-19, new efforts on recycling are currently under research. There is potential for plastics to be recycled into a high-density composite material through mixing sand and polymer material (Seghiri et al., 2017). Used masks are broken down into smaller fragments and decontaminated using ultraviolet light, combined with a binder, and used to form plastic products (Face, 2020). Shredded and condensed mask material can also be sanitized and used to make high-density composite material (The Venetian, 2020). Other research has shown that plastics can be partially broken down into wax and oil compounds through the use of various catalysts and light alkanes reagents, which can then be used as fuel (Plastic, 2016). However, these recycling methods depend on the type of disposable PPE, so improper disposal still has the potential to negatively impact the environment.

The waste management industry has faced an interesting challenge during this pandemic. Increases in potentially infectious waste products have caused difficulties for waste management plants. This poses an increased risk for workers as well as creates more steps to achieve proper disposal (Alverson, 2020). Waste management in developing countries does not often operate in line with nationally accepted standards, so additional difficulties have arisen as the amount of potentially contaminated waste has increased. This requires additional care in handling this waste during the treatment process (Onogawa, 2020). Many developing countries lack the infrastructure required for proper waste management, so the increase in PPE waste has caused added stress on already fragile systems.

COVID-19 has caused issues for waste disposal municipalities as well. U.S. cities saw a 20% increase in solid waste and recycling collection from March to April 2020, according to the Solid Waste Association of North America (citation). With many

Asian nations banning the imports of low-quality scrap (recycling, etc.) in 2018, the spike in solid waste has further stressed the American recycling infrastructure. Historically China took up to 700,000 tons of scrap per year (Love and Rieland, 2020).

Increases in medical waste have played a role in the accumulation of waste products as well. COVID-19 has created an increase in potentially infected materials in hospitals and medical facilities. These materials have additional protocols for disposal compared to non-infectious materials (Peng et al.,2020). These additional precautions require protective containers as well as disinfectant products.

While much of the funding and the attention of the scientific community have been funneled into COVID-19 diagnostic tests and vaccine research, COVID-19 poses an additional threat in the realm of AMR (*Tackling antimicrobial resistance in the COVID-19 pandemic,* 2020). AMR is a common, rapidly developing phenomenon where certain mutant strains of bacteria become resistant to treatment with antibiotics or entire classes of antibiotics. The majority of this antibiotic exposure is thought to be in two areas; the agricultural sector in animals and the general community medical use in humans (Wise et al., 1998). Nearly 75% of all antibiotic use has a questionable therapeutic advantage (Wise et al., 1998), and COVID-19 has resulted in increased antibacterial use in both hospital and public settings.

Many international organizations and national institutions have implemented policies designed to help slow the spread of COVID-19 and not overwhelm medical infrastructure. Common phrases such as “slowing the spread” and “flattening the curve” refer to the visual “curve” of the temporal onset of the spread of COVID-19, and coincide with directives that encourage social distancing as well as frequent sanitization of hands and commonly touched surfaces (Figure 4) (*Cleaning and Disinfection for Households*, 2020). The Center for Disease Control (CDC), for example, has issued guidance for cleaning and disinfecting depending on the type of location (i.e., public, emergency, and medical) (*Communities, Schools, Workplaces, & Events*, 2020).

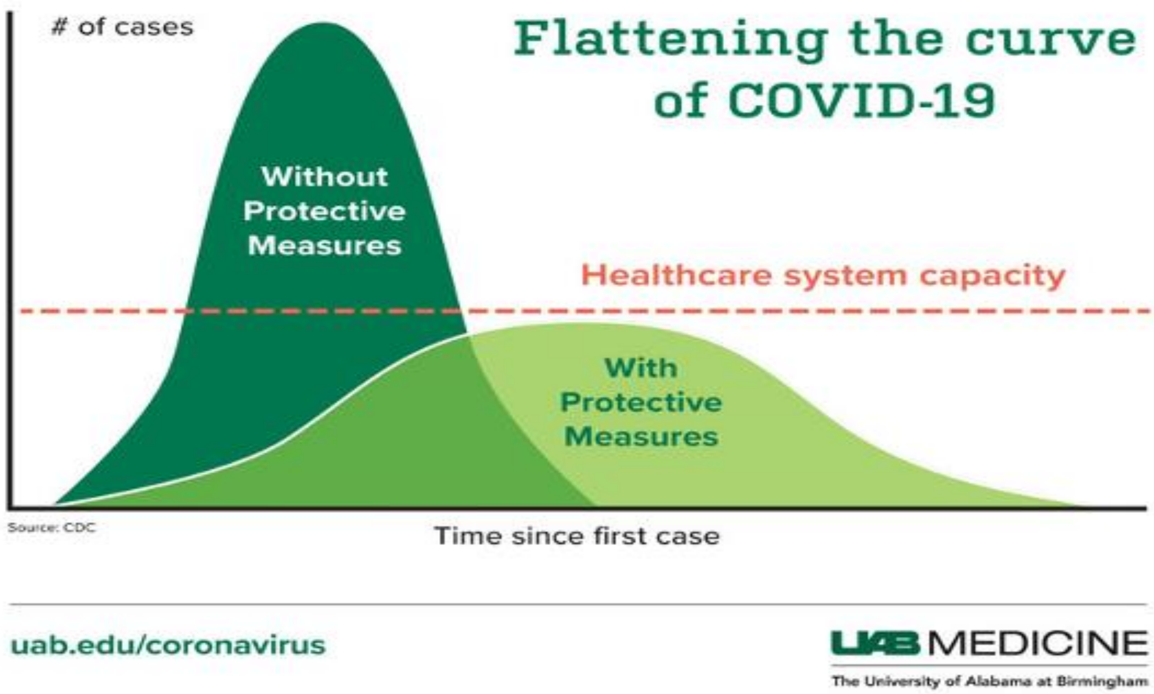

Figure 4: A visual representation of "Flattening the curve" (What exactly does it mean to 'flatten the curve'? UAB expert defines coronavirus terminology for everyday life - News, 2020)

Such frequent sanitization and disinfection may be successful in curbing the spread of COVID-19, but it is also harming the microbiome. Frequent exposure to surface biocides or prescribed antibiotics leaves behind mutant strains of bacteria that can survive this exposure and continue to reproduce. These evolutionary-successful bacteria may also facilitate horizontal gene transfer of antibiotic-resistant mobile genetic elements (i.e., plasmids) between genomes, resulting in AMR of additional species (Figure 5).

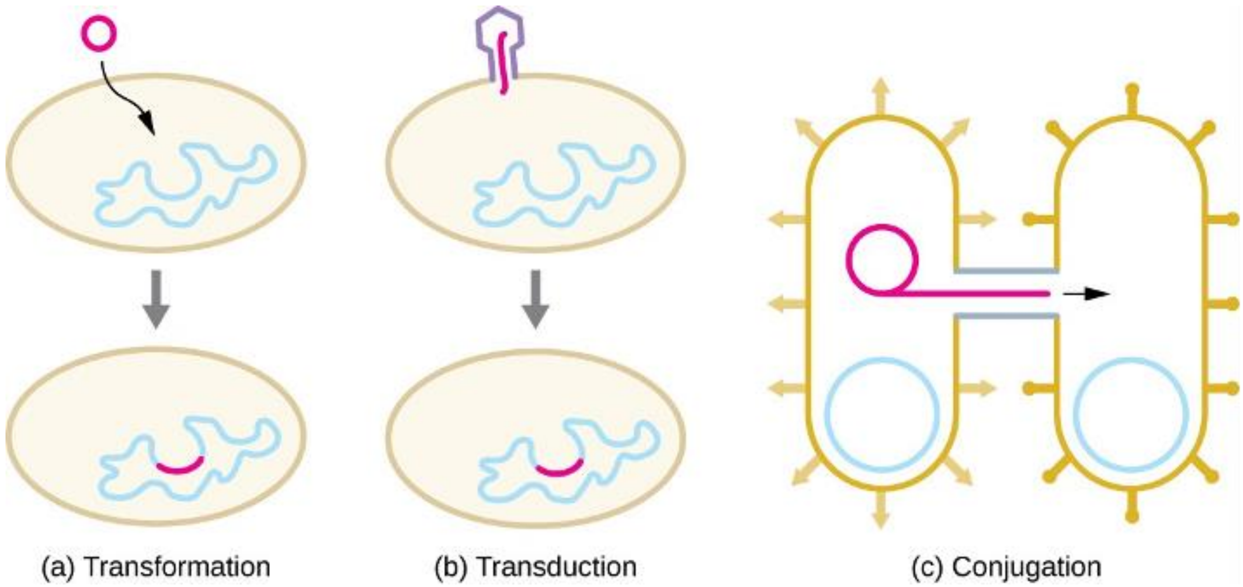

Figure 5: Three types of Horizontal Gene Transfer (How Asexual Prokaryotes Achieve Genetic Diversity, 2020)

While antibiotics are not a treatment for COVID-19, SARS-CoV-2 respiratory symptoms can often lead to bacterial coinfections (Reardon et al., 2020). These co-infections may be a deadly combination during the treatment of COVID-19, and a large portion of deaths have already been attributed to this phenomenon (*Considerations for AMR in the Covid-19 pandemic,* 2020). The World Health Organization has also published statistics from a review study of COVID-19 hospitalized patients, noting that "while 72% of patients received antibiotics, only 8% demonstrated superimposed bacterial or fungal co-infections," meaning that this crisis has resulted in the over-prescription of antibiotics, like azithromycin (often in conjunction with hydroxychloroquine, although the combined use has not yet been recommended outside of clinical trials) (*Tackling antimicrobial resistance in the COVID-19 pandemic,* 2020). One study found that 95% of patients in two hospitals in Wuhan, China, were treated for COVID-19 with antibiotics while only 21% were treated with antivirals (*Antimicrobial resistance in the age of COVID-19,* 2020).

The World Health Organization has noted that “AMR is a neglected global crisis that requires urgent attention and action,” and the COVID-19 pandemic may exasperate the current situation (*Tackling antimicrobial resistance in the COVID-19 pandemic,* 2020), with scientists predicting an AMR surge post-pandemic (*Antimicrobial resistance in the age of COVID-19,* 2020). AMR is also thought to increase the likelihood of future zoonotic (and non-zoonotic) infectious disease transmission because westernized populations have reduced their microbiota diversity (Kenyon, 2020).

The microbial community is integral to a lot of ecosystem functions that humans rely on, and antimicrobials can enter the environment in many different ways. A few sources for antimicrobials entering the ecosystem include livestock manure, landfill leachate, land runoff, and hospital and municipal wastewater (Korzeniewska & Harnisz, 1970). The over-prescription of antimicrobials for COVID-19 patients as well as over-use by the general public will be seen most clearly in wastewater treatment plants, where current activated sludge treatment techniques are unable to completely eliminate antibacterial biocides, leading to accumulation and subsequent disruption of native microbial species as well as biogeochemical cycling and remediation efforts (Figure 6) (Usman, Farooq, & Hanna, 2020).

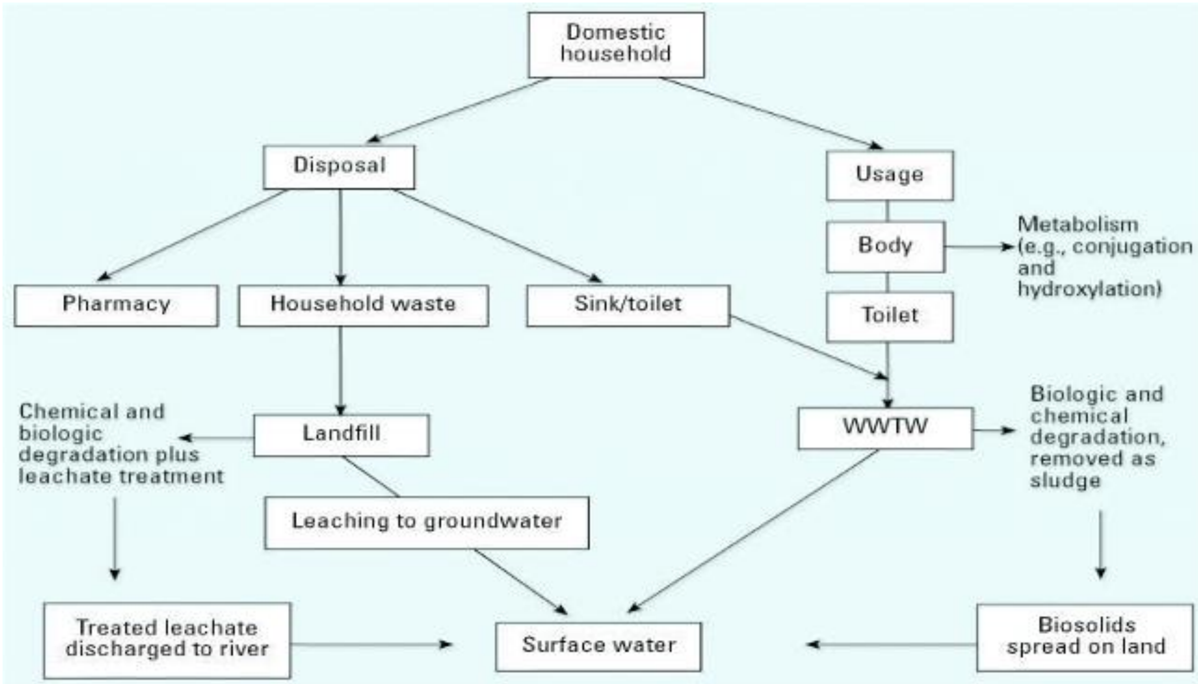

Figure 6: Antibiotic entrance into ecosystems (Bound & Voulvoulis, 2005)

Wastewater poses the largest risk for COVID-19-induced AMR, and this mode of entry is especially dangerous for aquatic ecosystems (Figure 7). One way to curb the effect on the ecosystem of COVID-19-induced AMR is to exercise caution in the use of biocides for disinfection and to prioritize biocidal agents that have demonstrated low or limited bacterial selection pressure, such as those recommended by the CDC and the Environmental Protection Agency (*Tackling antimicrobial resistance in the COVID-19 pandemic,* 2020).

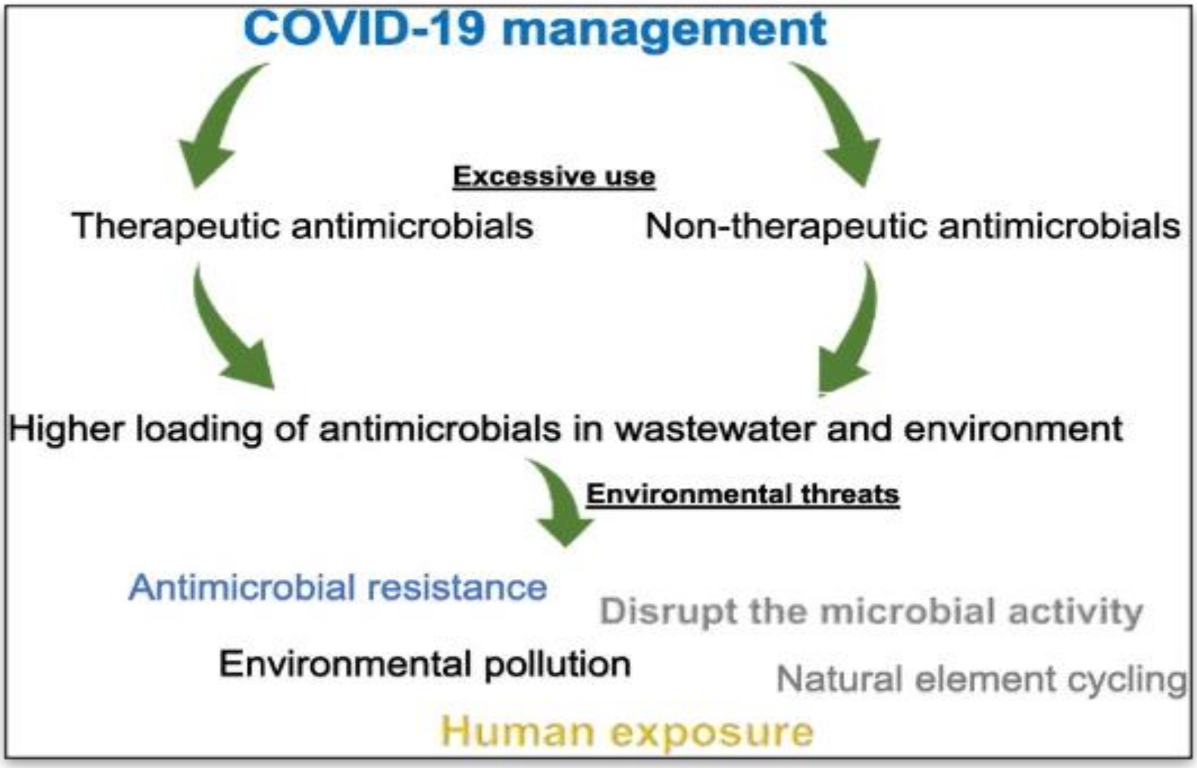

Figure 7: Effects of COVID-19 management on the environment (Usman, Farooq, & Hanna, 2020)

Some of the documented environmental impacts of AMR as a pollutant include disruption of methanogens, nitrogen-fixing bacteria, and sulfate reducers, and pose a large risk to humans and animals alike (Keen & Patrick, 2013). It has also been documented that bacteria are capable of metabolizing bactericidal antibiotics to result in reactive oxygen species (ROS), which are considered mutagens to many aerobic organisms (Kohanski et al., 2010). Antibiotic pollution from wastewater has also been linked to aggressive infections and physical deformities in amphibians (Carey, 2000). AMR has the potential to impact a wide variety of ecosystems, and COVID-19-induced increases in antibiotic use may compound the observed negative effects.

The COVID-19 outbreak is unprecedented, widening a large knowledge gap on how an AMR post-pandemic surge may impact the environment. The short-term consequences of industrial and commercial biocidal overuse are presumably negative, but there are a few areas where increased funding would be most beneficial. Containing the over-prescription of antibiotics during this pandemic is paramount but directing research and funding towards wastewater treatment plant AMR and new antibiotic development would also be valuable.

CONCLUSION

The COVID-19 pandemic has highlighted the environmental consequences of waste pollution through the increased production and disposal of medical waste. The increases in waste that have been observed globally have exposed flaws in many waste disposal systems. These flaws have major environmental repercussions that have been amplified during the COVID-19 pandemic, such as pollution resulting from single-use plastics and AMR arising from increased use of cleaning and sanitizing chemicals and antibiotics.

The use of disposable face masks and gloves as PPE in the COVID-19 pandemic has highlighted the overarching problem of waste disposal in the United States. In order to prevent the current issues arising from the increased consumption and disposal of medical PPE due to the pandemic, it is necessary to reduce or solve the ongoing problems with the production of single-use plastics across a range of applications and their resulting environmental consequences. Because the pandemic rose in severity so rapidly in the United States, there were limited options for preparing for the significant increase in PPE consumption. The only realistic ways that we could have prevented the observed increase in waste production would have been by either solving the larger waste management issue prior to the pandemic or by rapidly responding to the increases in single-use PPE consumption by establishing disposal protocols as soon as it became clear there would be an issue with medical waste pollution. One option that might have been beneficial in curbing COVID-19-induced AMR is to designate an EPA-safe label for disinfectants and to promote this label during safety procedure development. The frequently circulated infographics on handwashing could have also included advice about utilizing non-antibacterial soaps.

In terms of COVID-19 cleaning methods and antibiotic use moving forward, it is important for the public to maintain good pharmaceutical stewardship to prevent AMR in the environment. While physicians should be reminded only to prescribe antibiotics when absolutely necessary, it is also important that patients complete the entire course of antibiotic treatment to prevent AMR. If there are any excess antibiotics in their prescription, it is important that these be disposed of in a proper pharmaceutical receptacle (such as those near the pharmacy counter). The general public should be wary of antibacterial soaps and utilize EPA-registered disinfectants to protect against resistance while still removing SARS-CoV-2 from surfaces. Hand sanitizer should be used sparingly.

Single-use personal protective equipment is a necessary precaution to prevent the spread of COVID-19, so completely discontinuing their use is not a viable option. One method of reducing pollution from plastic face masks is the use of reusable cloth face coverings when appropriate. However, some settings require disposable PPE. As a result, the most significant method of minimizing waste pollution is proper disposal to reduce the amount of plastic entering the environment. In addition, there has been new research into developing specific recycling methods for plastic face masks and gloves. This research should continue in order to develop alternatives to landfill disposal of PPE, which increases the risk of these materials entering terrestrial and aquatic environments. Current literature shows a lack of research into the development of biodegradable PPE, which is another potential method of reducing waste pollution as a result of COVID-19. This option of more environmentally friendly disposable masks and gloves would be beneficial in reducing the negative consequences of consumption and waste disposal. The development of biodegradable disposable PPEs would help to reduce the burden of COVID-19 plastics on our environment. The COVID-19 pandemic has brought attention to public health, while related topics such as pollution and climate change have been pushed further from the public eye. As a result, these ideas haven’t been researched as extensively.

REFERENCES

Adyel, T. M. (2020). Accumulation of plastic waste during COVID-19. *Science, 369*(6509), 1314-1315. doi:10.1126/science.abd9925

Antimicrobial resistance in the age of COVID-19*. Nat Microbiol* **5,** 779 (2020). https://doi.org/10.1038/s41564-020-0739-4

Aragaw, T. A. (2020). Surgical face masks as a potential source for microplastic pollution in the COVID-19 scenario. Marine Pollution Bulletin, 159, 111517.

Bengoechea, J. A., & Bamford, C. G. G. (2020). SARS - CoV- 2, bacterial co-infections, and AMR: The deadly trio in COVID - 19? *EMBO Molecular Medicine, 12*(7) doi:http://dx.doi.org.proxybz.lib.montana.edu/10.15252/emmm.202012560

Bound, P., Voulvoulis, N. (2005). Household Disposal of Pharmaceuticals as a Pathway for Aquatic Contamination in the United Kingdom. *Environmental Health Perspectives* 113:12 CID: https://doi.org/10.1289/ehp.8315

Brian J. Love Professor of Materials Science and Engineering, & Julie Rieland, Ph.D. Candidate in Macromolecular Science and Engineering. (2020, September 06). COVID-19 is laying waste to many US recycling programs. Retrieved September 25, 2020, from https://theconversation.com/covid-19-is-laying-waste-to-many-us-recycling-programs-139733

Brink, S. (2020, May 14). *Why Antibiotic Resistance Is More Worrisome Than Ever*. Retrieved September 30, 2020, from https://www.npr.org/sections/goatsandsoda/2020/05/14/853984869/antibiotic-resistance-is-still-a-top-health-worry-its-a-pandemic-worry-too

Carey C. Infectious disease and worldwide declines of amphibian populations, with comments on emerging diseases in coral reef organisms and in humans. Environ Health Perspect. 2000 Mar;108 Suppl 1(Suppl 1):143-50. doi: 10.1289/ehp.00108s1143.

Center for Disease Control. (2020, June 01). *What you should know about COVID-19 to protect yourself and others*. Retrieved September 30, 2020, from https://www.cdc.gov/coronavirus/2019-ncov/downloads/2019-ncov-factsheet.pdf

Cleaning and Disinfection for Households. (n.d.). Retrieved September 30, 2020, from https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/cleaning-disinfection.html

Communities, Schools, Workplaces, & Events. Centers for Disease Control and Prevention. (2020). Retrieved 22 October 2020, from https://www.cdc.gov/coronavirus/2019-ncov/community/clean-disinfect/index.html.

Considerations for AMR in the Covid-19 pandemic. (n.d.). Retrieved September 30, 2020, from https://www.jpiamr.eu/considerations-for-antibiotic-resistance-in-the-covid-19-pandemic/

Donaghy, John Anthony, Jagadeesan, Balamurugan, Goodburn, Kaarin, Grunwald, Ludger, Jensen, Ove Niels, Jespers, AD, Kanagachandran, Kanagasooriyam, Lafforgue, Hervé, Seefelder, Walburga, and Quentin, Marie-Claude. (2019). Relationship of Sanitizers, Disinfectants, and Cleaning Agents with Antimicrobial Resistance. *Journal of Food Protection*, 82(5), 889-902.

Face mask recycling: French firm finds way to re-use Covid waste. (2020). France, 24, pp. France 24, 2020-08-27.

How Asexual Prokaryotes Achieve Genetic Diversity | *Microbiology*. Courses.lumenlearning.com. (2020). Retrieved 22 October 2020, from https://courses.lumenlearning.com/microbiology/chapter/how-asexual-prokaryotes-achieve-genetic-diversity/.

Jambeck, J. R, Geyer, R, Wilcox, C, Siegler, T. R, Perryman, M, Andrady, A, Narayan, R, and Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science* (American Association for the Advancement of Science), 347(6223), 768-771.

Joana C. Prata, Ana L.P. Silva, Tony R. Walker, Armando C. Duarte, and Teresa Rocha-Santos. (2020). *Environmental Science & Technology. 54* (13), 7760-7765. DOI: 10.1021/acs.est.0c02178

Keen PL, Patrick DM. Tracking Change: A Look at the Ecological Footprint of Antibiotics and Antimicrobial Resistance. *Antibiotics*. 2013; 2(2):191-205.

Kenyon, C. (n.d.). *We Need to Address the Underlying Ecological Determinants of COVID-19*. Retrieved September 30, 2020, from https://www.preprints.org/manuscript/202006.0040/v1

Korzeniewska, E., & Harnisz, M. (1970, January 01). *Sources, Occurrence, and Environmental Risk Assessment of Antibiotics and Antimicrobial-Resistant Bacteria in Aquatic Environments of Poland*. Retrieved September 30, 2020, from https://link.springer.com/chapter/10.1007/978-3-030-12139-6_9

Michael A. Kohanski, Mark A. DePristo, James J. Collins, (2010). Sublethal Antibiotic Treatment Leads to Multidrug Resistance via Radical-Induced Mutagenesis, *Molecular Cell*, 37 (3), 311-320, ISSN 1097-2765, https://doi.org/10.1016/j.molcel.2010.01.003.

Novo, Ana, André, Sandra, Viana, Paula, Nunes, Olga C, & Manaia, Célia M. (2013). Antibiotic resistance, antimicrobial residues and bacterial community composition in urban wastewater. *Water Research* (Oxford), 47(5), 1875-1887.

Peng, J., Wu, X., Wang, R., Li, C., Zhang, Q., & Wei, D. (2020). Medical waste management practice during the 2019-2020 novel coronavirus pandemic: Experience in a general hospital. *American Journal of Infection Control, 48*(8), 918-921. doi:10.1016/j.ajic.2020.05.035

Plastic waste turned into fuel. (2016). *Nature* (London), 534(7608), 439.

Sara Reardon, Lucy Hicks, Rasha Aridi, Jocelyn Kaiser, Rasha Aridi, & Rebekah Tuchscherer. (2020, April 17). *Antibiotic treatment for COVID-19 complications could fuel resistant bacteria*. Retrieved September 30, 2020, from https://www.sciencemag.org/news/2020/04/antibiotic-treatment-covid-19-complications-could-fuel-resistant-bacteria

Seghiri, Mehdi, Boutoutaou, Djamel, Kriker, Abdelouahed, & Hachani, Mohamed Ibrahim. (2017). The Possibility of Making a Composite Material from Waste Plastic. *Energy Procedia*, 119, 163-169

Sunjaya, Anthony Paulo, & Jenkins, Christine. (2020). Rationale for universal face masks in public against COVID- 19. *Respirology (Carlton, Vic.), 25*(7), 678-679.

Tackling antimicrobial resistance in the COVID-19 pandemic. (2020, June 30). Retrieved September 30, 2020, from https://www.who.int/bulletin/volumes/98/7/20-268573/en/

Talvitie, Julia, Mikola, Anna, Koistinen, Arto, & Setälä, Outi. (2017). Solutions to microplastic pollution – Removal of microplastics from wastewater effluent with advanced wastewater treatment technologies. *Water Research* (Oxford), 123, 401-407.

The Venetian Resort Announces New Innovative Recycling Program To Keep Face Masks Out Of Local Landfills. (2020). U.S. Newswire, pp. U.S. Newswire, 2020-07-21.

Trotter, B, Ramsperger, A F R M, Raab, P, Haberstroh, J, & Laforsch, C. (2019). Plastic waste interferes with chemical communication in aquatic ecosystems. *Scientific Reports*, 9(1), 5889-8.

United Nations, Institute for Global Environmental Strategies. (n.d.). *Waste Management during the COVID-19 Pandemic From Response to Recovery*.

Usman, M., Farooq, M., & Hanna, K. (2020, July 18). *Environmental side effects of the injudicious use of antimicrobials in the era of COVID-19*. Retrieved September 30, 2020, from https://www.sciencedirect.com/science/article/pii/S0048969720345824

What exactly does it mean to 'flatten the curve'? UAB expert defines coronavirus terminology for everyday life - News. UAB News. (2020). Retrieved 22 October 2020, from https://www.uab.edu/news/youcanuse/item/11268-what-exactly-does-it-mean-to-flatten-the-curve-uab-expert-defines-coronavirus-terminology-for-everyday-life.

Wise, R., Hart, T., Cars, O., Streulens, M., Helmuth, R., Huovinen, P., & Sprenger, M. (1998). Antimicrobial resistance. *BMJ*, *317*(7159), 609-610. https://doi.org/10.1136/bmj.317.7159.609

Wright et al., (2013). S.L. Wright, R.C. Thompson, T.S. Galloway. The physical impacts of microplastics on marine organisms: a review. *Environ. Pollut.*, 178 (2013), pp. 483-492