Antimicrobial Resistance in Urinary Tract Infections: Current Scenario, Mechanisms, and Challenges in India - A Narrative Review

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ABSTRACT
Background: Antimicrobial resistance (AMR) has emerged as a major health problem worldwide with low- and middle-income countries being especially vulnerable, with India being no exception. One of the most frequent bacterial infections is Urinary tract infections (UTIs) and are a significant contributor to antibiotic use and consequently resistance.
Purpose: This narrative review is a synthesis of literature on the epidemiology, the resistant patterns, molecular pathophysiology and clinical issues related to antimicrobial resistance of uropathogens in India.
Methods: A narrative review methodology was employed, which comprised evidence from 55 peer-reviewed studies covering the period 2010-2025, including national and international surveillance reports. Studies covering UTIs, antimicrobial susceptibility and resistance mechanisms in India and the world were included.
Results: The most prevalent uropathogen identified in the review is *Escherichia coli* and *Klebsiella pneumoniae*, which exhibit high resistance to commonly used antibiotics, such as fluoroquinolones, cephalosporins, and ampicillin. There has been an increasing trend in the number of NDM-1-producing organisms as well as extended-spectrum β-lactamase (ESBL) and carbapenemase-producing organisms in both community and hospital settings. Nitrofurantoin and fosfomycin remain moderately effective options, while carbapenems are increasingly reserved as treatments of last resort. The main causes of AMR in India are the misuse of antibiotics, low quality of healthcare facilities, socioeconomic inequalities, and environmental conditions. Diagnostic, treatment and surveillance systems continue to pose significant challenges.
Conclusion: AMR in Urinary tract infections (UTIs) in India is rapidly soaring, and multidrug-resistant Gram-negative uropathogens, as well as systemic healthcare inadequacies, are present. The key to reducing this increasing threat is to strengthen antimicrobial stewardship, improve surveillance networks, increase diagnostic capacity, and a One Health approach.
Keywords: Antimicrobial resistance; Urinary tract infections; Uropathogens; ESBL; Carbapenem resistance; India.
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INTRODUCTION

Background

Antimicrobial resistance (AMR) has turned into one of the most urgent threats to the overall state of the global health and has an adverse impact on decades of progress in the area of the treatment of the highly dangerous infections. According to the report of the global antimicrobial resistance and use surveillance system (GLASS) of the World Health Organization, the rates of resistance to commonly used antibiotics in different pathogens, including those in bloodstream and urinary tract issues are alarming (1). Of special concern is the developing resistance to last resort antibiotics like carbapenems that are normally linked with multidrug-resistant (MDR) infections and treatment failure (2–4). UTIs are also one of the most common forms of bacterial infections throughout the globe with a high proportion of antibioti cs being prescribed either in the community, or in hospitals. *Escherichia coli* has continuously been reported as the most common uropathogen followed by *Klebsiella pneumoniae* with growing resistance to fluoroquinolones, cephalosporins, and β-lactams (5,6). UTIs are a significant subject of AMR studies due to the high rates of antibiotics treatment leading to the development of resistance, and the rates of this infection are a key area of their investigation.

Indian Context

As a low- and middle-income country (LMIC), the burden of AMR disproportionately affects India driven by a complex mix of socioeconomic pressures and long-standing gaps in healthcare delivery. Surveillance data indicates that susceptibility rates of major uropathogens *E. coli* and *Klebsiella pneumoniae* to the antibiotics that clinicians rely on most heavily – penicillins, cephalosporins, fluoroquinolones and even carbapenems gradually decline according to the Diagnostic Data of the Indian Council of Medical Research (ICMR) Antimicrobial Resistance Surveillance Network (7). Similarly, other studies in India have also identified high prevalence rates of extended-spectrum β-lactamase (ESBL) production and new carbapenem resistance in the community and in the hospital setting (8,9). Other factors which have contributed to the burden are the amount of misuse of the antibiotics, sale of antimicrobials over the counter and lack of management of the infection (10–12). Regional differences in resistance pattern primarily between rural Odisha and tertiary care in metropolitan cities are taken to indicate the heterogeneity of AMR all over country.

Rationale for Review

Though literature on AMR in UTIs in India is growing, the existing studies are almost always narrowly scoped – tied to a particular region, population or pathogen, and provide uneven information. For example, clinical studies conducted in pregnant women, children, and the ICU reveal conflicting levels of prevalence and resistance profile, which is why it is hard to come up with a single national view (13,14). Additionally, although some of the studies are focused on epidemiological trends, some are focused either on the molecular processes involved such as the production of ESBL and carbapenemase, which creates a vacuum in the comprehensive knowledge. Thus, these gaps cannot be left unaddressed and can be filled by using a narrative synthesis of the existing evidence to have an overall picture of AMR in UTIs in India, including epidemiology, mechanisms, and challenges.

Objectives

The purpose of this narrative review paper is to present a summary of the current literature on the AMR in Urinary tract infections (UTIs) issue in India by answering the following questions: (i) recent trends and patterns of AMR in different parts of the world and healthcare facilities; (ii) underlying molecular and genetic processes that lead to resistance, including ESBL and carbapenemase production; and (iii) the key clinical and population health problems that are associated with AMR such as resistance to treatment.

METHODOLOGY

This study employs narrative review as a methodology to achieve a synthesis of the findings on the existing literature on the topic of antimicrobial resistance (AMR), i.e., the urinary tract infection (UTI) in India and its comparisons with the other parts of the world. Unlike systematic reviews, the narrative process allows a wider and expanded accommodation of a compilation of study designs and incorporation that can be observational studies, surveillance reports, and molecular studies, thereby allowing a global view on AMR in UTIs trends, mechanisms and challenges.

Fifty-five studies published between 2010-2025 were included. Peer-reviewed journal articles, national reports on surveillance, and international health reports were considered as data sources. Research works of tertiary care centers in India, domestic literature and foreign documents, such as the WHO GLASS surveillance data (1) and ICMR-AMR surveillance reports (7) among others, were considered as the main sources. The studies were selected based on those that provided epidemiological, clinical or molecular evidence on AMR trends.

Inclusion criteria were:

(i) included studies that dealt with AMR in UTIs or uropathogens;

(ii) included studies that were dealing with the pattern of antibiotic susceptibility, mechanism of resistance or risk factors.

(iii) Community-based studies, as well as hospital-based studies, were included, to see the entire picture of the situation.

Exclusion criteria consisted of:

(i) non-peer-reviewed articles/editorials/opinions;

(ii) studies themselves that were not related to UTIs or not contributing to AMR patterns, mechanisms, epidemiology or clinical relevance;

(iii) lack of methodological clarity or resistance data.

Data were sorted and thematic analysis of data conducted and sorted into major domains which included: AMR in Urinary tract infections (UTIs), global and national AMR patterns, regional differences, resistance patterns, and clinical issues. This approach provides a detailed picture of the dynamics of AMR, which offers a break in the dissenting scattered literature and offers unitary perspective, which can be transferred to clinical practice and policy in health services.

AMR CURRENT SCENARIO

Antimicrobial resistance in Urinary tract infections (UTIs) is an issue that has become a national and international crisis and has immense implications on the clinical outcomes and health care systems. The situation today is a complex interplay of biological, environmental and healthcare factors, which combine to cause the rapid emergence and spread of drug-resistant pathogens (15,16).

Global Scenario

AMR is now frightening around the globe particularly amongst Gram-negative uropathogens. The WHO GLASS report also discusses a high resistance to the use of the last-resort antibiotics such as carbapenems with the pathogens that cause severe infections (1). Besides, unequal surveillance in various countries leads to unequal data reporting as a low-income and low-middle income countries (LMICs) have significant problems with laboratory facilities and testing coverage. These gaps are obstacles to adequate AMR burden estimates, and they make answering the policy level difficult.

National Scenario (India)

The region of AMR in uropathogens is high in India, and surveillance statistics reveal that the sensitivity of the noteworthy pathogens *Escherichia coli* and *Klebsiella pneumoniae* decreased gradually over the years (7). The problem of multidrug-resistant (MDR) and extensively drug-resistant (XDR) pathogens is also heard by society, and in the hospital setting. Reduced susceptibility to commonly used antibiotics such as fluoroquinolones and cephalosporins is mentioned as well and restricts treatment options and increases reliance on drugs of last resort.

Regional Variations

The AMR pattern in uropathogens in India is very heterogeneous at the level of the region (16). Eastern India has resistance against fluoroquinolones and cotrimoxazole (17) this is indicative of misuse (18). The extent of carbapenem resistance has been reported to be more than 20 percent in the community in Central India; this means resistance is spreading beyond hospitals (8). Classic rural spaces, such as Odisha, display intimate associations amidst AMR and social-economic factors, such as poor hygiene and unavailability of health care (19). Meanwhile, the northeast Indian region has demonstrated high infection levels of ESBL-producing organisms, which depend upon genetic share of resistance determinants (9,20).

Community vs Hospital AMR

There is a growing blur between community- and hospital-acquired AMR in Urinary tract infections (UTIs). The rising prevalence of ESBLs has been observed even in outpatient (OPD) cases, which means that there is high usage of antibiotics within the community (21,22). On the other hand, hospital environments, especially intensive care units (ICUs), are typified by preponderance of MDR and XDR (*Acinetobacter baumannii* and *Pseudomonas aeruginosa*) pathogens (23). These infections are likely to be line related, linked with the invasive operation and a longer hospitalization and morbidity and mortality are likely to be greater.

Table 1. Summary of AMR Trends in Uropathogens Across Settings

Setting	Key Pathogens	Resistance Pattern	Key Concern
Global	*E. coli, Klebsiella*	Carbapenem resistance rising	Surveillance inequality
India (National)	*E. coli, Klebsiella*	Declining carbapenem sensitivity	MDR/XDR emergence
Eastern India	*E. coli*	High fluoroquinolone resistance	Empirical therapy failure
Central India	*E. coli, Klebsiella*	Carbapenem resistance >20%	Community spread of resistance
Rural India	Mixed flora	Variable resistance	Hygiene & socio-economic factors
Northeast India	*E. coli* (ESBL)	High ESBL prevalence	Genetic dissemination
Hospitals/ICU	*Acinetobacter, Pseudomonas*	MDR/XDR resistance	Limited treatment options

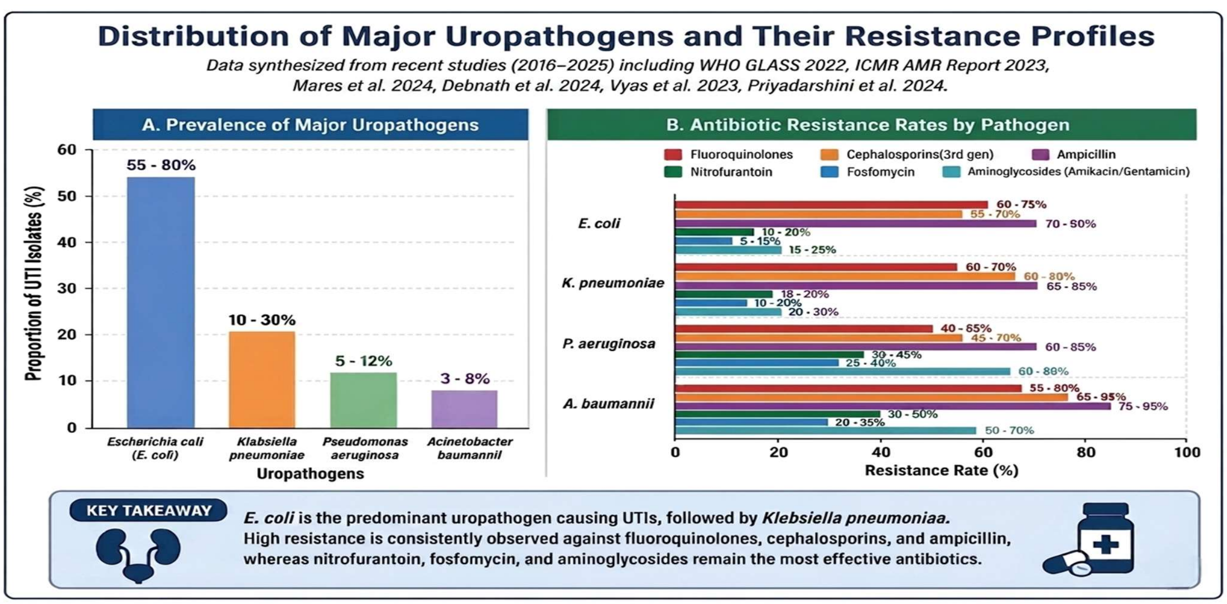
TYPICAL UROPATHOGENS AND ANTIMICROBIAL RESISTANCE

The list of bacterial pathogens which can lead to UTIs is relatively limited, with Gram-negative pathogens predominating in both community and hospital setting (24). Most frequent among them is *Escherichia coli* which has so far dominated infections in several recent studies (5,6). *Klebsiella pneumoniae* is the second pathogen and is more frequently associated with escalating levels of resistance and nosocomial illnesses (25). Specifically, *Pseudomonas aeruginosa* and *Acinetobacter baumannii* represent the non-fermenting Gram-negative bacteria that are of special interest in the ICUs, where they are responsible for some of the most treatment resistant infections encountered in clinical settings (8,26).These trends of resistance indicate that especially with the most commonly used antibiotics, namely fluoroquinolones, cephalosporins, and ampicillin, the resistance level is high, which is primarily due to the high rate of empirical use and natural selection (6,27). In their turn, nitrofurantoin, fosfomycin, and aminoglycosides have relatively low resistance rates, and may be administered as first-line or alternative therapy in most cases (5,7). Special populations exhibit unique patterns of infection and resistance. Urinary tract infections in pregnant women are often asymptomatic and can lead to life-threatening complications if untreated, as they are predominantly caused by *E. coli* and respond well to nitrofurantoin (14). Children, meanwhile, experience higher recurrence and resistance to commonly used antibiotics (13). This overload of resistant infections among diabetic individuals is tied to both immune compromise and frequent exposure to antibiotics (5).

Table 2. Common Uropathogens and Resistance Patterns

Pathogen	Prevalence	High Resistance Antibiotics	Effective Antibiotics
E. coli	Very High	Fluoroquinolones, Ampicillin, Cephalosporins	Nitrofurantoin, Fosfomycin
Klebsiella pneumoniae	High	Cephalosporins, Fluoroquinolones	Carbapenems, Aminoglycosides
Pseudomonas aeruginosa	Moderate	Carbapenems (increasing), Cephalosporins	Colistin, Combination therapy
Acinetobacter baumannii	Moderate	Carbapenems, Fluoroquinolones	Colistin, Minocycline

Figure 1. Distribution of Major Uropathogens and Their Resistance Profiles



ANTIMICROBIAL RESISTANCE MECHANISMS

The multifactorial evolution of antimicrobial resistance in uropathogens is caused by the interplay of enzymatic, genetic, cellular and biofilm-mediated mechanisms to enable bacteria to survive antibiotic challenges and undergo transmission (28).

Enzymatic Mechanisms

Among the key mechanisms is the expression of β-lactamases, specifically extended-spectrum β-lactamases (ESBLs): CTX-M, TEM, and SHV enzymes, that break down β-lactam antibiotics such as cephalosporins (9,29). Moreover, last-resort carbapenem resistance is provided by carbapenemases like NDM-1 and OXA-48, which has become a significant clinical problem in India (30).

Genetic Mechanisms

In most cases, resistance genes are located on plasmids, thus able to spread quickly to other bacterial species by means of horizontal gene transfer (31,32). Uropathogenic *E. coli* has been found to harbor plasmid-mediated ESBL and carbapenemase genes, such as blaNDM-1 and blaCTX-M variants (33). This genetic mobility augments the frequency of spread of resistance in society in addition to in hospitals.

Cellular Mechanisms

The efflux pumps, which actively discharge the antibiotics, and low membrane permeability which inhibits the uptake of drugs are some of the adaptations against antibiotics that have been used by the bacteria. In addition, alterations to target sites alter the drug binding sites, reducing the activities of the drugs. All these mechanisms contribute to multidrug resistance in particular the ones which are resistant to fermentation like *Pseudomonas* and *Acinetobacter* (34).

Biofilm Formation

The formation of biofilms has been very important in the pathogenesis of chronic and recurrent urinary tract infections (UTIs) since the biofilms protect the bacterial communities. In biofilms, bacteria are less active and are therefore less vulnerable to antibiotics that act on actively dividing bacteria. The extracellular matrix also prevents the penetration of antibiotics and assists the bacteria to avoid the host immunity. This mechanism especially plays an important role in catheter-associated UTIs in which biofilms grow on the surface of indwelling catheters causing long-term infection and treatment failure.

Table 3. Mechanisms of Antimicrobial Resistance

Mechanism Type	Key Features	Examples
Enzymatic	Antibiotic degradation	ESBL (CTX-M, TEM), NDM-1
Genetic	Gene transfer via plasmids	blaNDM-1, blaCTX-M
Cellular	Efflux pumps, permeability changes	MDR in *Pseudomonas*
Biofilm	Protective bacterial communities	Chronic UTI, catheter infections

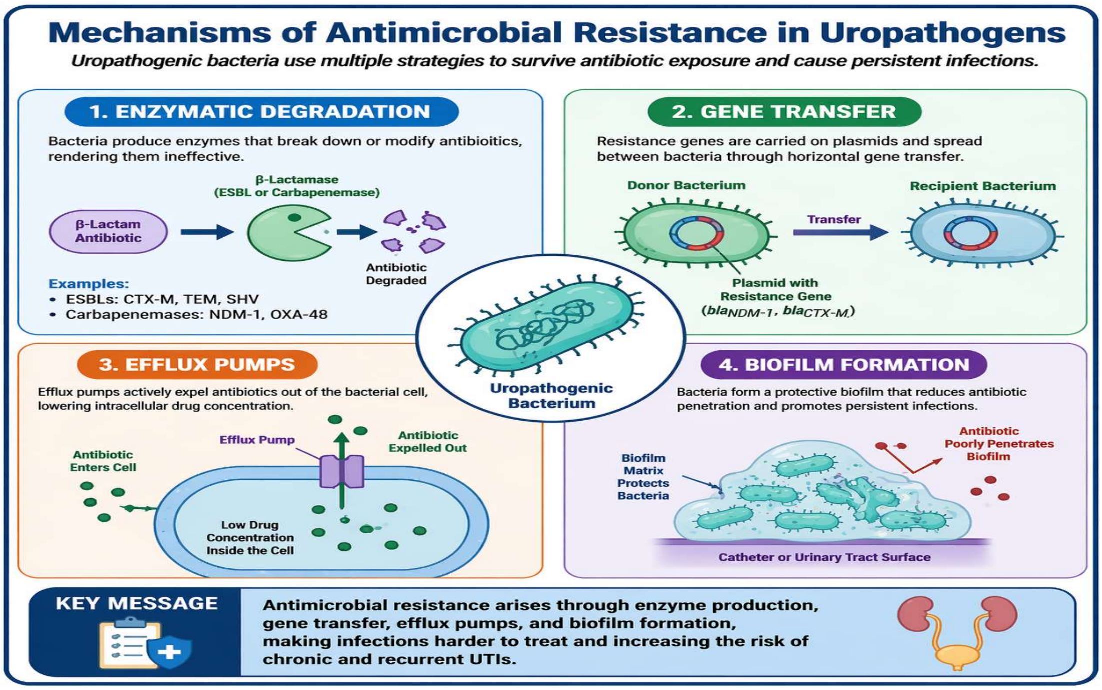


Figure 2. Mechanisms of Antimicrobial Resistance in Uropathogens

DRIVERS OF ANTIMICROBIAL RESISTANCE IN URINARY TRACT INFECTIONS (UTIs) IN INDIA

There is a complex interaction between behavioral, healthcare, socioeconomic, and environmental factors in India that leads to antimicrobial resistance (AMR) (35). Combined, these drivers promote the outbreak and proliferation of resistant pathogens in society and hospitals.

Antibiotic Misuse

One of the most significant AMR contributors is the indiscriminate use of antibiotics, particularly, with over-the-counter (OTC) use (36). Most parts of India have easy access to antibiotics such as fluoroquinolones and β-lactams, which promotes self-treatment and incorrect dosage (9). Moreover, the use of empirical prescribing, often lacking culture testing, also facilitates the selection of resistance especially common infections like UTIs (37).

Healthcare System Factors

Limitation of healthcare infrastructure is also very critical. A significant number of healthcare environments do not have a routine of antibiogram-guided treatment, and clinicians use broad-spectrum antibiotics. Such practices can be related to the trend of reducing the antibiotic susceptibility as reported by the ICMR surveillance report (7). In addition, inadequate infection prevention and control (IPC) measures in hospitals and the ICUs, in particular, facilitate the spread of multidrug-resistant organisms (8).

Socioeconomic Determinants

The dynamics of AMR are greatly affected by socioeconomic conditions. The rural and slum populations are susceptible to poor hygiene, overcrowding, and the inability to obtain medical care, which also contributes to the increased rate of infection and antibiotic abuse (14). In particular, overcrowding has been identified as one of the key predictors of UTI prevalence and spread (38,39). These factors contribute to conditions, that do not just increase infection spread but also actively accelerate resistance development too.

Agricultural and Environmental Factors

Every time antibiotics are used in agriculture or livestock, resistance genes accumulate in the surrounding environment – soil, water (40,41). Antibiotic residues and resistant bacteria are introduced into water systems and soil and are transmitted to the human beings. In addition, the release of pharmaceutical wastes and effluents by hospitals is also associated with the transmission of AMR, particularly in overcrowded places (42).

Table 4. Key Drivers of AMR in UTIs in India

Driver Category	Key Factors	Impact on AMR
Antibiotic Misuse	OTC access, empirical therapy	Selection of resistant strains
Healthcare System	Lack of antibiograms, poor IPC	Spread of MDR pathogens
Socioeconomic	Poor hygiene, overcrowding	Increased infection transmission
Environmental	Livestock antibiotic use, contamination	Reservoirs of resistance genes

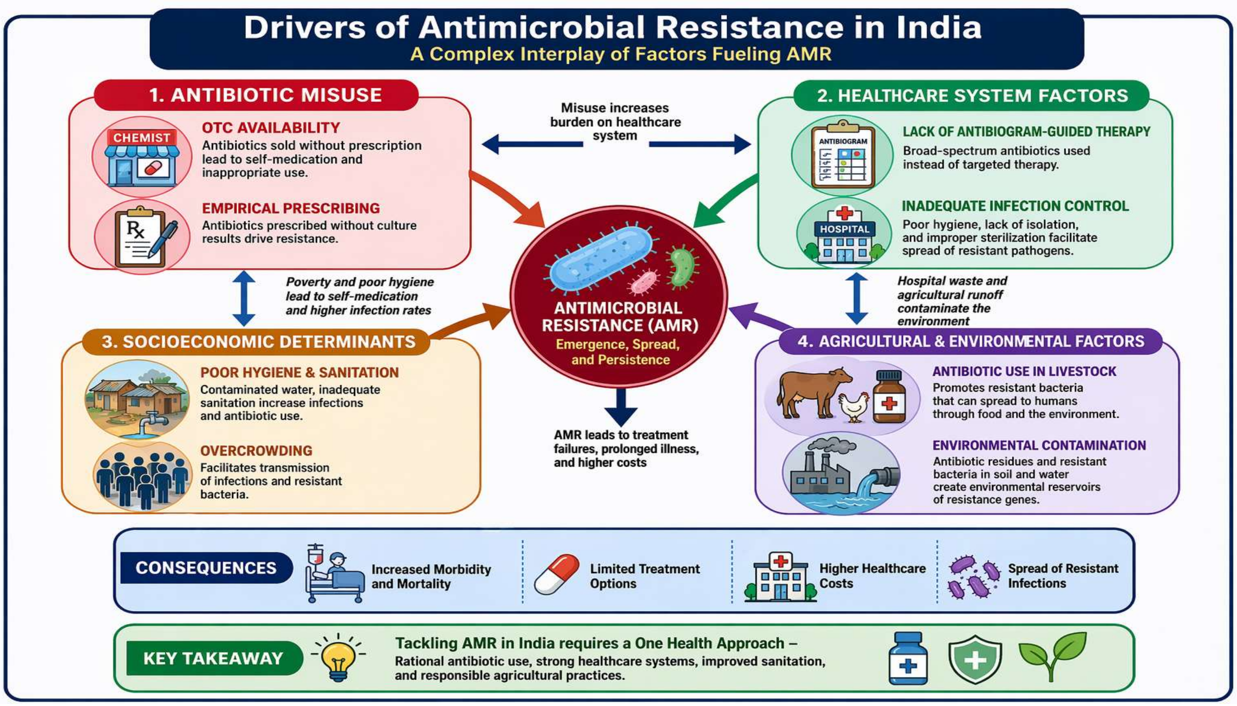


Figure 3. Drivers of Antimicrobial Resistance in India

CLINICAL AND PUBLIC HEALTH CHALLENGES

The development of antimicrobial resistance has been rising at an extremely rapid pace and has resulted in significant clinical and population health challenges such as the diagnosis, treatment and disease control interventions in the entire state of India (35)

Diagnostic Challenges

The lack of access to diagnostic facilities, in particular primary and rural medical centers is one of the greatest weaknesses of AMR management. Lots of patients receive treatment that is not based on culture and sensitivity testing and receive the wrong antibiotic (9). Late and even non-diagnosis further contributes to the disease development and resistance.

Therapeutic Challenges

It has led to the decreased effectiveness of the commonly used antibiotics in the treatment of UTIs, because of the increasing percentage of MDR and XDR pathogens. Fluoroquinolone and cephalosporin resistance is common, which has led to the need to use last-resort medications like carbapenems (27). However, with the growing carbapenem resistance, the treatment process becomes even more complex, leading to more cases of treatment failure and recurrence (8)

Surveillance Gaps

Despite the efforts made, including the ICMR-AMR network, the surveillance of AMR in UTIs is not uniform across the regions, and rural and community settings remain, for the most part, a blind spot in the surveillance data (43,44). This lack of adequate data cannot be used to develop localized treatment recommendations and policy interventions.

Special Challenges

There are certain groups of people with specific AMR-related problems. The issue of frequent infections and the absence of antibiotics to cure illnesses complicate the situation with pediatric patients (13). Bacteriuria in pregnant women is asymptomatic and can lead to severe complications without treatment and necessitate a prudent selection of antibiotics (14). Further, ICUs are the units where MDR infections spread, and death rates are elevated due to the opportunity of such hazardous pathogens as *Acinetobacter* and *Pseudomonas* to become resistant to drugs (45,46).

Table 5. Clinical and Public Health Challenges of AMR in UTIs

Challenge Type	Key Issues	Consequences
Diagnostic	Limited testing, delayed diagnosis	Inappropriate therapy
Therapeutic	MDR/XDR pathogens, limited drugs	Treatment failure, recurrence
Surveillance	Regional data gaps	Poor policy implementation
Special Populations	Paediatric, pregnancy, ICU cases	Increased morbidity and mortality

EXISTING TREATMENT PLANS AND TRENDS

Treatment of antimicrobial resistance (AMR) in urinary tract infections (UTIs) has evolved over the decades with a greater focus on preserving the efficacy of the available antibiotics, and the identification of alternative ways to treat this disease. Currently preferred agents are nitrofurantoin and fosfomycin, both of which has solid activity against typical UTI pathogens such as *Escherichia coli* with a low resistance rate and can be applied in the treatment of empirical therapy in uncomplicated UTIs (5,7). They are useful especially in the community environments as they are targeted and have low collateral resistance.

Conversely, carbapenems are regarded as the last-resort drugs and are mainly used in severe infections with multidrug-resistant (MDR) bacteria, such as ESBL-producing bacteria (29). However, the threat of the emergence of carbapenem-resistant strains that jeopardizes their further usefulness is increasing (2). Newer approaches lean on β-lactamase inhibitors (e.g., clavulanic acid combinations), and combination therapy, which will also serve to overcome mechanisms of enzyme resistance and make the treatment more effective (47). They are especially effective in the treatment of infections with resistant Gram-negative organisms.

Also, the increasing focus on personalized medicine, such as culture-based therapy and risk-based choice of antibiotics that maximize the effectiveness of treatment and reduce unnecessary exposure to antibiotics (48). This prescription transformation to evidence-based prescription is the need of the hour to slow the AMR progression and improve patient outcomes.

PREVENTION AND CONTROL STRATEGIES

Antimicrobial resistance in Urinary tract infections (UTIs) is a complex issue that should be managed by a mixture of clinical, population health, and policy-level interventions.

Antimicrobial Stewardship

The AMR control relies on antimicrobial stewardship programs (ASPs). The programs encourage rational prescribing whereby antibiotics are prescribed only when they are needed and in the right quantities and within the right time. The implementation of antibiotic restriction, in particular, for last-resort antibiotics such as carbapenems, have been proven to reduce the prevalence of resistance (49).

Infection Prevention

The use of antibiotics will be minimized by infection prevention which eventually reduces the burden of UTIs and resistant uropathogens. Hygiene measures like handwashing and sanitation are especially noteworthy in the community, whereas hospital infection prevention and control (IPC) measures, such as sterilization, isolation, and surveillance, play a crucial role in reducing the transmission of MDR pathogens.

Surveillance Systems

The surveillance of AMR patterns in UTI pathogens and communication of treatment policies need to be well-developed. By improving global systems, such as WHO GLASS, and national networks, such as ICMR-AMR surveillance program, it will be possible to predict the trends of resistance in time and support evidence-based decision-making (1,7). Nevertheless, the increase in the scope of coverage of surveillance to rural and primary care is a priority.

Public Awareness

Aspects such as education of the people are important but have not been considered. Education regarding the risks of antibiotic misuse and self-medication, as well as the need to take an entire course of treatment, can greatly decrease the number of unnecessary cases of antibiotic use (50,51). Community involvement activities and policy measures should be in place to provide the responsible use of antibiotics.

FUTURE PERSPECTIVES

The future of AMR in UTIs management lies in the combination of developed technologies with the public health strategies. Artificial intelligence (AI)-based resistance prediction is one promising field, capable of analyzing large amounts of data to predict trends in resistance and inform empirical therapy (52,53). They can help clinicians make smarter prescribing decisions.

The other important development is the invention of quick diagnostic tools, that allow early detection of pathogens and their resistance profile. These technologies have the potential to enhance the use of empirical therapy to a great extent and enhance the precision of treatment, especially in resource-constrained environments.

The development of vaccines is a long-term measure to decrease the burden of infection, and, accordingly, the use of antibiotics (54). Although vaccines against the common uropathogens are presently under research, their effective implementation can greatly reduce the rates of AMR.

Lastly, a One Health approach, which combines human, animal, and environmental health, is vital for a comprehensive approach to AMR (55). This strategy acknowledges the interrelation of resistance dissemination and advocates intersectoral interventions, such as healthcare, agriculture, and environment management.

CONCLUSION

The problem of rising antimicrobial resistance in UTIs in India is a big threat to the health and clinical practice. This narrative review based on evidence from 55 peer-reviewed studies and national surveillance reports, demonstrates that *Escherichia coli* and *Klebsiella pneumoniae* are the major uropathogens exhibiting alarming multidrug resistance patterns. Multidrug resistant strains of common antibiotics such as fluoroquinolones and cephalosporins, have reduced treatment options and increased dependence on last-resort antibiotics, like carbapenems.

Four resistance mechanisms (enzymatic deactivation, horizontal gene transfer via plasmids, efflux pump, biofilm formation) and systemic factors that include unregulated over-the-counter antibiotic supply, absence of antibiogram-driven prescribing recommendation, socioeconomic inequality, and antibiotic contamination from agricultural use, contribute to this crisis. Lack of diagnostic services and non-coordinated surveillance, especially in rural and community settings, also hinder informed policy making.

The findings of this review prove that the urgent need to reinforce surveillance systems and antimicrobial stewardship programs and manage the tendencies towards resistance exists. Increase in diagnostic capacity, promotion of rational use of antibiotics and control of infections are also part of the AMR treatment.

It is worth noting that the coordinated and integrated country approach, coupled with international regulations such as WHO GLASS, is important in combating AMR and preserving the efficacy of existing therapies.

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