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TRACING THE EMERGENCE OF ANTIMICROBIAL-RESISTANT BACTERIA IN PUBLIC TOILETS ACROSS URBAN NIGERIA.

Ochechi Joseph Ugbede
Department of Public Health, Sciences Faculty of Allied Health
State University of Medical and Applied Sciences, Enugu, Nigeria
joseph.ochechi@sumas.edu.ng

Abstract

The emergence of antimicrobial-resistant (AMR) bacteria in environmental settings poses a growing threat to public health, especially in rapidly urbanizing regions of Nigeria. This study investigates the prevalence, resistance profiles, and genetic characteristics of AMR bacteria isolated from public toilets across six major Nigerian cities. Using a cross-sectional design, 1,080 samples were collected from 180 public toilets, including surface swabs and wastewater. Bacterial isolates such as *Escherichia coli*, *Klebsiella pneumoniae*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa* demonstrated high rates of multidrug resistance (MDR), with over 58% of all isolates classified as MDR. Molecular analysis identified key resistance genes, including *blaCTX-M*, *tetA*, *qnrB*, and *blaNDM*, indicating significant dissemination of clinically relevant resistance mechanisms. Resistance was most pronounced in toilets located in markets and motor parks, suggesting strong correlations with hygiene conditions and user density. These findings underscore public toilets as critical yet underrecognized reservoirs for AMR pathogens in Nigeria, highlighting the urgent need for improved sanitation infrastructure, regulatory enforcement, and environmental AMR surveillance.

Keywords: Antimicrobial resistance, Public toilets, Nigeria, Environmental surveillance, Multidrug-resistant bacteria, AMR genes, Urban sanitation, Public health, Fecal contamination, Antibiotic stewardship

Introduction

The rise of antimicrobial-resistant (AMR) bacteria poses a significant global public health threat, undermining the effectiveness of antibiotics and complicating the treatment of infectious diseases (World Health Organization [WHO], 2023). In Nigeria, urban areas have become hotspots for the emergence and spread of AMR pathogens due to high population density, inadequate sanitation infrastructure, and widespread antibiotic misuse (Adebayo et al., 2024). Public toilets, frequently used by diverse populations and often characterized by poor hygiene conditions, represent critical reservoirs and transmission points for AMR bacteria (Eze & Okafor, 2023). These communal facilities, especially in densely populated Nigerian cities, provide environments conducive to bacterial survival and gene exchange, fostering resistance development (Oluwole et al., 2022).

Despite growing awareness of AMR in clinical settings, limited research has focused on environmental reservoirs such as public toilets in Nigeria, where exposure risk to resistant bacteria is high but understudied (Ibrahim & Musa, 2023). Urban public toilets often suffer from inadequate cleaning protocols and improper waste disposal, contributing to contamination with multi-drug resistant organisms (Chukwu & Nwankwo, 2024). Furthermore, the unregulated sale and misuse of antibiotics in Nigeria exacerbate resistance pressures in these communal environments (Akinyemi et al., 2023).

Understanding the patterns and drivers of AMR emergence in public toilets is essential to inform public health interventions and antimicrobial stewardship strategies in Nigeria's urban centers. This study aims to trace the occurrence and characterize the antimicrobial resistance profiles of bacteria isolated from public toilets across selected cities in Nigeria, thereby highlighting environmental contributors to the AMR crisis and identifying potential points for targeted sanitation and policy actions.

Problem Statement

The emergence and spread of antimicrobial-resistant (AMR) bacteria pose a significant global public health threat, with urban environments in low- and middle-income countries like Nigeria being particularly vulnerable (Ojo et al., 2023). Public toilets in densely populated urban areas serve as critical hotspots for microbial transmission due to high human traffic and often inadequate sanitation infrastructure (Adebayo & Oladipo, 2024). Despite their importance, there is limited empirical data on the prevalence and types of AMR bacteria colonizing public toilet environments in Nigerian cities. This knowledge gap hinders the development of targeted interventions to curb environmental reservoirs of resistance (Nwankwo et al., 2022).

Urban Nigerian public toilets frequently suffer from poor maintenance, suboptimal hygiene practices, and lack of effective disinfection protocols, creating ideal conditions for resistant pathogens to thrive and disseminate (Eze et al., 2023). Moreover, increasing antibiotic misuse in Nigeria contributes to heightened selective pressure, accelerating resistance evolution in environmental bacteria (Ibrahim & Musa, 2023). The role of public toilets as potential sources of community-acquired infections, particularly those caused by multi-drug resistant organisms, remains underexplored, raising concerns about public health risks and the efficacy of current sanitation policies (Umar & Okeke, 2024).

This research aims to trace the emergence of antimicrobial-resistant bacteria in public toilets across urban Nigeria, addressing the critical need to understand environmental reservoirs of AMR and inform sanitation and antibiotic stewardship strategies to mitigate the spread of resistant infections.

Literature Review

1. Introduction to Antimicrobial Resistance (AMR)

Antimicrobial resistance (AMR) occurs when microorganisms such as bacteria evolve to survive exposure to drugs designed to kill them, rendering treatments ineffective (WHO, 2023). AMR is a growing global health crisis, threatening to reverse decades of medical progress by increasing morbidity, mortality, and healthcare costs worldwide (CDC, 2022). Bacteria develop resistance through multiple mechanisms, including enzymatic degradation of antibiotics, modification of drug targets, increased efflux pump activity, and horizontal gene transfer of resistance elements (Munita & Arias, 2022). Developing countries face disproportionate challenges due to limited diagnostic capacity, widespread misuse of antibiotics, and poor infection control (Okeke et al., 2021). Historically, AMR emerged soon after the introduction of the first antibiotics in the early 20th century and has escalated with antibiotic overuse and environmental factors (Laxminarayan et al., 2020). The WHO's Global Antimicrobial Resistance and Use Surveillance System (GLASS) and CDC reports emphasize increasing prevalence of multidrug-resistant pathogens globally, with sub-Saharan Africa exhibiting rapid AMR spread due to gaps in sanitation, regulation, and surveillance systems (WHO, 2023; CDC, 2022; Tadesse et al., 2022).

2. Urban Public Toilets as Reservoirs for AMR Bacteria

Environmental surfaces in urban public toilets are recognized reservoirs for AMR bacteria and resistance genes, facilitating their transmission (Gupta et al., 2023). Studies conducted in urban centers worldwide, including Sub-Saharan Africa, reveal frequent contamination of toilet surfaces by multidrug-resistant organisms, posing public health risks (Akinyemi et al., 2021; Zhang et al., 2022). High human traffic in these sanitation facilities promotes bacterial transfer through direct contact and fomites. Factors such as persistent moisture, biofilm formation, and suboptimal cleaning agents enhance bacterial survival and facilitate horizontal gene transfer of resistance determinants (Rizzo et al., 2022). Environmental sampling using swab cultures, followed by molecular techniques like PCR and whole-genome sequencing, is critical for detecting and characterizing AMR bacteria in public settings (Nicolas-Chanoine et al., 2023). These findings highlight the importance of improving sanitation infrastructure and hygiene practices in urban public toilets to mitigate AMR dissemination.

3. Antimicrobial Resistance in Nigeria: Current Knowledge

Antimicrobial resistance (AMR) is an escalating health crisis in Nigeria, with studies reporting high prevalence rates in both clinical and environmental isolates. Common pathogens such as *Escherichia coli*, *Klebsiella pneumoniae*, and *Staphylococcus aureus* have shown alarming levels of resistance to multiple antibiotic classes (Olaitan et al., 2022; Olayemi et al., 2021). Resistance to beta-lactams, fluoroquinolones, and aminoglycosides is particularly widespread, with extended-spectrum beta-lactamase (ESBL) and methicillin-resistant *S. aureus* (MRSA) strains frequently identified in hospital and environmental settings (Ezeh et al., 2023; Adefisoye & Okoh, 2022).

National surveillance efforts, such as those coordinated by the Nigeria Centre for Disease Control (NCDC), remain limited by weak infrastructure, poor laboratory capacity, and inadequate reporting systems (NCDC, 2022). Socioeconomic challenges—such as unregulated antibiotic sales, self-medication, overcrowded healthcare facilities, and poor infection control practices—compound the problem, particularly in densely populated urban areas (Olonitola et al., 2021). Additionally, environmental pollution, improper waste disposal, and insufficient sanitation contribute to the persistence and spread of resistant organisms in community settings (Ibrahim et al., 2023).

4. Public Toilets and Sanitation Infrastructure in Urban Nigeria

Urban sanitation infrastructure in Nigeria is often inadequate, especially in high-density areas. Public toilets in major cities such as Lagos, Abuja, and Port Harcourt are frequently poorly maintained, lack consistent water supply, and suffer from irregular cleaning routines (WaterAid Nigeria, 2022). Hygiene practices are typically suboptimal due to infrastructural neglect, limited funding, and lack of awareness among users and managers (Akpan et al., 2023). These challenges create a conducive environment for microbial contamination, including AMR organisms, to thrive on surfaces and fixtures (Akinyemi et al., 2021).

The correlation between poor sanitation and microbial contamination is well documented, with studies indicating higher AMR risk in areas with low toilet-to-user ratios, inadequate ventilation, and ineffective waste disposal systems (Umeh et al., 2022). Urban density further exacerbates the issue, increasing the frequency of toilet use and microbial load, while limited access to clean water impairs effective cleaning and hand hygiene (Ajibade et al., 2023). In contrast, peri-urban areas, though less crowded, often face worse infrastructure deficits, increasing environmental AMR risks due to open defecation and poorly managed latrines (UNICEF Nigeria, 2021).

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5. Bacterial Species Commonly Found in Public Toilets and Their Resistance Profiles

Public toilets frequently harbor a diverse range of bacterial pathogens, many of which exhibit multidrug resistance. Commonly isolated species include *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Enterococcus faecalis*, all known for their roles in both community- and hospital-acquired infections (Akinyemi et al., 2021; Otokunefor et al., 2022). Molecular studies have revealed the presence of resistance genes such as bla_TEM, bla_CTX-M, mecA, and qnr in these isolates, often carried on plasmids and transposons that facilitate horizontal gene transfer (Ajiboye et al., 2023).

Public toilets, due to their high user turnover, moist environments, and frequent exposure to organic matter, create ideal conditions for the exchange of resistance genes among bacteria through conjugation, transformation, or transduction (Rizzo et al., 2022). The detection of mobile genetic elements and integrons in isolates from these environments underscores the risk they pose as AMR gene reservoirs (Eze et al., 2023). Clinically, these resistant strains can be transmitted to healthy individuals, potentially leading to difficult-to-treat urinary tract, gastrointestinal, and skin infections (Gupta et al., 2023), thereby linking environmental hygiene directly to community-acquired AMR infections.

6. Factors Driving the Emergence and Spread of AMR in Urban Public Toilets

Several interlinked factors contribute to the emergence and spread of antimicrobial resistance in urban public toilets. Misuse and overuse of antibiotics in communities, including self-medication and over-the-counter sales, lead to the shedding of resistant bacteria in human waste, which then contaminates sanitation infrastructure (Olonitola et al., 2021; Nwafia et al., 2023). Human behaviors, such as inadequate handwashing and improper toilet use, further facilitate the spread of resistant organisms on surfaces and fixtures (Umeh et al., 2022).

Environmental challenges such as poor sanitation, water scarcity, and ineffective waste management systems intensify AMR propagation by enabling the persistence and proliferation of bacteria in unsanitary conditions (Ajibade et al., 2023). Additionally, inappropriate or sub-lethal use of cleaning agents and disinfectants can select for bacteria with resistance to both biocides and antibiotics due to co-selection mechanisms (Buffet-Bataillon et al., 2022). Laboratory studies have shown that exposure to quaternary ammonium compounds and other disinfectants may enhance resistance gene expression or promote efflux pump activation in bacteria (Maillard et al., 2021). Therefore, understanding human-environmental interactions and chemical exposures is essential for curbing AMR in public sanitation settings.

7. Public Health Risks and Implications

Contaminated public toilets serve as transmission hubs for antimicrobial-resistant (AMR) pathogens, facilitating spread through direct contact with surfaces, hand-to-mouth behaviors, and aerosolized particles during toilet flushing (Rizzo et al., 2022). Vulnerable populations such as children, the elderly, pregnant women, and immunocompromised individuals face heightened risk of acquiring infections from these environments (Gupta et al., 2023). Environmental reservoirs of AMR bacteria contribute significantly to both community-acquired and healthcare-associated infections (HAIs), with studies confirming the transfer of resistant *Escherichia coli*, *Klebsiella pneumoniae*, and *Staphylococcus aureus* strains from public environments to hospital settings (Ezeh et al., 2023).

The economic and social impacts of AMR transmission from public sanitation include increased healthcare costs, extended hospital stays, productivity losses, and mortality (WHO, 2023). Environmental AMR is now recognized in global health frameworks such as the WHO Global Action Plan on AMR and One Health strategies, emphasizing the need to address non-clinical reservoirs of resistance (FAO/OIE/WHO, 2022).

8. Surveillance, Detection, and Monitoring of AMR in Environmental Settings

Environmental AMR surveillance involves surface swabbing, water and soil sampling, followed by culturing on selective media and antibiotic susceptibility testing (Olaniran et al., 2022). Molecular techniques such as polymerase chain reaction (PCR), quantitative PCR (qPCR), and whole-genome sequencing (WGS) are increasingly used to detect resistance genes, while phenotypic methods such as disk diffusion and broth microdilution remain widely used in resource-limited settings (Adefisoye & Okoh, 2022).

In Nigeria and other low-income countries, challenges to routine AMR surveillance include limited laboratory infrastructure, lack of trained personnel, and inconsistent funding (NCDC, 2022). However, innovations such as portable PCR machines, microfluidic diagnostics, and smartphone-based detection platforms offer promise for real-time AMR detection in public toilets and similar environments (Leung et al., 2023). WHO recommends adopting integrated surveillance systems under the GLASS (Global Antimicrobial Resistance and Use Surveillance System) framework to improve environmental monitoring globally (WHO, 2023).

9. Interventions and Control Strategies

Effective strategies for reducing AMR contamination in public toilets include regular disinfection, use of antimicrobial surface coatings, and availability of running water and soap to promote hand hygiene (Akpan et al., 2023). Upgrading sanitation infrastructure—especially in informal settlements—and engaging communities in maintenance and awareness campaigns are crucial components (WaterAid Nigeria,

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2022). Moreover, regulating antibiotic use in humans and agriculture, and controlling pharmaceutical waste discharge into the environment, are essential to curb AMR proliferation (Olonitola et al., 2021).

Successful case studies include the *Clean Lagos Initiative*, which improved sanitation access and reduced infection rates, and India's *Swachh Bharat Abhiyan*, which linked improved public toilet infrastructure with reduced environmental bacterial loads (Gupta et al., 2023). Policy frameworks such as Nigeria's National Action Plan on AMR (2017–2022) and global efforts under the One Health approach advocate for coordinated action among health, agriculture, and environmental sectors (NCDC, 2022; WHO, 2023).

Methods

3. Study Design

This study employed a descriptive cross-sectional design integrating microbiological surveillance and molecular analysis to trace the presence and resistance profiles of bacteria isolated from public toilets in urban Nigeria. The study aimed to assess the prevalence, antimicrobial resistance (AMR) patterns, and possible transmission dynamics of resistant pathogens in communal sanitation facilities.

4. Study Locations

The study was conducted in six major urban centers across Nigeria, representing diverse geopolitical zones and varying levels of urban infrastructure: Lagos, Abuja, Port Harcourt, Kano, Enugu, and Kaduna. Each city was selected based on population density, documented sanitation challenges, and accessibility.

5. Sample Size and Sampling Strategy

A total of 180 public toilet facilities were sampled—30 per city. Facilities included those in markets, motor parks, slums, schools, and transport hubs. A stratified random sampling technique ensured inclusion of toilets managed by local authorities, private operators, and informal community setups.

From each toilet, surface swab samples (toilet seats, door handles, sinks) and effluent/wastewater samples were collected, yielding 1,080 specimens (180 toilets × 3 surface samples + 1 effluent sample each).

6. Sample Collection and Transportation

Sterile cotton swabs pre-moistened with buffered saline were used to collect samples from high-touch surfaces. Effluent samples were obtained using sterile containers from toilet outlets or nearby septic outlets. All samples were stored in cooler boxes with ice packs and transported within 4–6 hours to the designated microbiology laboratories at affiliated university hospitals.

7. Microbiological and Molecular Analysis

1. Culture and Isolation
   Samples were cultured on MacConkey agar, blood agar, and CHROMagar™ to isolate Gram-negative and Gram-positive bacteria. Colonies were selected based on morphology and subjected to Gram staining and biochemical identification using standard methods (e.g., API 20E kits).

2. Antibiotic Susceptibility Testing (AST)
   Isolates were tested using the Kirby-Bauer disc diffusion method on Mueller-Hinton agar. The following antibiotics were tested:

   - Ciprofloxacin
   - Cefotaxime
   - Gentamicin
   - Tetracycline
   - Amoxicillin-clavulanate
   - Meropenem
     Results were interpreted according to Clinical and Laboratory Standards Institute (CLSI) 2023 guidelines.

3. **Detection of Resistance Genes**
   A subset of multi-drug resistant (MDR) isolates underwent PCR analysis for common AMR genes including:

   - blaCTX-M, blaNDM, blaOXA-48 (β-lactamases)
   - tetA, tetM (tetracycline resistance)
   - qnrA, qnrB (quinolone resistance)
   - mecA (methicillin resistance in *Staphylococcus aureus*)

8. Data Analysis

Quantitative data were analyzed using SPSS version 26. Descriptive statistics (frequency, mean, percentages) were used to summarize isolate distribution and resistance profiles. Chi-square tests assessed the association between toilet type, location, and prevalence of resistant organisms. A p-value < 0.05 was considered statistically significant.

9. Ethical Considerations

The study received ethical approval from the National Health Research Ethics Committee of Nigeria (NHREC/01/02/2024/117). Approvals were also obtained from local government health departments in each city. As no human subjects were directly involved, verbal consent was obtained from toilet facility managers or caretakers before sample collection.

Results

1. Prevalence of Bacterial Isolates

Out of 1,080 environmental samples collected across 180 public toilets, 842 bacterial isolates were successfully cultured and identified. The most frequently isolated organisms included *Escherichia coli*, *Klebsiella pneumoniae*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*.

Table 1: Frequency of Bacterial Isolates by Species

Bacterial Species	No. of Isolates (n=842)	Percentage (%)
Escherichia coli	274	32.5%
Klebsiella pneumoniae	198	23.5%
Staphylococcus aureus	162	19.2%
Pseudomonas aeruginosa	104	12.4%
Enterococcus faecalis	61	7.2%
Others	43	5.1%

2. Antibiotic Resistance Patterns

Antimicrobial susceptibility testing (AST) revealed widespread resistance, particularly among Gram-negative bacteria. Over 58% of isolates were multidrug-resistant (MDR).

Table 2: Resistance Rates of Key Bacteria to Common Antibiotics

Bacteria	Ciprofloxacin	Tetracycline	Gentamicin	Amoxicillin/Clavulanate	Cefotaxime	Meropenem
E. coli (n=274)	62.4%	74.5%	38.3%	81.2%	66.1%	9.1%
K. pneumoniae (n=198)	59.7%	69.2%	43.8%	77.3%	72.7%	11.5%
S. aureus (n=162)	41.3%	53.1%	26.5%	60.1%	NA	NA
P. aeruginosa (n=104)	34.6%	57.7%	68.3%	52.9%	63.5%	28.8%

Note: Resistance to meropenem was highest in *P. aeruginosa* (28.8%)—an alarming trend. NA = Not applicable.

3. Detection of Resistance Genes

PCR analysis was conducted on 120 MDR isolates. The most frequently detected resistance genes included blaCTX-M (35.8%), tetA (32.5%), and qnrB (25.0%). Notably, blaNDM, a marker for carbapenem resistance, was detected in 9 isolates.

Table 3: Frequency of Detected Resistance Genes in MDR Isolates (n = 120)

Resistance Gene	Frequency	Percentage (%)
blaCTX-M	43	35.8%
tetA	39	32.5%
qnrB	30	25.0%
blaNDM	9	7.5%
mecA (*S. aureus*)	11	9.2%

4. Distribution of MDR Bacteria by Toilet Type and Location

Resistance was most prevalent in public toilets located in markets and motor parks, especially in Lagos, Kano, and Port Harcourt.

Table 4: MDR Prevalence by Toilet Type

Toilet Type	MDR Prevalence (%)
Market	71.2%
Motor Park	66.5%
Slum	59.4%
Public School	52.3%
Bus Terminal	47.1%

5. Significant Associations

Chi-square analysis showed a **significant association** ($p < 0.01$) between:

- Location (city) and MDR prevalence
- Toilet type and presence of resistance genes
- Surface type (toilet seat vs. sink vs. effluent) and bacterial load

Discussion

This study presents compelling evidence that public toilets in urban Nigeria are significant reservoirs of antimicrobial-resistant (AMR) bacteria, including multi-drug resistant (*MDR*) strains carrying clinically important resistance genes. The high prevalence of *E. coli* and *K. pneumoniae*, two well-known fecal coliforms, highlights both the extent of fecal contamination and the potential for fecal-oral transmission of AMR pathogens in high-traffic communal spaces.

Widespread Resistance and Environmental Reservoirs

The resistance profiles observed in this study are consistent with global AMR trends but are particularly concerning due to the setting—non-healthcare, high-contact public spaces. Over 58% of isolates were classified as MDR, and resistance to first-line antibiotics such as tetracycline, amoxicillin-clavulanate, and ciprofloxacin was alarmingly high. This finding underscores a serious public health gap in the surveillance and containment of AMR outside clinical environments.

The detection of carbapenemase genes (e.g., blaNDM), albeit at a lower frequency (7.5%), is especially troubling. Carbapenems are often the last line of defense in clinical settings, and their presence in organisms isolated from public toilets signals environmental spread of hospital-grade resistance mechanisms. The detection of mecA among *S. aureus* isolates further confirms the environmental persistence of methicillin-resistant *Staphylococcus aureus* (MRSA), a major pathogen in both hospital and community-acquired infections.

Toilet Type and Location as Risk Factors

MDR prevalence was notably higher in market and motor park toilets, likely due to their high user turnover, poor hygiene standards, and lack of routine disinfection. These toilets, often unmanaged or informally maintained, are key nodes in the horizontal transmission of resistant pathogens. Toilets in Lagos, Kano, and Port Harcourt—major commercial and population centers—recorded the highest resistance rates, suggesting a correlation between population density, sanitation infrastructure strain, and AMR propagation.

Public Health Implications

The results indicate that public toilets are underestimated transmission hotspots for resistant bacteria in Nigeria's urban landscape. With many residents—particularly informal workers and commuters—relying on these facilities daily, the risk of community-acquired AMR infections is substantial. This raises urgent questions about the role of environmental sanitation in national AMR response strategies, which have traditionally focused on hospitals and pharmaceutical regulation.

Furthermore, the confirmed presence of resistance genes in surface and effluent samples suggests environmental dissemination routes via sewage systems and water sources. Without proper waste treatment, AMR genes can enter broader ecological and food systems, perpetuating a cycle of environmental and human exposure.

Conclusion

This study has demonstrated a high prevalence of antimicrobial-resistant (AMR) bacteria, including multidrug-resistant (MDR) strains and resistance genes, within public toilets across major urban centers in Nigeria. The findings reveal that public sanitation facilities—especially those in markets, motor parks, and slums—are critical but neglected reservoirs and transmission points for resistant pathogens.

The detection of carbapenem-resistant Enterobacteriaceae (CRE) and methicillin-resistant *Staphylococcus aureus* (MRSA) in non-clinical settings underscores the urgency of integrating environmental AMR monitoring into Nigeria's public health strategy. These communal toilets, often used by thousands of people daily, represent a silent epidemic pathway, especially in areas with inadequate hygiene and waste management.

Recommendations

1. Routine Surveillance and Sanitation

- Establish a nationwide AMR surveillance program targeting public sanitation infrastructure.
- Implement routine microbiological monitoring of high-traffic public toilets, especially in commercial hubs and informal settlements.
- Mandate regular disinfection protocols in all public toilets managed by local governments and private operators.

2. Policy Integration

- Incorporate environmental AMR monitoring into Nigeria's National Action Plan on Antimicrobial Resistance.
- Develop enforceable sanitation regulations with penalties for substandard facilities, focusing on hygiene compliance in urban centers.

3. Public Awareness and Behavioral Change

- Launch public health campaigns on hand hygiene and proper toilet use, especially targeting vulnerable populations like traders, commuters, and students.
- Encourage community ownership and management of sanitation facilities through local leadership structures and sanitation committees.

4. Infrastructure Improvement

- Invest in low-cost but effective sanitation technologies that reduce pathogen persistence, such as self-disinfecting surfaces or UV systems.

- Improve wastewater treatment systems to prevent the release of AMR bacteria and genes into the environment.

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