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Research Article

DETECTION OF VIRULENCE AND ANTIBIOTIC RESISTANCE GENES IN SOME BACTERIAL ISOLATES FROM DUMPSITES- A REVIEW

[1*]Obot Uduak Malachy, [2]Daniel Ugbomoiko

[1,2]Igbinedion University Okada, Nigeria. Department of Medical Laboratory Science, College of Health Sciences.

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Abstract

Dumpsites remain a major environmental and public health concern, particularly in developing countries where inadequate waste management systems encourage the widespread use of open dumping. These sites receive mixed municipal, industrial, medical, and pharmaceutical wastes, creating favourable conditions for the proliferation of microorganisms, including pathogenic and antibiotic-resistant bacteria. The decomposition of waste generates leachates, gases, and other pollutants that contaminate soil, groundwater, and air, leading to ecosystem degradation and increased health risks for nearby communities. Common bacterial isolates found in dumpsites include Escherichia coli, Klebsiella pneumonia, Enterobacter spp., Proteus spp., Salmonella spp., Staphylococcus aureus, and Pseudomonas aeruginosa, many of which possess multidrug resistance traits. Dumpsites also serve as reservoirs of antibiotic resistance genes (ARGs) such as blaTEM, blaSHV, blaCTX-M, mecA, tetA, tetM, sul1, and sul2, which can spread through horizontal gene transfer mechanisms. The persistence of these genes contributes significantly to antimicrobial resistance, resulting in treatment failure, increased healthcare costs, prolonged hospital stays, and higher mortality rates. Detection of ARGs is commonly achieved through culture-based methods, polymerase chain reaction (PCR), quantitative PCR, sequencing technologies, and metagenomic approaches. Effective management of dumpsites requires the adoption of engineered sanitary landfills, waste segregation, recycling, environmental monitoring,

remediation strategies, and strong regulatory frameworks. Overall, improving waste management practices is essential for reducing environmental contamination, limiting the spread of antimicrobial resistance, and protecting both human health and ecosystem sustainability.
Keywords: Dumpsite, polymerase chain reaction, Escherichia coli, Klebsiella pneumoniae, Enterobacter spp., Proteus spp., Salmonella spp., Staphylococcus aureus, and Pseudomonas aeruginosa.

Introduction

Waste generation is an inevitable consequence of human activities, and its increasing volume due to population growth, urbanization, and industrialization has become a major environmental challenge worldwide (Iheanacho et al., 2022). In Nigeria, inadequate waste management systems and the absence of modern landfill facilities have led to the widespread use of open dumpsites for waste disposal (Adedara et al., 2023). Poorly managed dumpsites contribute to environmental pollution through the release of leachates, offensive odours, and the attraction of disease vectors, while also contaminating surrounding soil and groundwater (Ekundayo et al., 2025).

Dumpsites provide favourable environments for the growth of microorganisms, including pathogenic bacteria and fungi, many of which can contaminate food and cause diseases in humans (Selvarajan et al., 2022). In rapidly growing towns such as Keffi, indiscriminate disposal of household, hospital, and pharmaceutical wastes has further encouraged the emergence of pathogenic and antibiotic-resistant bacteria (Apake et al., 2024). Antimicrobial resistance (AMR) is now a major global public health threat, with resistant bacteria increasingly linked to environmental reservoirs such as waste dumpsites (Haribabu, 2025). Antimicrobial resistance (AMR) has become a major global health threat, accounting for approximately 1.27 million deaths directly and contributing to nearly 4.95 million deaths worldwide. The World Health Organization has warned that the continued rise in antibiotic resistance could result in a post-antibiotic era where common infections become difficult or impossible to treat (Haribabu, 2025).

Chung et al., 2018 study demonstrated that landfill leachates contain antibiotic residues capable of promoting the development of antibiotic-resistant bacteria. In Nigeria, improper disposal of antibiotics and chemical wastes creates selective pressure that enhances bacterial resistance and the spread of resistance genes such as blaTEM, mecA, tetA, and sul1 through leachates into the environment. These findings highlight the public health risks associated with poorly managed dumpsites and the need for improved waste management practices (Adekanmbi et al., 2021).

Dumpsites

Dumpsites are designated areas used for the disposal of municipal, industrial, and sometimes hazardous wastes. Unlike sanitary landfills, which are engineered with systems for leachate and gas control, traditional dumpsites are often poorly regulated and characterized by indiscriminate accumulation of mixed wastes (Nanda & Berruti, 2021). In developing countries such as Nigeria, waste collection and management remain major environmental challenges due to rapid urbanization, poor infrastructure, and inadequate waste disposal practices (Abubakar et al., 2022).

Municipal wastes in these regions commonly include household refuse, plastics, metals, food remnants, electrical appliances, medical wastes, and other hazardous materials, which are often disposed of without sorting, recycling, or treatment. Improper waste disposal contributes to environmental pollution, aesthetic degradation, and serious public health risks, with solid wastes commonly found along roadsides, drainage channels, and vacant lands in major Nigerian cities (Gautam et al., 2024).

Beyond waste accumulation, dumpsites also reflect socio-economic and environmental challenges associated with poor urban planning and weak waste management systems. Open dumpsites are particularly associated with leachate contamination, pathogen proliferation, and air pollution resulting from uncontrolled gas emissions. Although some controlled dumpsites employ limited management practices such as periodic covering of waste, the risks of environmental contamination and disease transmission still persist (Zondi, 2025).

Types of Dumpsites

Open dumpsites

Open dumpsites are the most basic and environmentally hazardous form of waste disposal, where mixed wastes are deposited without proper engineering controls or environmental protection measures. They commonly develop in areas with poor waste management infrastructure, rapid urbanization, and limited financial resources. Open dumpsites often contain household refuse, plastics, metals, electronic waste, industrial by-products, and hazardous materials such as medical and chemical wastes. In the absence of proper liners and waste containment systems, rainfall produces toxic leachates that contaminate surrounding soils and groundwater with heavy metals, organic pollutants, and pathogenic microorganisms (Koliyabandara et al., 2024).

The decomposition of organic wastes in open dumpsites also releases harmful gases such as methane, carbon dioxide, and other toxic emissions that contribute to air pollution and respiratory illnesses. Frequent fires and uncontrolled waste burning further degrade air quality, while exposed waste attracts disease vectors including rodents, flies, and mosquitoes that spread infections such as cholera, typhoid, and diarrheal diseases (Rastogi et al., 2020). In addition, open dumpsites negatively affect nearby communities by reducing land value, contaminating agricultural lands, and exposing waste scavengers and low-income residents to serious health risks.

The persistence of open dumpsites reflects inadequate environmental governance, weak enforcement of waste management regulations, and insufficient investment in sustainable waste disposal systems. Consequently, they remain major environmental and public health concerns, highlighting the need for improved waste management strategies and the adoption of controlled dumpsites and sanitary landfills (Aluko et al., 2022).

Controlled dumpsites

Controlled dumpsites are transitional waste disposal systems that provide a moderate improvement over open dumping but lack the advanced engineering features of sanitary landfills. They involve limited operational management practices such as controlled access, periodic covering of waste with soil, basic waste compaction, and partial separation of recyclable materials. These measures help reduce odour, wind dispersal, and the spread of disease vectors; however, controlled dumpsites often lack proper liners, leachate collection systems, gas management infrastructure, and environmental monitoring systems, allowing continued contamination of soil and groundwater (Nanda & Berruti, 2021).

In many developing countries, controlled dumpsites serve as practical alternatives where financial and technical limitations hinder the establishment of sanitary landfills. They represent an important step toward improved waste governance by promoting better waste management practices and reducing the environmental impacts associated with open dumpsites. Despite these improvements, significant environmental and public health risks remain due to methane emissions, scavenging activities, and persistent exposure to harmful pollutants and disease vectors. The effectiveness of controlled dumpsites largely depends on proper regulation, technical expertise, and sustained governmental support for upgrading waste management systems (Awino & Apitz, 2024).

Sanitary landfills

Sanitary landfills are the most advanced and engineered form of solid waste disposal, designed to minimize environmental and public health risks associated with open and controlled dumpsites. They are constructed with multilayer protective liners made of compacted clay, geomembranes, and geotextiles that prevent leachate from contaminating soil and groundwater. In addition, they are equipped with leachate collection and treatment systems, as well as structured gas management facilities that capture methane and other landfill gases for flaring or energy recovery, thereby reducing greenhouse emissions and enabling potential energy use (Ozbay et al., 2021).

Operationally, waste is compacted, placed in designated cells, and covered daily to reduce odour, vector breeding, fire hazards, and windblown litter. Sanitary landfills also include environmental monitoring systems that assess groundwater quality, air emissions, and structural stability throughout their operational and post-closure phases. Despite their high effectiveness in pollution control and public health protection, they require substantial financial investment, technical expertise, and strong regulatory enforcement, which can limit their adoption in developing regions. Nevertheless, they remain the global standard for sustainable waste management due to their long-term environmental protection and resource recovery benefits (Kamaruddin et al., 2022).

Environmental Impact of Dumpsites

Dumpsites generate wide-ranging environmental impacts due to their unregulated nature and inability to properly manage waste decomposition by-products, affecting air, water, soil, ecosystems, and human communities (Akai-Tetteh, 2021).

Air pollution is one of the most immediate effects, arising from waste decomposition, open burning, and gas emissions. Decomposing waste releases greenhouse gases such as methane and carbon dioxide, as well as harmful gases like hydrogen sulfide and ammonia. Open burning further produces particulate matter, dioxins, and toxic compounds that contribute to respiratory and cardiovascular diseases and global climate change (Bamotra et al., 2025). In addition, dust, landfill fires, and volatile emissions degrade air quality and pose risks to both residents and workers (Hroncová et al., 2020).

Water contamination occurs mainly through leachate infiltration into soil and groundwater. This leachate contains heavy metals, nutrients, pathogens, pharmaceuticals, and persistent organic pollutants, which pollute drinking water sources and aquatic ecosystems (Njewa et al., 2025). It also leads to eutrophication, biodiversity loss in aquatic systems, and long-term health risks such as cancers, neurological disorders, and infections in exposed populations (Islam & Quaff, 2024).

Soil contamination results from the accumulation of heavy metals, hydrocarbons, plastics, and toxic chemicals that persist for decades. These pollutants reduce soil fertility, disrupt microbial activity, alter soil structure, and impair plant growth, ultimately affecting agricultural productivity and food safety. Contaminants may also enter the food chain through crops and livestock, increasing human exposure through biomagnification (Njewa et al., 2025).

Dumpsites also significantly impact biodiversity and ecosystem stability. They destroy natural habitats, reduce plant diversity, and favor invasive or pollution-tolerant species. Wildlife is exposed to toxins through ingestion of contaminated waste, leading to disease, reproductive failure, and death. In addition, dumpsites attract disease vectors such as rodents and insects, disrupting ecological balance and increasing disease transmission risks (Chavan et al., 2022).

Finally, dumpsites have major socio-economic consequences. They contribute to public health burdens, reduce property values, discourage investment, and reinforce environmental inequality, as low-income communities are disproportionately affected. While they support informal livelihoods such as scavenging, these activities are unsafe and socially precarious. Overall, dumpsites hinder urban development, strain government resources, and reduce the economic potential of land, highlighting the need for improved waste management systems and sustainable urban planning (Weldeyohanis et al., 2022).

Public Health risks associated with Dumpsites

Public health risks associated with dumpsites are extensive due to the presence of biological, chemical, and physical hazards in unmanaged waste. Dumpsites act as reservoirs for pathogens such as bacteria, viruses, fungi, and parasites, which spread through contaminated air, water, soil, and disease vectors. As a result, nearby communities are highly susceptible to gastrointestinal infections, cholera, typhoid, diarrheal diseases, and parasitic infestations, particularly where leachate contaminates drinking water sources. Air pollution from decomposing waste also contributes to respiratory and cardiovascular conditions, including asthma and chronic bronchitis. In addition, open burning releases toxic substances such as dioxins, heavy metals, and polycyclic aromatic hydrocarbons, which are linked to cancer, reproductive disorders, immune suppression, and other chronic health effects (Oluwagbayide et al., 2024).

Dumpsites also promote vector-borne diseases by providing breeding grounds for mosquitoes, flies, and rodents that transmit infections such as malaria, dengue fever, Lassa fever, and leptospirosis. Vulnerable groups, including children, pregnant women, and the elderly, face higher risks due to prolonged exposure and weaker immunity, especially in low-income communities where dumpsites are often located near residential areas. Occupational exposure is also a major concern for waste pickers and informal recyclers who work without protective equipment, increasing their risk of injury, infection, and long-term toxic exposure. Overall, dumpsites contribute significantly to disease burden, reduced life expectancy, and long-term public health challenges (Nta et al., 2020).

Management and Mitigation Strategies for Dumpsites

Effective mitigation of dumpsite impacts requires an integrated approach combining engineering solutions, policy enforcement, environmental monitoring, and community participation to address both immediate hazards and underlying waste management challenges (Mokotong & Ribeiro, 2023).

A key strategy is the transition from open dumping to engineered waste disposal systems such as sanitary landfills. This involves proper waste containment using liners, leachate collection systems, and gas recovery technologies that reduce soil and groundwater contamination, control emissions, and improve waste handling efficiency. Additional practices such as daily covering, compaction, recycling integration, and site closure and rehabilitation further enhance environmental protection. Although costly and technically demanding, this transition significantly reduces pollution and improves public health outcomes (Al-Wabel et al., 2022).

Waste segregation at source is another fundamental strategy that reduces the volume of mixed waste reaching dumpsites. By separating organic, recyclable, hazardous, and electronic wastes at the point of generation, communities can reduce pollution, improve recycling efficiency, and support composting and energy recovery systems. It also lowers occupational risks for waste handlers and improves the efficiency of downstream waste facilities. Successful implementation depends on public awareness, policy support, and appropriate infrastructure such as color-coded bins and collection systems (Yuan et al., 2024).

Resource recovery and circular economy practices further minimize dumpsite reliance by promoting reuse, recycling, composting, and material recovery from waste streams. These approaches reduce greenhouse gas emissions, conserve natural resources, and create economic opportunities through recycling industries and green jobs. Circular systems also encourage sustainable production and consumption patterns that reduce waste generation at its source, thereby supporting long-term environmental sustainability (Nalladiyil & Babu, 2024).

Remediation and rehabilitation strategies focus on restoring contaminated dumpsite environments through techniques such as bioremediation, phytoremediation, soil stabilization, and engineered capping. These interventions reduce pollutant mobility and prevent further environmental contamination. Rehabilitation also includes reshaping landforms, re-vegetation, gas management, and long-term monitoring, with some closed sites being converted into parks, energy farms, or other productive land uses (Bhattacharya et al., 2023).

Policy and regulatory frameworks are essential for guiding waste management practices, enforcing standards, and preventing illegal dumping. Effective policies regulate waste handling, promote producer responsibility, support recycling incentives, and ensure environmental compliance through inspections and penalties. Strong governance, adequate funding, and public participation are critical for successful implementation and sustainability of waste management systems (Unegbu & Yawas, 2024).

Finally, monitoring and surveillance systems ensure continuous assessment of environmental conditions at dumpsites. These include tracking leachate quality, gas emissions, soil and water contamination, and structural stability using tools such as GIS, sensors, and remote sensing. Community reporting and institutional oversight complement technological monitoring, enabling early detection of hazards and timely intervention to prevent environmental and health risks (Oyebode et al., 2023).

Common Bacterial Isolates in Dumpsites

Dumpsites host a diverse and potentially hazardous range of bacterial isolates due to the decomposition of mixed waste materials. Commonly identified organisms include members of the Enterobacteriaceae family such as Escherichia coli, Klebsiella pneumoniae, Enterobacter spp., Proteus spp., and Salmonella spp., which thrive in organic-rich environments and are spread through leachate, soil, water, and disease vectors. These enteric bacteria are often associated with fecal contamination and are linked to gastrointestinal infections, with E. coli serving as an indicator of fecal pollution, while K. pneumoniae and Enterobacter spp. are notable for their persistence and multidrug resistance potential (Selvarajan et al., 2022).

Other important isolates include Staphylococcus aureus (including MRSA strains), Bacillus spp., and Clostridium spp., which originate from medical waste and environmental sources and can survive harsh conditions through spore formation. Pseudomonas aeruginosa and related non-fermenting bacteria are also common due to their ability to degrade complex pollutants and their intrinsic resistance to many antibiotics. Biomedical waste further introduces high-risk pathogens such as Shigella spp., Vibrio spp., and drug-resistant Acinetobacter spp., increasing infection risks (Manandhar et al., 2021).

The coexistence of diverse bacterial species in dumpsites promotes horizontal gene transfer, enabling the exchange of virulence and antibiotic resistance genes. This process contributes to the emergence and spread of multidrug-resistant organisms, making dumpsites significant environmental reservoirs of public health concern beyond their immediate surroundings (Manandhar et al., 2021).

Common Antibiotic resistance genes in some Bacterial isolates

Antibiotic resistance genes (ARGs) in bacterial isolates from dumpsites are increasingly recognized as a major environmental and public health concern because dumpsites function as reservoirs where diverse microbial populations, antibiotics, and chemical pollutants interact. In these environments, bacteria are continuously exposed to selective pressures from residual antibiotics originating from discarded pharmaceuticals, hospital waste, household medicines, and other improperly disposed materials. This exposure, combined with heavy metals and toxic compounds present in waste, promotes the survival and enrichment of resistant bacteria and the persistence of resistance genes even outside clinical settings (Anand et al., 2021).

Among the most widely reported genes are blaTEM, blaSHV, and blaCTX-M, which encode extended-spectrum beta-lactamases responsible for resistance to penicillins and cephalosporins (El Aila et al., 2023). Others include mecA, associated with methicillin-resistant Staphylococcus aureus (MRSA), as well as tetA and tetM, which confer resistance to tetracyclines, and sul1 and sul2, which are linked to sulfonamide resistance and often associated with mobile genetic elements that facilitate their spread (Abdulmanea et al., 2025). Aminoglycoside resistance genes such as aadA and related modifying enzymes have also been identified in environmental isolates from dumpsites. The persistence and spread of these genes in dumpsite ecosystems are largely driven by horizontal gene transfer mechanisms, including conjugation, transformation, and transduction. The high microbial density in decomposing waste, together with the presence of plasmids, transposons, and integrons, enhances gene exchange between environmental and pathogenic bacteria. This makes dumpsites important hotspots for genetic recombination and the evolution of multidrug-resistant organisms. Additionally, pollutants such as heavy metals and disinfectant residues exert co-selective pressure, meaning that bacteria exposed to these substances may retain antibiotic resistance genes even in the absence of antibiotics, further strengthening resistance persistence in the environment (Nimaichand et al., 2023).

Antibiotic resistance genes (ARGs) impact on health

Antibiotic resistance genes (ARGs) have significant and wide-ranging impacts on human health because they reduce the effectiveness of antibiotics used to treat bacterial infections. When bacteria acquire genes such as blaTEM, blaSHV, mecA, tetA, and sul1, they become resistant to commonly used antibiotics, making infections more difficult to control. As a result, diseases that were once easily treated such as urinary tract infections, respiratory infections, wound infections, and diarrheal diseases can become prolonged, more severe, and in some cases life-threatening (Lathakumari et al., 2024).

One major health impact of ARGs is treatment failure. Patients infected with resistant bacteria often do not respond to first-line antibiotics, requiring the use of stronger, more expensive, and sometimes more toxic alternative drugs. This increases the risk of side effects and reduces treatment success rates. In severe cases, multidrug-resistant infections can lead to complications such as sepsis, organ failure, and increased mortality, especially in vulnerable populations such as children, the elderly, and immunocompromised individuals (Anand et al., 2021). ARGs also increase the burden on healthcare systems by prolonging hospital stays and raising treatment costs. Infections caused by resistant organisms require more laboratory testing, longer monitoring, and combination antibiotic therapy, all of which place financial strain on both patients and healthcare providers. This is particularly critical in low- and middle-income countries where access to advanced antibiotics and diagnostic tools may already be limited (Anand et al., 2021).

Another important concern is the spread of ARGs from environmental sources such as dumpsites into human populations. These genes can be transferred through contaminated water, food, soil, airborne dust, and direct contact with waste. Once introduced into humans, resistant bacteria can circulate within communities and healthcare facilities, increasing the overall prevalence of antimicrobial resistance. This creates a continuous cycle of transmission between the environment, animals, and humans. Furthermore, many ARGs are located on mobile genetic elements such as plasmids and integrons, which allow them to spread rapidly between different bacterial species. This accelerates the emergence of multidrug-resistant organisms, making infections even harder to manage (Song et al., 2023).

Detection of Antibiotic resistance genes (ARGs)

The detection of antibiotic resistance genes (ARGs) is a critical component of understanding and monitoring antimicrobial resistance in both clinical and environmental settings. ARG detection involves identifying specific genes in bacterial isolates or environmental samples that confer resistance to antibiotics. This process helps researchers determine the presence, distribution, and potential risk of resistant bacteria, especially in high-risk environments such as dumpsites, wastewater, and hospitals (Djordjevic et al., 2024).

Traditionally, ARG detection begins with culture-based microbiological methods, where bacteria are first isolated from samples such as soil, water, or waste. These isolates are then subjected to antibiotic susceptibility testing using methods like disk diffusion, broth dilution, or agar dilution to determine their resistance profiles. While these phenotypic methods do not directly identify resistance genes, they provide important preliminary evidence of resistance patterns that guide further molecular analysis (Yamin et al., 2023). Molecular techniques are the most reliable and widely used approaches for detecting ARGs. Polymerase chain reaction (PCR) is the most common method, allowing for the amplification and detection of specific resistance genes such as blaTEM, blaSHV, mecA, tetA, and sul1. Conventional PCR confirms the presence or absence of these genes, while real-time PCR (qPCR) provides quantitative data on gene abundance, making it useful for assessing the level of contamination in environmental samples. These methods are highly sensitive, rapid, and specific, making them suitable for both clinical diagnostics and environmental surveillance (Kaprou et al., 2021).

Advanced molecular techniques such as multiplex PCR allow simultaneous detection of multiple ARGs in a single reaction, improving efficiency and reducing cost (Harris et al., 2023). Sequencing technologies, including Sanger sequencing and next-generation sequencing (NGS), provide deeper insights by identifying known and novel resistance genes within complex microbial communities (Li and Yan, 2021). Metagenomic analysis is particularly important in environmental studies because it allows researchers to detect ARGs directly from samples without the need for culturing bacteria, thereby capturing a broader diversity of resistance genes present in dumpsites and other environments (De Abreu et al., 2021). Other modern approaches include quantitative metagenomics, microarray-based detection, and whole-genome sequencing (WGS), which offer high-resolution data on gene location, genetic context, and mobile genetic elements such as plasmids and integrons. These techniques help in understanding how ARGs spread among bacteria through horizontal gene transfer mechanisms (Aldea et al., 2025).

Conclusion

In conclusion, dumpsites represent significant sources of environmental pollution and public health risks due to poor waste management practices. They support the survival of diverse bacterial isolates and the spread of antibiotic resistance genes, which contribute to antimicrobial resistance and complicate disease treatment. The continuous release of contaminants into air, water, and soil further worsens ecosystem degradation and increases exposure risks to surrounding communities. Therefore, effective waste management strategies such as engineered landfills, waste segregation, and strict regulatory enforcement are essential to reduce these impacts and safeguard environmental and human health.

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