Airborne outdoor environmental multidrug resistance bacteria: mini review on ecological source and health impact

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Abstract

The emergence of multidrug-resistant (MDR) bacteria in outdoor environments present a growing threat to public health and ecosystems. This mini-review aims to explore the ecological sources and pathways of airborne MDR bacteria, emphasizing their prevalence in diverse outdoor environments such as urban areas, agricultural lands, and natural habitats. The review is based on a systematic literature review using electronic databases, where relevant studies were identified and analyzed for data on airborne MDR bacteria. The factors contributing to the dissemination of these bacteria, including human activities, animal interactions, and environmental changes, are discussed. Data was sourced from peer-reviewed journals, government reports, and environmental health studies. Health impacts, particularly the role of airborne MDR bacteria in respiratory infections and the potential for community-wide outbreaks, are focused on. The findings emphasize the need for enhanced monitoring, control measures, and global collaboration. By synthesizing current research, this review provides evidence-based recommendations to reduce the risks associated with airborne MDR bacteria and supports policy development.

Keywords: Multidrug-resistant, Environments, Antibiotic, Air outdoor

Introduction

Multidrug-resistant (MDR) bacteria have emerged as a critical global public health threat, contributing to 1.27 million deaths in 2019 alone and 4.95 million deaths overall due to antimicrobial resistance (AMR) (Kariuki et al., 2022). The growing prevalence of these pathogens presents a unique challenge as they have developed mechanisms to withstand multiple antibiotics, making treatment difficult. The spread of MDR bacteria not only complicates healthcare management but also increases risks for widespread community-level infections, particularly respiratory diseases.

The rise of MDR bacteria is driven by a variety of factors, including inappropriate antibiotic usage in medical, agricultural, and industrial settings. This, combined with environmental changes such as increased urbanization and pollution, accelerates the spread of these resistant pathogens. Urban areas, agricultural lands, and wastewater treatment plants have become reservoirs for MDR bacteria, leading to increased human exposure (Kumar & Pal, 2018). Trends such as the misuse of antibiotics in livestock farming for growth promotion and disease prevention exacerbate the environmental contamination, with bacteria traveling through air and water pathways to distant locations (Mulchandani et al., 2023). These developments heighten the risk of outbreaks and the spread of resistance genes across bacterial populations.

Health risks are mounting as these bacteria contribute to a range of respiratory infections and other conditions that are becoming increasingly difficult to treat (Browne & Mitchell, 2023). Moreover, environmental contamination caused by industrial emissions, wastewater discharge, and agricultural runoff further complicates the issue by facilitating the persistence and spread of MDR bacteria in outdoor environments (Sambaza & Naicker, 2023). The role of airborne transmission, in particular, has been identified as a significant but underexplored factor in the spread of these pathogens (Husna et al., 2023).

This review aims to provide a comprehensive overview of the ecological sources, transmission mechanisms, and health impacts of airborne MDR bacteria in outdoor environments. By examining the mechanisms of transmission, the ecological and health impacts, and the strategies for mitigation, this paper seeks to focus on the urgent need for coordinated efforts to monitor, understand, and address the risks associated with airborne MDR bacteria. Understanding the dynamics of these pathogens in the outdoor air is essential for developing effective public health policies and interventions to lessen their spread and impact on global health.

Study Methods

This review synthesized secondary data from peer-reviewed literature, government reports, and environmental studies. The structured search focused on databases like PubMed and ScienceDirect using terms related to airborne MDR bacteria, environmental contamination, and health impacts. Studies from the last 20 years were included, with a focus on outdoor transmission and public health risks. Data was categorized into themes such as ecological sources, transmission pathways, and health impacts.

Source of MDR bacteria

1. Agriculture and Farming

Livestock can be a significant source of multidrug-resistant bacteria that contribute to outdoor environmental multidrug resistance (MDR). In large-scale livestock operations, animals are often given antibiotics to prevent diseases and promote growth. However, some bacteria in these animals can become resistant to these antibiotics over time. When animals produce waste, such as manure, it can contain these resistant bacteria. This waste can then release bacteria into the environment through various pathways (Alegbeleye, O.O. & A.S. Sant'Ana, 2020). For example, when manure is spread on fields as fertilizer, bacteria can leach into the soil and potentially contaminate nearby water sources (Ananna, F.H., et al., 2021). Additionally, airborne particles from livestock facilities, such as dust and aerosols, can carry bacteria into the air. These bacteria can travel long distances and settle in other outdoor environments, contributing to the overall pool of multidrug-resistant organisms in the air (Zhao, Y., et al., 2014). Therefore, livestock operations serve as a significant source for outdoor environmental multidrug resistance by releasing resistant bacteria into the environment, where they can persist and potentially spread to humans, animals, and other organisms.

Livestock can indeed be a significant source of multidrug-resistant bacteria contributing to outdoor environmental multidrug resistance (MDR). According to a study conducted by Muchandani et al., which used statistical models, antimicrobial usage in livestock farming was estimated at 99,502 tons in 2020 (Mulchandani, R., et al., 2023). The study projected an 8% increase to 107,472 tons based on current trends. This extensive use of antibiotics in livestock operations creates selective pressure, favoring the survival and proliferation of antibiotic-resistant bacteria within animal populations (Manyi-Loh, C., et al., 2018). Consequently, when animals produce waste such as manure, it can contain these resistant bacteria. Manure, when used as fertilizer, can introduce resistant bacteria into the soil, which can then potentially contaminate nearby water sources. Furthermore, airborne particles from livestock facilities, including dust and aerosols, can carry bacteria into the air (Manyi-Loh, C., et al., 2018). These bacteria can travel long distances, settling in other outdoor environments and contributing to the overall pool of multidrug-resistant organisms in the air. Therefore, livestock operations play a significant role in outdoor environmental multidrug resistance by releasing resistant bacteria into the environment, where they can persist and potentially spread to humans, animals, and other organisms, exacerbating the global challenge of antibiotic resistance.

2. Industry

The presence of multidrug-resistant bacteria in industrial factories signifies a concerning trend with far-reaching implications for both worker health and public safety. Research conducted across various industrial sectors, including textiles, food processing, and pharmaceutical manufacturing, has unveiled alarming levels of multidrug-resistant bacteria within these settings (Nikaido, H., 2009). Factors contributing to this phenomenon range from the dense concentration of workers in confined spaces to the extensive use of antimicrobial agents in production processes. For instance, studies have documented high prevalence rates of antibiotic-resistant strains in textile factories, where workers are routinely exposed to contaminated materials and environments (Muteeb, G., et al., 2023). Similarly, food processing plants, reliant on antimicrobials to control microbial growth, have emerged as hotspots for the development and dissemination of multidrug-resistant bacteria.

The detection of multidrug-resistant bacteria in industrial factories underscores the urgent need for proactive measures to address this growing threat. Beyond jeopardizing the health and safety of workers, the presence of these pathogens raises significant concerns regarding their potential transmission beyond factory boundaries (Prestinaci, F., P. Pezzotti, & A. Pantosti, 2015). Workers in such environments face heightened risks of acquiring infections that are increasingly difficult to treat, leading to prolonged illnesses and increased absenteeism (Salam, M.A., et al., 2023). Moreover, the release of contaminated wastewater and airborne emissions from industrial facilities present a risk of environmental contamination, further perpetuating the spread of multidrug-resistant bacteria (Koutsoumanis, K., et al., 2021). Factors contributing to this phenomenon range from the dense concentration of workers in confined spaces to the extensive use of antimicrobial agents in production processes. For instance, studies have documented high prevalence rates of antibiotic-resistant strains in textile factories, where workers are routinely exposed to contaminated materials and environments (Dehari, D., et al., 2023). Similarly, food processing plants, reliant on antimicrobials to control microbial growth, have emerged as hotspots for the development and dissemination of multidrug-resistant bacteria (Host institution: Department of Food, 2018).

3. Wastewater treatment

Wastewater is a significant source of MDR bacteria due to the presence of high concentrations of antibiotics and other pharmaceuticals, which create selective pressure that fosters bacterial resistance. Additionally, wastewater often contains a diverse range of microbial communities that can exchange genetic material, further promoting the spread of resistance (Sambaza, S.S. & N. Naicker, 2023). Research has shown that wastewater from hospitals, pharmaceutical industries, and agricultural runoff often contains significant levels of antibiotics and resistant bacteria (Samrot, A.V., et al., 2023). For example, a study published in Environmental International found that wastewater treatment plants are hotspots for the accumulation and proliferation of antibiotic resistance genes (Pazda, M., et al., 2019). Another study in the Journal of Hazardous Materials demonstrated that the effluents from these plants frequently carry MDR bacteria into natural water bodies, contributing to environmental and public health risks (Kumar, A. and D. Pal, 2018). The presence of antibiotics in wastewater creates an environment where only resistant bacteria can survive and thrive, leading to the selection and proliferation of these strains. This selective pressure accelerates the development of resistance mechanisms within bacterial populations. Furthermore, wastewater treatment plants serve as convergence points for diverse bacterial communities, facilitating horizontal gene transfer, a process by which bacteria exchange genetic material, including resistance genes (Ju, F., et al., 2019). This gene exchange can rapidly spread resistance traits across different bacterial species, compounding the problem. As a result, wastewater acts as a reservoir and a conduit for the dissemination of MDR bacteria into the environment, where they can potentially become airborne and pose significant health risks.

4. Hospital

MDR bacteria in hospitals pose a significant and ongoing challenge to patient care and healthcare systems. Hospitals, designed for healing, inadvertently foster the development and transmission of these resilient pathogens due to factors like antibiotic overuse and patient vulnerability. This phenomenon extends beyond hospital walls, impacting patient outcomes, healthcare costs, and public health. Addressing this challenge requires a multifaceted approach focused on understanding transmission dynamics, preserving antimicrobial efficacy, and enhancing infection control measures.

Numerous studies have documented the widespread presence of MDR bacteria in hospitals worldwide. These pathogens are often detected in various healthcare settings, including intensive care units, surgical wards, and long-term care facilities (Fernández-Martínez, 2021). Factors contributing to their spread include the overuse and misuse of antibiotics, inadequate infection control practices, and the presence of immunocompromised patients. Research has identified common multidrug-resistant organisms such as methicillin-resistant Staphylococcus aureus (MRSA), vancomycin-resistant

Enterococci (VRE), and multidrug-resistant Gram-negative bacteria like Acinetobacter baumannii and Klebsiella pneumoniae within hospital settings (Szabó, S., et al., 2022).

Factors Contributing to Airborne Outdoor MDR

1. Emission Sources

Using the antibiotics in agriculture for livestock growth promotion and disease prevention contributes to the development of antibiotic-resistant bacteria in animals and their surrounding environment. These bacteria can be released into the air through manure management practices or by direct contact with animals. In addition, urbanization and population density can lead to increased microbial contamination from human activities such as sewage disposal, inadequate waste management, and overcrowding, creating environments conducive to the spread of MDR bacteria (Szabó, S., et al., 2022). Moreover, industrial processes, such as wastewater treatment plants, food processing facilities, and pharmaceutical manufacturing, can release MDR bacteria into the air through aerosolization or wastewater discharge, contributing to environmental contamination (Zieliński, W., et al., 2021). Environmental factors such as temperature, humidity, and air currents can influence the survival and dispersion of MDR bacteria in outdoor air. For example, warm and humid conditions may favor bacterial growth and persistence, while wind can facilitate the spread of bacteria over long distances (Qiu, Y., et al., 2022). Improper disposal of animal waste, including from livestock farming operations and pet waste, can introduce MDR bacteria into the outdoor environment (Bai, H., et al., 2022). Runoff from agricultural fields or untreated waste can contaminate water sources and soil, potentially leading to airborne transmission. These factors require a multifaceted approach, including improved agricultural practices to reduce antibiotic use, better waste management strategies, enhanced surveillance of MDR bacteria in environmental reservoirs, and public health interventions to reduce the risk of transmission.

Research indicates that healthcare settings, including hospitals and clinics, are significant contributors to MDR bacterial emissions due to the widespread use of antibiotics and the challenges in infection control protocols (Kumar, N.R., et al., 2024). This is underscored by findings suggesting that improper disposal of medical waste containing MDR bacteria present a notable risk to environmental contamination. Moreover, statistics reveal that livestock farming, where antibiotics are routinely administered for growth promotion and disease prevention, stands out as another major source of MDR bacteria, amplifying their dissemination (Vidovic, N. & S. Vidovic, 2020). Specifically, agricultural practices such as the application of manure, containing antibiotic residues, to fields result in the introduction of

MDR bacteria into water bodies and soil, thus further exacerbating their spread. Urban areas, characterized by dense populations and industrial activities, also significantly contribute to MDR bacterial emissions through air pollution and wastewater discharge (Vassallo, A., et al., 2022). Notably, international travel and trade play a pivotal role in the global transmission of MDR bacteria, with contaminated goods and infected individuals serving as vectors for dissemination across borders (Okeke, I.N. & R. Edelman, 2001). These statistics underscore the urgent need for comprehensive strategies encompassing healthcare practices and agricultural policies to reduce MDR bacterial emissions and combat antibiotic resistance effectively.

2. Environmental Conditions

Environmental conditions play a significant role in the presence and spread of airborne multidrug-resistant (MDR) bacteria. Understanding how these conditions contribute to the development and dissemination of MDR bacteria is crucial for managing public health risks. Environmental conditions can promote airborne MDR bacteria such as warmer temperatures which enhance the growth and survival of bacteria, including MDR strains, in the environment. Heat can also cause bacteria to undergo stress responses that may include the acquisition of resistance genes (Dawan, J. & J. Ahn, 2022). Due to the mutation of some bacteria during the seasons which might also increase the rate of growth consider the stimulation or the triggering factors (Ryall, B., G. Eydallin, & T. Ferenci, 2012). Moreover, the genetic determinants also classify the types and the intensity of resistance. As well, high humidity levels can support the survival and spread of bacteria in the air, making them more likely to be inhaled by humans or animals (Guarnieri, G., et al., 2023). The strong winds and storms can disperse bacteria over wide areas, potentially spreading MDR bacteria from one location to another. When wind speed is high, it can disperse bacteria over larger distances, increasing the likelihood of encountering different environments and potentially exchanging genetic material with other bacteria (Ruiz-Gil, T., et al., 2020). This can lead to the spread of antibiotic resistance genes among bacteria. Additionally, wind speed can impact the moisture content of the environment. High wind speeds can cause desiccation, drying out bacteria and reducing their ability to survive and reproduce (Acosta-Martínez, V., et al., 2015). On the other hand, low wind speeds can lead to stagnant air, creating conditions favorable for bacterial growth and proliferation (Acosta-Martínez, V., et al., 2015).

3. Urbanization and Human Activity

Urbanization and various human activities significantly contribute to the spread of airborne outdoor MDR bacteria, as evidenced by recent research on antibiotic resistance genes (ARGs) in urban watersheds. The study found that the relative abundance of ARGs in water increased significantly with urbanization, with urban areas exhibiting nearly fifteen times higher ARG levels than rural areas (Zhu, L., et al., 2022). This rise is attributed to factors such as higher population density, increased medical facilities, and greater discharge of domestic sewage, which all lead to the release of antibiotics and other pollutants into the environment (Kusi, J., et al., 2022). Construction and demolition activities in urban areas further release dust and particulates that can carry MDR bacteria (Tao, G., et al., 2022). Moreover, global travel and trade facilitate the spread of MDR bacteria, introducing new strains into different regions (Bokhary, H., et al., 2021). In addition to the previously mentioned findings, another study provides compelling evidence about the impact of urbanization on the spread of MDR bacteria. According to research published in Nature Microbiology, urban environments have a significantly higher prevalence of antibiotic-resistant bacteria compared to rural areas (Zhang, Z., et al., 2022). The study, which analyzed samples from various cities worldwide, found that urban areas had up to 50% higher concentrations of ARGs in their water systems compared to rural areas (Hendriksen, R.S., et al., 2019). This is primarily due to increased human activity, such as higher rates of antibiotic use in densely populated regions, inadequate waste management, and greater industrial pollution. This further underscores the critical role urbanization plays in facilitating the spread of MDR bacteria and the urgent need for targeted interventions to reduce this growing public health threat. These findings focus on the need for comprehensive mitigation strategies to address the environmental and public health risks associated with the urbanization-driven dissemination of MDR bacteria.

4. Pollutants and Particulate Matter

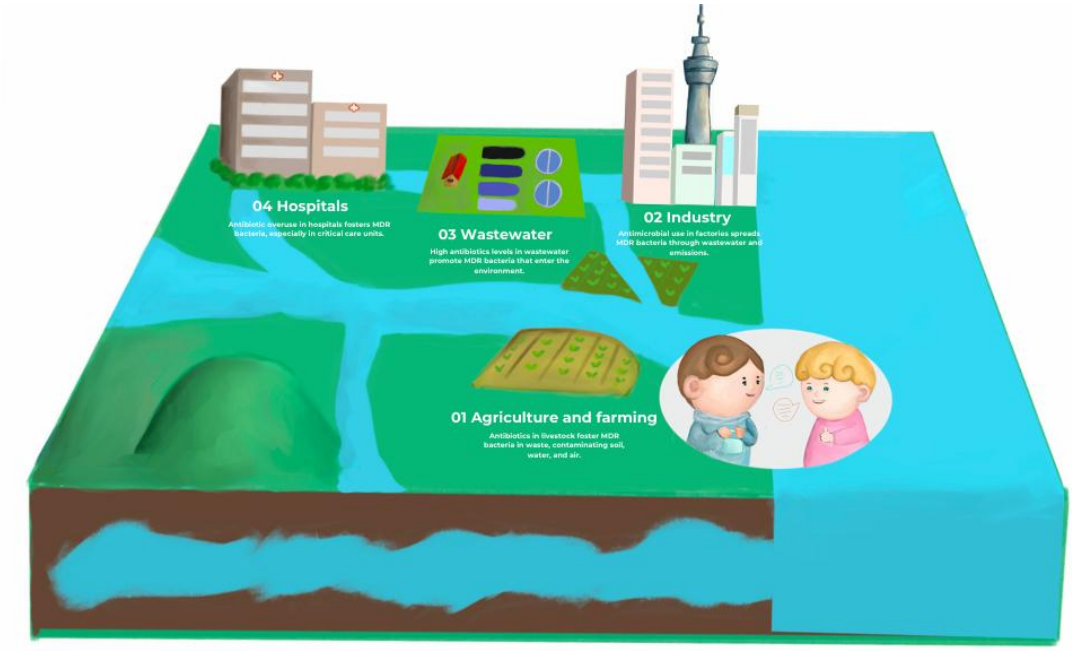
The impact of particulate matter (PM)2·5 pollution on the dissemination of antibiotic resistance is increasingly recognized as a significant global health concern. Studies have revealed that PM2·5 contains a diverse array of antibiotic-resistant bacteria and antibiotic-resistance genes, which can be directly inhaled by humans, leading to respiratory-tract injury and infection (Hendriksen, R.S., et al., 2019). Furthermore, PM2·5 pollution has been shown to increase cell-membrane permeability, thereby enhancing the efficiency of horizontal gene transfer and accelerating the evolution and exchange of antibiotic-resistance elements among bacterial pathogens (Zhou, Z., et al., 2023). Despite these findings, there is a dearth of quantitative data on the contribution of PM2·5 to global antibiotic resistance, limiting our understanding of its full impact on human health. Through comprehensive univariate and multivariate analysis, recent research has provided the first global estimates of the association between PM2·5 pollution and antibiotic resistance. This analysis revealed a positive correlation between PM2·5 levels and antibiotic resistance, underscoring the role of air pollution in exacerbating the spread of antibiotic resistance worldwide (Zhou, Z., et al., 2023). Moreover, the study focused on the potential health and economic benefits of controlling air pollution to reduce PM2·5 concentrations, suggesting that such measures could help reduce the burden of antibiotic resistance on a global scale (Zhou, Z., et al., 2023). These findings emphasize the urgent need for concerted efforts to address the environmental factors contributing to antibiotic resistance and implement effective strategies to safeguard public health.

Results

The review reveals that airborne MDR bacteria are spread through agriculture, industry, wastewater treatment, and healthcare settings. Agriculture, particularly livestock farming, is a major source of resistant bacteria, which are released through manure and airborne particles. Industrial emissions and wastewater from factories further contribute to the environmental spread. Wastewater treatment plants, while intended to purify water, facilitate resistance through antibiotic accumulation and gene transfer. Hospitals, due to improper waste disposal and infection control, exacerbate the spread. Environmental factors such as wind, humidity, and pollution amplify this transmission, with PM2.5 playing a significant role in the airborne dissemination of MDR bacteria.

Discussion

The proliferation of airborne MDR bacteria presents a multifaceted global challenge, driven by agriculture, industry, wastewater management, and healthcare practices. Agriculture's extensive use of antibiotics in livestock farming creates a breeding ground for resistant bacteria that spread via air and water. Similarly, industries contribute to environmental contamination through emissions and wastewater, necessitating stricter regulations. Wastewater treatment plants, despite their cleaning role, exacerbate bacterial resistance due to antibiotic accumulation and microbial gene transfer. Hospitals, due to improper waste management and infection control, also contribute significantly to the problem. Environmental factors such as temperature, humidity, and wind further aid the long-distance spread of MDR bacteria, while urbanization and human activities intensify the problem. Air pollution, particularly PM2.5, serves as a vector for antibiotic resistance, complicating respiratory health and accelerating gene transfer between bacteria. Addressing the issue requires a coordinated effort across sectors. Agricultural antibiotic use must be reduced, industrial and wastewater practices reformed, and hospital waste management improved. Additionally, environmental monitoring and air pollution controls must be enhanced to limit the spread of MDR bacteria and safeguard public health. However, the global spread of airborne MDR bacteria is a complex issue requiring immediate action across agriculture, industry, healthcare, and environmental management. Implementing stricter regulations and promoting responsible practices can reduce the risk and protect public health.



Sources of Multidrug-Resistant (MDR) Bacteria.

Figure 1 represents the source of multidrug resistant bacteria including hospitals, where advance antibiotic use and untreated hospital wastewater, and agricultural activities, where antibiotics are heavily used in livestock and crops plants, leading to environmental contamination. Industrial and municipal waste, including effluents from pharmaceutical industries and sewage systems, also play a major role in dispersing MDR bacteria into soil and water bodies. Natural environments such as soil, rivers, and oceans act as reservoirs, further amplified by airborne transmission through bioaerosols in urban and industrial areas. Community environments, including public spaces and human-to-human transmission, and wildlife interactions also facilitate the spread of MDR bacteria, making this a widespread ecological and public health challenge.

Conclusion

Airborne multidrug-resistant (MDR) bacteria present a growing global health threat, fueled by antibiotic overuse in agriculture, industrial emissions, improper wastewater treatment, and poor healthcare waste management. Environmental factors, such as wind and pollution, exacerbate the spread. To reduce this risk, stricter regulations on antibiotic use, improved waste management, enhanced industrial and healthcare practices, and better environmental monitoring are essential. Coordinated global efforts are needed to curb the spread of MDR bacteria and safeguard public health.

Applications

The research on airborne multidrug-resistant (MDR) bacteria can be applied in real life by informing various sectors to implement better practices and regulations. In agriculture, farmers can reduce the overuse of antibiotics in livestock farming, thus limiting the development and environmental spread of resistant bacteria. Industrial sectors, particularly in textiles, pharmaceuticals, and food processing, can enforce stricter hygiene protocols and improve waste management to prevent the release of MDR bacteria through emissions and wastewater. Healthcare facilities can strengthen infection control measures and ensure proper disposal of medical waste to prevent bacteria from escaping into outdoor environments. Policymakers can develop regulations to reduce air pollution, particularly particulate matter (PM2.5), which plays a significant role in the transmission of MDR bacteria and improve urban waste management systems. Upgrading wastewater treatment plants with advanced technologies will further help remove antibiotics and MDR bacteria, preventing their release into water bodies and the air. Public health agencies can integrate environmental monitoring systems to track the spread of airborne MDR bacteria, allowing for early detection and control of potential outbreaks. By applying these strategies, the research can contribute to reducing the global spread of MDR bacteria and safeguarding public health.

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