The Bioscan 19(2): S2: 406-415, 2024 www.thebioscan.com
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES

The Evolving landscape of Antibiotic resistance: A state-by-state Perspective and Mapping of Antibiotic resistance Hotspots in India

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DOI: https://doi.org/10.63001/tbs.2024.v19.i02.S2.pp406-415

KEYWORDS
AMR, States of India, Before and After Covid, AMR Hotspots, AMR organisms and pattern.
Received on:

01-08-2024

Accepted on:

18-11-2024

ABSTRACT

Antibiotic resistance is a serious concern of developing countries like India and is expected to hit its rockbottom.Antimicrobial resistance (AMR) is one of the top global public health and development threats. It is estimated that bacterial AMR was directly responsible for 1.27 million global deaths in 2019 and contributed to 4.95 million deaths Priorities to address AMR in human health include preventing all infections, which may result in inappropriate use of antimicrobials; ensuring universal access to quality diagnosis and appropriate treatment of infections; and strategic information and innovation, for example surveillance of AMR and antimicrobial consumption/use, and research and development for novel vaccines, diagnostics and medicines.(WHO, November 2023).Surveillance of AMR plays a pivotal role in research and helps us to steer the course of AMR against the setbacks in modern medicine and treatment better.This paper reviews meticulously the evolving landscape of Antibiotic resistance and Mapping of Antibiotic resistance Hotspots in India from before COVID for a period of four years 2015 to 2019 and after covid 2020 to 2024.

INTRODUCTION

Antibiotic resistance has emerged as one of the most significant challenges in global healthcare, threatening the effective treatment of infectious diseases. This phenomenon occurs when bacteria evolve mechanisms to withstand the effects of antibiotics, rendering standard treatments ineffective and leading to persistent infections, increased transmission, and higher mortality rates. In India, a country with diverse healthcare practices and varying access to medical resources, the challenge of antibiotic resistance is particularly acute. The country's vast population and the significant burden of infectious diseases create a complex landscape for managing antibiotic use and resistance.

This review focuses on the state-wise analysis of antibiotic resistance in India from 2020 to 2024 and comparing these findings with data collected from 2015-2019, highlighting the drugs with the highest resistance and the organisms most commonly associated with this resistance. The methodology involved a comprehensive collection of articles from reputable databases, focusing on reports and studies that provided detailed information on antibiotic resistance patterns across different states in India. These data were meticulously tabulated to identify the most resistant drugs and the corresponding organisms, offering a clear picture of the resistance landscape in various regions.

One of the key findings from this analysis is the alarming resistance observed against cephalosporins, a class of antibiotics widely used in treating bacterial infections. Cephalosporins were found to have the highest resistance among all drug classes examined, raising significant concerns about the continued efficacy of this critical treatment option. Additionally, the state-wise analysis revealed that Gujarat had the highest number of antimicrobial-resistant patients, making it a focal point for understanding the regional dynamics of antibiotic resistance in India.

The burden of antimicrobial resistance extends beyond individual patients, affecting the broader community and placing a significant strain on healthcare systems. In states like Gujarat, where resistance is particularly high, the public health implications are even more severe, necessitating immediate and targeted interventions.

This review article is crucial in understanding the current state of antibiotic resistance in India. By providing a detailed, state-wise analysis of resistance patterns, it offers valuable insights for healthcare professionals, policymakers, and researchers. The findings underscore the need for coordinated efforts to combat antibiotic resistance, including stricter regulations on antibiotic use, improved public awareness, and enhanced surveillance systems. Ultimately, this review aims to contribute to the development of effective strategies to mitigate the spread of antibiotic resistance in India and ensure the continued efficacy of antibiotics in treating infectious diseases.

Data Sources:

The data for this review article were collected from two primary sources: PubMed and Google Scholar. These databases were selected due to their extensive coverage of peer-reviewed literature in the field of medicine and microbiology, ensuring access to relevant and high-quality articles on antibiotic resistance in India.

Inclusion and Exclusion Criteria

Articles were included if they met the following criteria:

1. Published between 2015 and 2024.
2. Focused on antibiotic resistance in India, specifically providing data on resistance patterns at the state level.
3. Provided specific information on the types of resistant organisms and the drugs to which resistance was observed.
4. Published in peer-reviewed journals.

Articles were excluded if:

1. Focused on antibiotic resistance outside of India.

2. Lacked sufficient data on resistance patterns or did not specify the organisms and drugs involved.
3. Were reviews, editorials, or opinion pieces without original research data.

GEOGRAPHICAL DISTRIBUTION OF ANTIBIOTICS RESISTANCE IN INDIA, MAJOR RESISTANT ORGANISMS, AND DRUG RESISTANCE TRENDS (2020-2024)

Antibiotic resistance in India shows significant variation across different states over the two distinct time periods of 2015-2019 and 2020-2024. Our analysis of articles collected from both intervals reveals key insights into the evolving landscape of antimicrobial resistance across the country.

Among the states, Gujarat and Andhra Pradesh were found to have the highest number of antimicrobial-resistant patients during both the period, as revealed by our analysis. Other states, including Tamil Nadu, Bihar and Assam also exhibited alarming resistance rates, driven largely by the misuse of antibiotics and limited access to quality healthcare. Northern and western regions tended to report more resistant infections, likely due to higher population densities and healthcare infrastructure challenges. Southern states such as Tamil Nadu and Karnataka reported resistance trends that also reflect high usage of broad-spectrum antibiotics, including cephalosporins.

The most common resistant organisms identified in India during this period were Escherichia coli, *Klebsiella pneumoniae, Staphylococcus aureus, and Acinetobacter baumannii*. These organisms exhibited significant resistance to cephalosporins, beta-lactams, and carbapenems. Escherichia coli and *Klebsiella pneumoniae* were particularly associated with the production of extended-spectrum beta-lactamases (ESBLs), while methicillin-resistant *Staphylococcus aureus* (MRSA) showed widespread resistance to beta-lactam antibiotics. *Acinetobacter baumannii,* primarily associated with hospital-acquired infections, displayed resistance to carbapenems and other last-resort antibiotics, contributing to increased mortality in critical care units.

During 2015-2019, fluoroquinolones showed the highest resistance, followed closely by cephalosporins and penicillins. By 2020-2024, resistance to cephalosporins outpaced other drugs, with a rising trend in beta-lactamase producers like E. coli and K. pneumoniae

Drug resistance trends from 2015 to 2024 showed a marked increase in resistance to cephalosporins, especially third-generation cephalosporins, across multiple states. The rising prevalence of ESBL-producing organisms and carbapenem-resistant strains further aggravated the situation. Cephalosporins were the most resistant drug class, particularly in western states like Gujarat and Maharashtra. Resistance to fluoroquinolones and aminoglycosides also showed an upward trend, complicating treatment strategies for both community-acquired and hospital-acquired infections. This period witnessed a worrying escalation of multidrug-resistant organisms, signalling an urgent need for improved antibiotic stewardship and better infection control practices across the country.

MECHANISM OF RESISTANCE:

In India, several factors contribute to the growing problem of antibiotic resistance, as highlighted in our review. A major factor is the **misuse and overuse of antibiotics**, both in healthcare and agriculture. In many parts of the country, antibiotics are often available without prescriptions, leading to their widespread and unregulated use. Patients may self-medicate or fail to complete prescribed antibiotic courses, allowing bacteria to survive and develop resistance.

Socioeconomic disparities also play a critical role. In regions with limited access to quality healthcare, infections are often inadequately treated, contributing to the emergence and spread of resistant strains. Furthermore, the **lack of diagnostic facilities** means that antibiotics are frequently prescribed without proper identification of the causative organism, leading to inappropriate use of broad-spectrum antibiotics like cephalosporins, which we found to have the highest resistance rates.

The **variation in healthcare infrastructure** across states exacerbates the issue, with some areas, such as Gujarat, showing higher rates of antimicrobial resistance due to factors like population density and resource constraints. Additionally, poor infection control practices in hospitals and communities further facilitate the spread of resistant bacteria, compounding the public health challenge.

This complex interplay of factors necessitates targeted interventions to curb the rise of antibiotic resistance in India.

PUBLIC HEALTH IMPLICATIONS:

Infection caused by antimicrobial resistance microbes makes the infection difficult to treat. It increases risk of disease spread, severe cold illness and even death of the person . Antimicrobial resistance is the natural process that occurs through genetic changes in the pathogenic microbes .It spread and emergence is initiated by human activity like misuse and overuse of antibiotics to treat and prevent infection in humans.

Bacteria possess remarkable genetic adaptability. Human overuse of antibiotics selects for resistant strains, allowing them to exploit resistance genes and horizontal gene transfer mechanisms. This has resulted in the emergence of multidrug-resistant bacteria, posing a serious threat to public health.Infections caused by resistant organisms take longer to treat, leading to extended hospital stays, increased use of more toxic or expensive drugs, and prolonged illness.

Common infections, such as pneumonia, tuberculosis, and urinary tract infections, can become life-threatening when resistant to treatment.Resistant bacteria can spread from person to person, from animals to humans and through the environment, leading to outbreaks that are difficult to control.

Many medical procedures like organ transplant surgeries, cancer treatments etc rely on antibiotics to prevent or treat infections. Antibiotic resistance increases the risk of complications during these procedures and makes them more dangerous. Resistant microbes can spread more easily within healthcare settings, communities, and across borders, leading to outbreaks that are harder to control and treat.

With fewer effective antibiotics available doctors are forced to use older, less effective, or more toxic medications, which can have serious side effects and may not fully eliminate the infection.

Children, the elderly, and individuals with weakened immune systems are at higher risk of severe outcomes from resistant infections, including death. Antibiotic resistance is a global health threat that can lead to widespread epidemics of untreatable infections, potentially causing a public health crisis.

STRATEGIC INTERVENTIONS TO COMBAT ANTIBIOTIC RESISTANCE IN INDIA

To combat the rising threat of antibiotic resistance in India, targeted intervention strategies are crucial. Given the varying levels of antibiotic resistance across states like Gujarat, Andhra Pradesh, and Uttar Pradesh, localised programs are essential. These programs should focus on educating healthcare providers about appropriate antibiotic prescribing practices, limiting the overuse of broad-spectrum antibiotics like cephalosporins, and promoting the use of culture and sensitivity testing to guide treatment. Hospitals and clinics should adopt stewardship protocols to monitor antibiotic use and resistance patterns regularly.

The threat of AMR is not only individual health but also societal well-being by potentially rendering common infections untreatable. Green healthcare advocates for harnessing natural antimicrobial from plants and microorganisms. These alternatives could potentially reduce reliance on conventional antibiotics, thereby curbing the selection pressure that drives AMR development. By using green chemistry techniques in the production of antibiotics to microbial resistance against antibiotics. Use herbal and traditional medicine.

Encourage the use of plant-based treatments and probiotics as alternatives to traditional antibiotics, particularly in agriculture and human health where appropriate.

Another important intervention is the launch of public awareness campaigns. Many patients in India use antibiotics without proper prescriptions, often discontinuing treatment prematurely. Educational campaigns targeting both urban and rural populations should emphasize the dangers of antibiotic misuse, the importance of completing prescribed courses, and the risks of self-medication. These campaigns can be broadcast via social

media, radio, television, and community outreach programs to maximise impact, ensuring that both literate and non-literate populations are reached.

Improving diagnostic technologies is another key strategy. Rapid diagnostic tests should be made more accessible and affordable, especially in rural areas where healthcare infrastructure is often lacking. These technologies can help in the early and accurate identification of resistant infections, allowing for appropriate, targeted treatment and reducing the need for broad-spectrum antibiotics. Government investment in diagnostic infrastructure, along with training for healthcare professionals, would significantly reduce the inappropriate use of antibiotics.

Enhancing regulatory frameworks to manage the sale of antibiotics is crucial. Over-the-counter antibiotic sales must be strictly regulated, and penalties for non-compliance should be enforced. By implementing a multi-faceted approach combining education, improved diagnostics, stewardship programs, and regulatory control, India can effectively tackle the growing challenge of antibiotic resistance, preserving the efficacy of current treatments for future generations.

INFERENCE:

The analysis of antibiotic resistance in India from 2020 to 2024 revealed alarming trends, particularly concerning cephalosporins, which exhibited the highest levels of resistance among all drug classes. Extended-spectrum beta-lactamase (ESBL)-producing organisms, such as *Escherichia coli* and K*lebsiella pneumoniae*, were frequently identified as highly resistant to cephalosporins. This resistance was particularly pronounced in states like Gujarat, which had the highest number of antimicrobial-resistant cases. Other states with significant resistance included Andhra Pradesh, Uttar Pradesh, Karnataka, and Assam

In addition to cephalosporins, resistance to other major antibiotics, such as fluoroquinolones and aminoglycosides, was observed across the country. Methicillin-resistant *Staphylococcus aureus* (MRSA) was notably prevalent, especially in northern and western regions of India. Gram-negative organisms, such as *Pseudomonas aeruginosa and Acinetobacter baumannii*, exhibited multi-drug resistance, particularly to carbapenems, making infections caused by these pathogens difficult to treat.

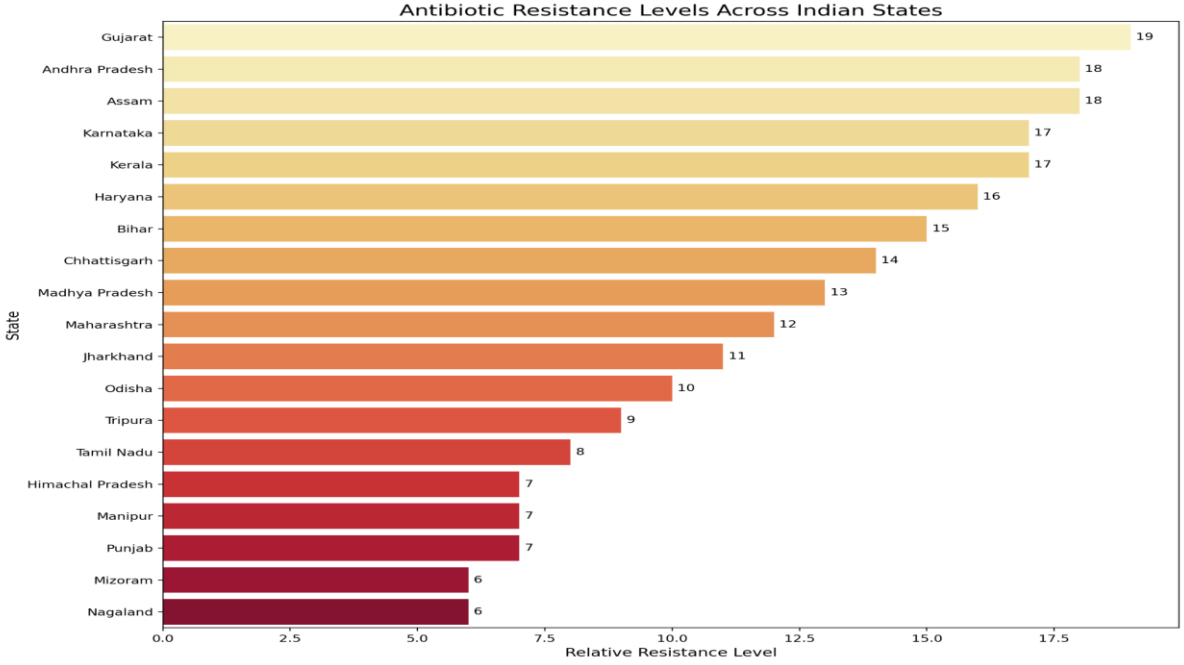
Over the 2020-2024 period, the overall trend showed an increase in resistance across multiple drug classes. This was accompanied by a rise in the prevalence of multi-drug resistant organisms (MDROs), which were resistant to at least three different classes of antibiotics. These findings underscore the growing threat of antibiotic resistance in India and highlight the regional variations in resistance patterns, with some states facing a more severe burden than others.

State Wise antibiotic resistance from 2015 - 2019

During this period, the states of Gujarat, Andhra Pradesh, Assam, Karnataka, and Kerala exhibited the highest levels of antimicrobial resistance. The state-wise ranking based on the number of resistant cases is as follows:

No articles were seen for Arunachal Pradesh, Goa, Meghalaya, Rajasthan, Sikkim, Telangana, Uttarpradesh, Uttarakhand, West Bengal

The below graph shows the relative resistance level in India from 2015 to 2019

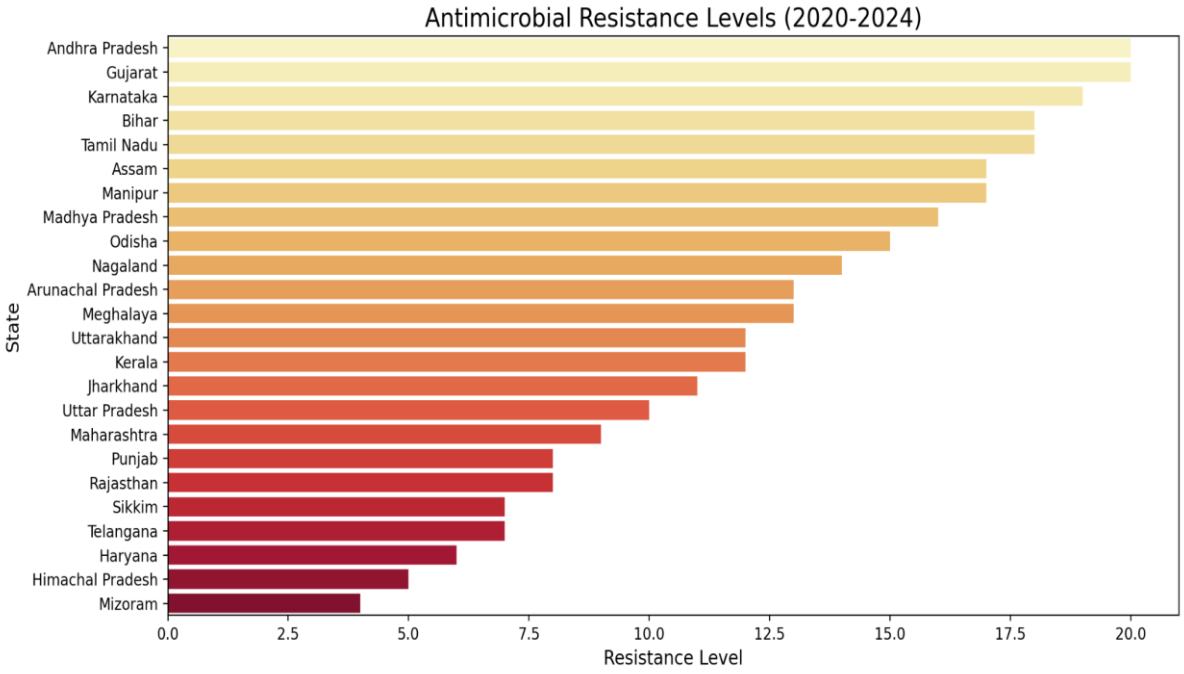


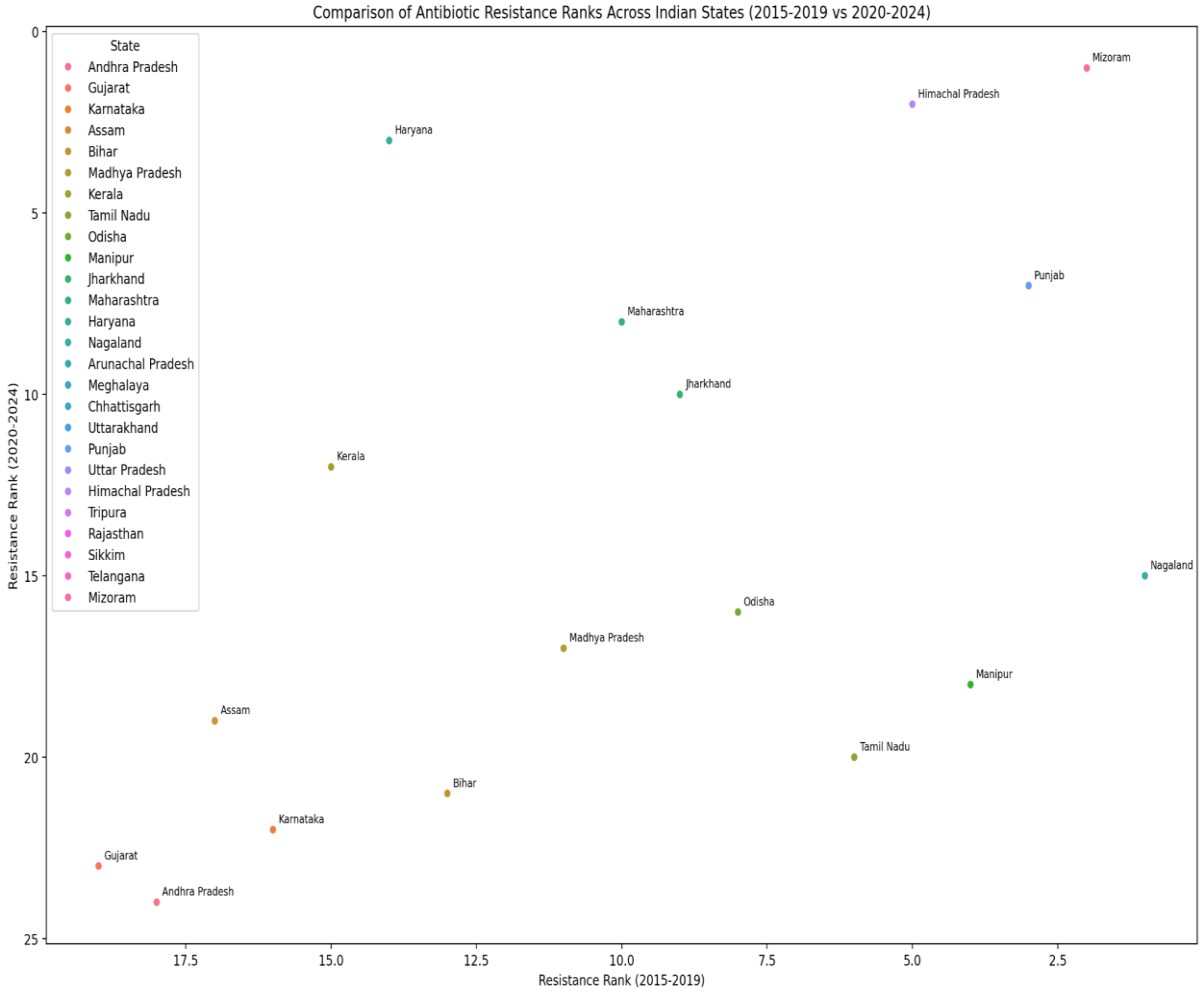
Statewise antibiotic resistance from 2020 - 2024

In contrast, our analysis for 2020-2024 shows that Gujarat, Andhra Pradesh, Tamil Nadu, Bihar, and Assam continue to experience high resistance rates. The state ranking during this period is:

No articles were seen for Chattisgarh, Goa, Tripura, West Bengal

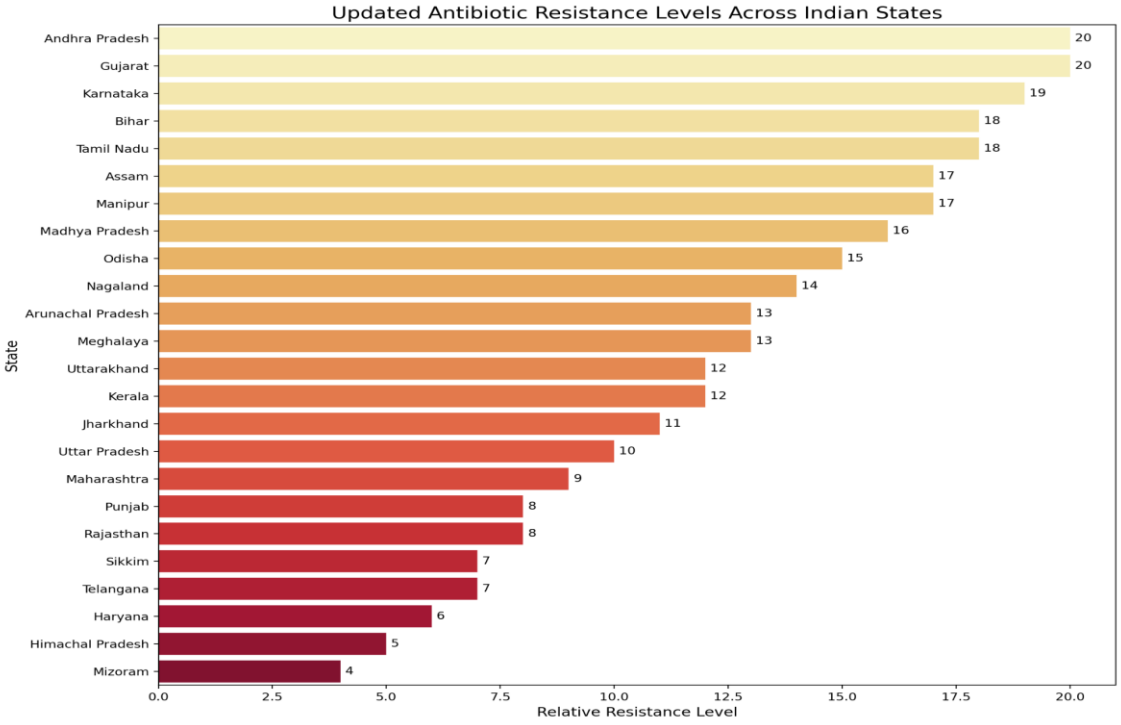
The below graph shows the relative resistance level in India from 2020 to 2024





Data depicting State and its Total Rank Andhra Pradesh 42.0 Gujarat 42.0 Karnataka 38.0 Assam 36.0 Bihar 34.0

This analysis reveals that Andhra Pradesh and Gujarat consistently show high levels of antibiotic resistance across both time periods. Karnataka, Assam, and Bihar also demonstrate significant resistance levels.

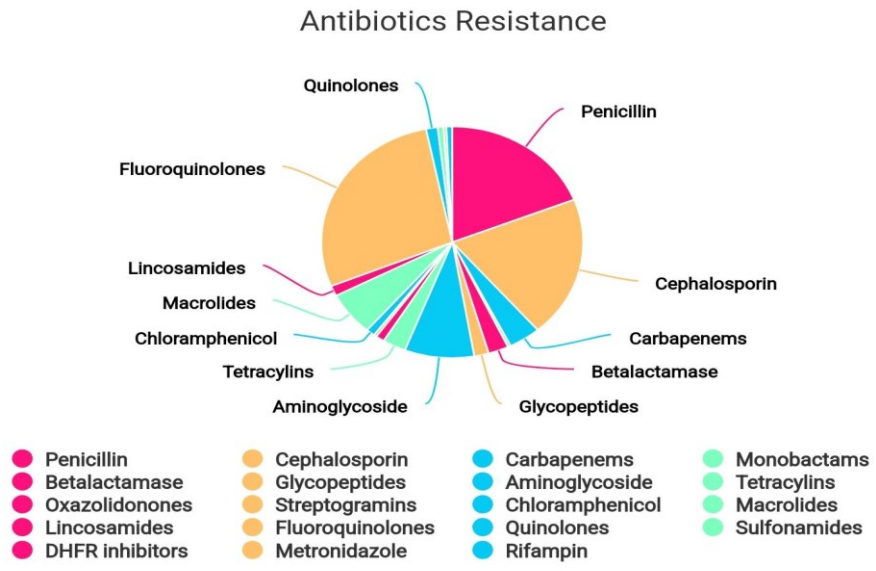


Antibiotics based on their level of antimicrobial resistance from 2015 - 2019

The drugs most resistant during this time were fluoroquinolones, followed by cephalosporins and penicillin, reflecting the high use of broad-spectrum antibiotics. The complete ranking of drug resistance observed is:

DHFR inhibitors not shown any resistance

The below pie chart shows the resistance antibiotics in India from 2015 to 2019

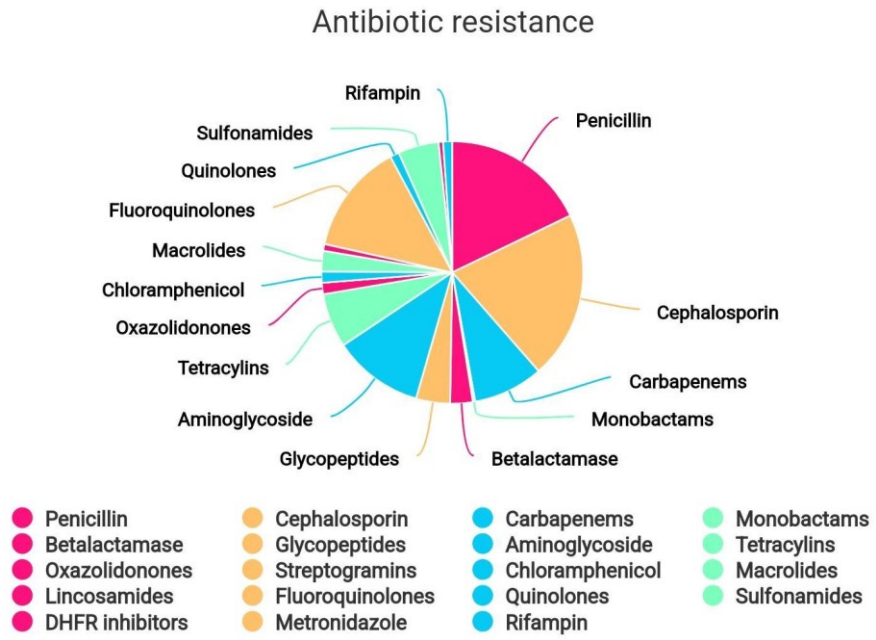


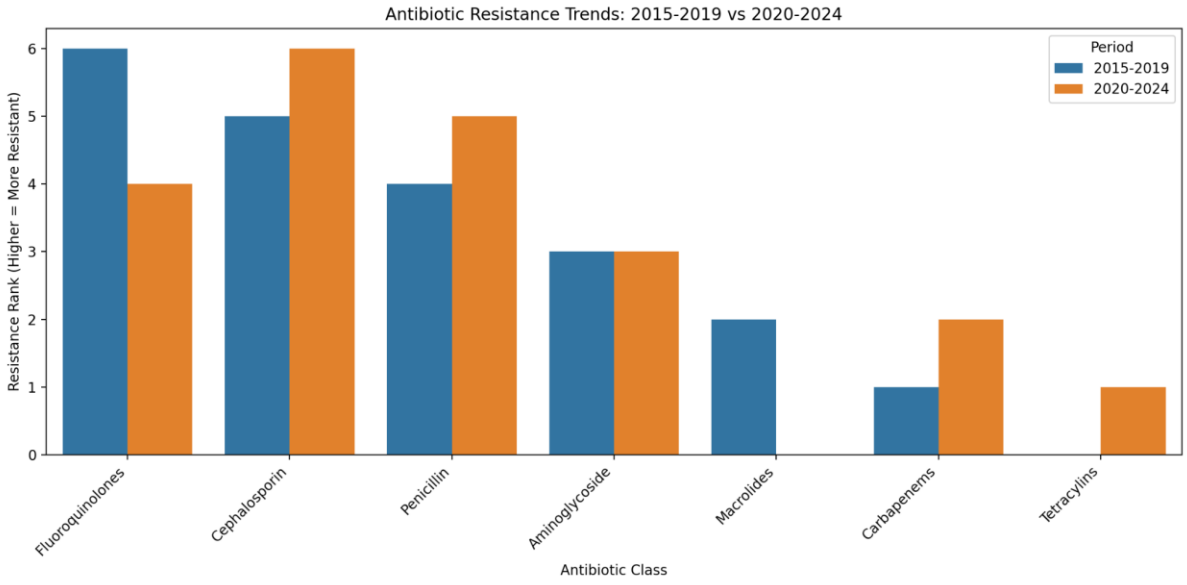
Antibiotics based on their level of antimicrobial resistance from 2020 - 2024

During 2015-2019, fluoroquinolones showed the highest resistance, followed closely by cephalosporins and penicillins. By 2020-2024, resistance to cephalosporins outpaced other drugs, with a rising trend in beta-lactamase producers like E. coli and K. pneumoniae.

Metronidazole and streptomycin class of antibiotics were not shown any resistance

The below pie chart shows the resistance antibiotics in India from 2020 to 2024





Summary of
major changes in antibiotic resistance:
Penicillin: Increased resistance (Rank change: 1)
Carbapenems: Increased resistance (Rank change: 1)
Cephalosporin: Increased resistance (Rank change: 1)
Tetracyclines: Not in top 6 for 2015-2019, present in 2020-2024
Fluoroquinolones: Decreased resistance (Rank change: -2)
Macrolides: Present in 2015-2019, not in top 6 for 2020-2024
This analysis shows that resistance to Cephalosporins, Penicillin, and Carbapenems has increased, while Fluoroquinolones have decreased in resistance. Tetracyclines have emerged as a concern in the later period.

The evolving landscape of antimicrobial resistance (AMR) in India before and after COVID-19 reveals significant trends and changes in resistance patterns across different states.

Mapping of AMR Hotspots:

The study mapped AMR hotspots, identifying regions with particularly high resistance rates. Gujarat and Andhra Pradesh were consistently highlighted as critical areas of concern.The geographical distribution of resistance showed significant variation, with northern and western states reporting more resistant infections compared to southern states, which also reflected high usage of broad-spectrum antibiotics.

DISCUSSION

The findings of this review indicate a worsening trend in antibiotic resistance in India, particularly with regard to cephalosporins, which emerged as the drug class with the highest resistance rates. The widespread presence of ESBL-producing organisms, such as *Escherichia coli* and *Klebsiella pneumoniae*, points to the overuse of broad-spectrum antibiotics in both healthcare and agricultural settings. The high resistance rates in Gujarat and other states, such as Andhra Pradesh and Uttar Pradesh, reflect regional disparities in healthcare infrastructure, antibiotic usage, and infection control practices.

The rise of methicillin-resistant *Staphylococcus aureus* (MRSA) and multi-drug resistant Gram-negative bacteria like *Pseudomonas aeruginosa* and *Acinetobacter baumannii* further complicates treatment options, as these organisms are resistant to multiple classes of antibiotics. The increasing resistance to carbapenems, a last-resort antibiotic, is particularly concerning, as it limits the

therapeutic options for treating severe infections in hospital settings.

The geographical variation in resistance patterns highlights the need for state-specific interventions to control the spread of resistant organisms. States with higher resistance, such as Gujarat, may require more targeted strategies, including improved antibiotic stewardship programs, better infection control practices, and stronger regulations on the sale and use of antibiotics.

In conclusion, the comparative analysis from 2015-2024 reveals shifting resistance patterns, with cephalosporins and fluoroquinolones showing alarming resistance. Gujarat consistently reported the highest levels of antimicrobial resistance across both time frames. These findings underscore the urgency of developing targeted interventions, improving antibiotic stewardship, and strengthening public awareness to combat the growing threat of antibiotic resistance and preserve the efficacy of existing antibiotics for future use in India.

The key recommendations are to Develop targeted interventions for states with higher resistance, to Improve antibiotic stewardship programs Strengthen infection control practices,To Implement stronger regulations on antibiotic sale and its use and toEnhance public awareness about antibiotic resistance.

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