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*Original Article*

# Antimicrobial Resistance in Lower Respiratory Tract Infections among Hospitalized Patients in Kazakhstan

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## ABSTRACT

**Background:** Lower respiratory tract infections (LRTIs) are a major cause of illness and death worldwide. This study assessed bacterial pathogens and antimicrobial resistance (AMR) among hospitalized LRTI patients in Astana and Shymkent, Kazakhstan (2022–2024).

**Methods:** A laboratory-based retrospective study of hospitalized patients with LRTI (ICD-10: J12–J22) from 2022 to 2024 among 2,098 patients were analyzed. Pathogen distribution, AMR patterns and patient characteristics were examined using descriptive statistics, Wilson 95% confidence intervals, compound annual growth rate (CAGR) and chi-square tests.

**Results:** The analysis result shows that Gram-negative bacteria (43.6%) predominate, followed by Gram-positive bacteria (39.1%) and fungal pathogens, accounting for (17.3%) of all isolates. The most common isolates were Staphylococcus aureus (8.29%), Candida albicans (6.91%), Klebsiella pneumoniae (5.77%), Streptococcus mitis (5.34%), and N. flavescens (4.81%). Resistance varies markedly by organism and antibiotic. Among Klebsiella pneumoniae isolates, 34.9% (95% CI 26.6–44.2; n = 109) were resistant to ceftriaxone and 2.1% (n = 96) to meropenem; among Escherichia coli, 61.5% (n = 52) were resistant to ceftriaxone. Resistance to azithromycin is 60.2% (n = 118) in the Streptococcus mitis group, and resistance to fluconazole was 32.9% (n = 143) in Candida albicans. Estimates are reported only for organism–antibiotic pairs with at least 10 tested isolates. Patients aged ≥60 years accounted for 588 cases (28.0%), and their share of annual cases rose from 8.4% in 2022 to 32.1% in 2024.

**Conclusion:** Resistance varies markedly by organism. Therefore, empirical therapy should be guided by local, organism-specific antibiograms, supported by stronger antimicrobial stewardship, infection prevention and national surveillance in Kazakhstan.

**Keywords:** Antimicrobial Resistance, Lower Respiratory Tract Infections, Antibiotic Resistance, Bacterial Trends, Hospitalized Patients, Kazakhstan

## Introduction

Lower respiratory tract infections (LRTIs) represent one of the most common infectious diseases globally, contributing to acute morbidity and mortality, particularly among underage children and elderly individuals. The prevalence of LRTIs is associated with high antimicrobial use in both community and hospital settings (1). One of the common LRTIs among hospitalized patients is Community-acquired Pneumonia (CAP), an admission diagnosis, and hospital-acquired pneumonia (HAP) or Ventilator-Associated Pneumonia (VAP). Hospital-acquired pneumonia (HAP) is defined as pneumonia that occurs after more than 48 hours of hospitalization. In contrast, VAP is identified in patients who have had more than 48 hours of mechanical ventilation. (2). These variations between the two types are clinically important because they differ by setting, severity of illness, prior exposure to any antibiotic, and the readiness of care delivered (3,4). Gram-negative pathogens, including Acinetobacter baumannii, Pseudomonas aeruginosa, and Enterobacterales (e.g., Klebsiella pneumoniae), along with Gram-positive organisms such as Staphylococcus aureus, are often involved in severe cases of hospitalized pneumonia, and a majority of these isolates are multidrug-resistant, particularly in high-acuity wards and intensive care units (2,5). The management of LRTIs in hospitalized patients is becoming more complex due to antimicrobial resistance. Given that these infections are often treated empirically before microbiological results are available, local information on the pathogen's distribution and resistance patterns is necessary to choose the right antibiotic and manage antimicrobial resources. (2,6).

Although CAP and hospital-onset infections have distinct epidemiological characteristics, the two environments are interrelated through exposure to antimicrobials and drug resistance. The misuse of antibiotics in treating community-acquired infections also creates evolutionary pressure, leading to the emergence of resistant strains that can later spread within hospital settings, particularly in high-admission, high-antibiotic-use environments (7). LRTI outcomes are further complicated by several structural risk factors, including domestic air pollution, malnutrition, and limited access to effective antibiotics, highlighting the necessity of an enhanced surveillance system and targeted health interventions, especially in areas with poor data coverage (1).

The Global Burden of Disease 2021 estimated that non-COVID-19 LRIs resulted in 344 million incident cases and 2.18 million deaths in 2021, with the highest rates among young children and the elderly (8). In the hospital setting, high rates of antimicrobial use and a highly vulnerable patient population can accelerate the emergence of resistance, underscoring the necessity for regular laboratory monitoring of pathogens and susceptibility patterns among admitted patients (2,7).

In Kazakhstan, available evidence indicates an increasing burden of healthcare-associated infection (HAIs) and significant consumption of antibiotics in acute-care hospitals. A point-prevalence survey conducted in four acute care hospitals in 2022 revealed that healthcare-associated infections affected 3.8 percent of patients, and 48.1 percent of incidents occurred among patients in intensive care units (9). Subsequently, a nationwide survey conducted in 2023 across 26 acute-care hospitals in Kazakhstan shows a total of 2.4% healthcare-associated infection rate; however, pneumonia was found to be the predominant healthcare-associated infection at 25.0%. The study findings also highlighted that 40.2% of patients who were hospitalized were antimicrobial users, reflecting the high pressure of selective pressure to resistance in hospitals (10). These findings suggest that LRTIs are not only clinically significant in Kazakhstan but also part of a broader trend of heavy antimicrobial exposure in hospitals.

Despite growing national and global concerns about antimicrobial resistance (AMR), Kazakhstan lacks adequate, comprehensive city-level data on the distribution of bacterial pathogens and antimicrobial resistance trends in LRTI among hospitalized patients. This gap in the temporal and geographical dynamics of lower respiratory tract infections, pathogenicity, and pathogen patterns restricts clinicians, hospitals and policymakers from optimizing empirical treatment, enhancing antimicrobial stewardship and designing targeted prevention and monitoring approaches. This present study aims to describe the distribution of bacterial pathogens and antimicrobial resistance patterns in lower respiratory tract infection (LRTIs) among hospitalized patients in Astana and Shymkent, Kazakhstan, using routine laboratory-confirmed antimicrobial susceptibility testing (AST) data to improve antimicrobial stewardship and strengthen hospital-based surveillance systems.

This article draws on global and regional literature to contextualize the findings on lower respiratory infections (LRTIs) in hospitalized patients, antimicrobial resistance, and healthcare-associated infections (HAI) on a global level, including evidence from Central Asia and Kazakhstan. In cases where data on the area of study is scarce, other relevant, tangential information from comparable nations and hospital

settings will be used to provide context for local patterns.

Based on the International Classification of Diseases 10th Revision (ICD-10), lower respiratory tract infection is coded as J12-J22, which comprises conditions such as J12-J18 (Pneumonia), J20 (acute bronchitis), J21 (bronchiolitis), and J22 (unspecified lower respiratory infection) (11).

## Materials and Methods

This study adopted a retrospective, quantitative research design, which gives room for systematic examination of the current microbiological laboratory data to extract patterns, trends, and associations of clinical and public health importance. The quantitative design used existing data (retrospective) to observe the trends of antimicrobial resistance over a long period in time, which is crucial in identifying significant changes in epidemiology that may not be evident in cross-sectional or short-term investigations.

The research data were obtained from the Olymp Clinical Diagnostic Laboratory network facilities across two major cities. The data were collected from Astana, the capital city of Kazakhstan, and Shymkent, the third-largest city of the country, which serves as a significant urban centre in southern Kazakhstan. The choice of two geographically and administratively different urban centres gives room to enhance the generalizability and good representation of the resistance trends and data in major urban settings.

**Sampling strategy**

This sampling method used for this study may also be referred to as 'consecutive' or 'total population' sampling in the context of the retrospective approach, as it seeks to obtain all available eligible cases rather than using any probabilistic approach to obtain data from the population of interest.

All eligible respiratory specimen records at the study sites during the period were included; no sampling was applied (consecutive or total-population sampling). The findings describe patients whose specimens were processed by this laboratory and may not represent other hospitals, secondary or rural settings. The total population sampling was used to include all respiratory specimens that met the established requirements at the identified study sites in Astana and Shymkent. The data were obtained from Olymp Clinical Diagnostic Laboratory, a Joint Commission International (JCI)-accredited laboratory that provides laboratory services in accordance with international quality standards and accounts for about 50% of all laboratory diagnostics in Kazakhstan.

**Study Population and Selection criteria**

For this study, the selected population data encompasses data of hospitalized patients diagnosed with lower respiratory tract infections who had respiratory specimens submitted for microbiological culture and antimicrobial susceptibility testing at the participating institutions during the selected time frame (1st January 2022 to 31st December 2024). This population was chosen because antimicrobial resistance patterns in hospitalized patients with LRTI have the most direct relevance for empirical therapy guidelines. Several criteria were established for population selection. The International Classification of Diseases (ICD) codes were considered LRTI cases J12-J22.

Eligible specimens were sputum, bronchoalveolar lavage or endotracheal aspirate collected more than 48 hours after admission, consistent with the definition of hospital-acquired pneumonia. All clinically significant microbial isolates recovered from lower respiratory tract specimens (sputum, bronchoalveolar lavage, and/or endotracheal aspirate) were included in the analysis, comprising both bacterial and fungal pathogens. Fungal isolates were identified using standard culture and biochemical methods and/or the VITEK identification system for susceptibility testing. Fungal isolates were included in the overall distribution of organisms and, where applicable, in the antifungal susceptibility analysis.

Antifungal susceptibility results were interpreted using EUCAST clinical breakpoints where established and applicable to the identified fungal species and antifungal agent. For organism–antifungal combinations without established EUCAST clinical breakpoints, susceptibility results were not categorized using EUCAST clinical breakpoint criteria. Organism identification and susceptibility results were retrieved from the laboratory database. Data completeness was assessed based on the availability of relevant sociodemographic information, including age and sex, specimen collection date, organism identification, and antimicrobial or antifungal susceptibility results. Only records collected between 1 January 2022, and 31 December 2024 were eligible for inclusion. Specimens collected less than 48 hours after hospital admission were excluded to minimize the inclusion of infections likely acquired in the community. Each patient was counted once per organism: repeat isolates of the same organism from the same patient were treated as a single isolate. A patient with two different organisms contributed two isolates, so the 2,098 patients yielded 2,110 isolates. In addition, specimens with incomplete antimicrobial susceptibility data, particularly those lacking interpretable results for key antibiotics used to treat lower respiratory tract infections (LRTIs), were excluded from the analysis. Proportions are presented

with Wilson 95% confidence intervals, and percentages are not reported for organism–antibiotic pairs with fewer than 10 isolates.

**Data Collection**

For data collection, specimen data were extracted from the electronic laboratory information systems (ELIS) maintained by the microbiology departments at both study sites. Foremost, consent was sought from the heads of microbiology laboratories in Astana and Shymkent. The data collection process took about two months in both cities. Google translators were used to translate the data from Russian to English. There was no direct contact with the patients; therefore, the requirement for informed consent from study participants was waived by the Institutional Review Board of Nazarbayev University (protocol code: NU-IREC; submission 946/30092024; date of approval: 1st October 2024), with an exemption from informed consent. An archive was used that contained all microbiological culture results, pathogen identifications, and antimicrobial susceptibility test results in a structured digital format. The patients' demographic and clinical data (patient age, sex, admission date, specimen collection date) were also retrieved from a linked hospital information system. Extracted data were exported to the comma-separated values (CSV) format, de-identified by removing patient names and medical record numbers and assigned unique study identifiers.

**Data Analysis**

A descriptive analysis characterized the study population, pathogen distribution, and resistance patterns. Data cleaning, data management, and statistical analysis were performed using STATA 19.5 MP. Categorical variables such as sex, pathogen species, and susceptibility categories were summarized using frequencies and percentages. Continuous variables, such as age were presented as median (interquartile range). The number of antibiotics tested per isolate is summarized as median (IQR). Pathogen distribution was calculated as the proportion of each bacterial species among all isolates and stratified by year and city. Antimicrobial resistance prevalence was calculated as the proportion of isolates classified as resistant to each tested antibiotic, with Wilson's 95% confidence intervals at $\alpha$=0.05 significant level. To test the association between demographic characteristics and LRTIs, a chi-square test was performed, with a p-value <0.05 considered statistically significant.

**Ethical Considerations**

Ethical approval for this study was obtained from the institutional review boards of Nazarbayev University and the participating hospitals' ethics committees prior to data collection. The study was conducted in compliance with the declaration of Helsinki guidelines. The patients' data were fully anonymized before analysis.

## Results

**Demographic characteristics**

A total of 2,098 hospitalized patients with lower respiratory tract infections (LRTIs) were included in the study, comprising 279 patients from Astana and 1,819 from Shymkent as presented in Table 1. The age distribution differed significantly between the two cities ($p < 0.001$). Children aged 0–9 years formed the largest single age group (389 cases; 18.5%), followed by patients aged 60–69 years (328; 15.6%) and 50–59 years (294; 14.0%). Patients aged ≥60 years accounted for 588 cases (28.0%). The age distribution differed between cities ($\chi^2 = 92.5$, df = 7, $p < 0.001$): patients aged ≥60 years made up 40.1% of cases in Astana and 26.2% in Shymkent, whereas children aged 0–9 years made up 2.9% in Astana and 20.9% in Shymkent.

**Table 1.** Demographic characteristics of LRTIs among Hospitalized Patients in Astana and Shymkent from 2022 to 2024

| Age group (years) | Astana (n) | Shymkent (n) | Total (n) | Percentage of all cases | Df/ P |
|---|---|---|---|---|---|
| 0–9 | 8 | 381 | 389 | 18.5% | |
| 10–19 | 14 | 205 | 219 | 10.4% | |
| 20–29 | 18 | 168 | 186 | 8.9% | ($\chi^2 = 92.5$, df = 7, $p < 0.001$) |
| 30–39 | 41 | 185 | 226 | 10.8% | |
| 40–49 | 45 | 151 | 196 | 9.3% | |

| Age group (years) | Astana (n) | Shymkent (n) | Total (n) | Percentage of all cases | Df/ P |
|---|---|---|---|---|---|
| 50–59 | 41 | 253 | 294 | 14.0% | |
| 60–69 | 67 | 261 | 328 | 15.6% | |
| 70+ | 45 | 215 | 260 | 12.4% | |
| **Total** | **279** | **1,819** | **2,098** | **100.0%** | |

| Factor | Level | Astana | Shymkent | p-value |
|---|---|---|---|---|
| **Sex** | Female | 160 (57.3%) | 1033 (56.8%) | 0.86 |
| | Male | 119 (42.7%) | 786 (43.2%) | |
| **year** | 2022 | 3 (1.1%) | 175 (9.6%) | <0.001 |
| | 2023 | 96 (34.4%) | 748 (41.1%) | |
| | 2024 | 180 (64.5%) | 896 (49.3%) | |

The share of cases aged ≥60 years rose from 8.4% in 2022 to 27.0% in 2023 and 32.1% in 2024 (in Shymkent alone, 8.6%, 24.9% and 30.7%), while the share aged 0–9 years fell from 30.9% to 21.8% and 13.9%. Overall, children aged 0–9 years constituted the largest single age group, accounting for 389 cases (18.5%). Patients aged 60 years and above accounted for 588 cases (28.0%), comprising 328 patients aged 60–69 years and 260 aged 70 years or older. In Astana, the largest age group was 60–69 years (67; 24.0%), whereas in Shymkent, children aged 0–9 years accounted for the largest proportion (381; 20.9%).

Table 2 shows the yearly distribution of isolates from lower respiratory tract infections among hospitalized patients between 2022 and 2024, by age category, with the compound annual growth rate (CAGR) for each cohort. The isolate counts in each age group increased over the study period. The most significant increase was observed in the older age group, especially those aged ≥60, which showed the highest CAGR (379.6% per year; 15 isolates in 2022 and 345 in 2024).

**Table 2.** Age and Year category of LRTI isolates among hospitalized patients in Astana and Shymkent, 2022–2024, with the Compound Annual Growth Rate (CAGR).

| Age category (years) | 2022 (n) | 2023 (n) | 2024 (n) | Total (n) | Compound annual growth rate, 2022–2024 (%) |
|---|---|---|---|---|---|
| 0–9 | 55 | 184 | 150 | 389 | 65.1 |
| 10–19 | 32 | 77 | 110 | 219 | 85.4 |
| 20–29 | 23 | 76 | 87 | 186 | 94.5 |
| 30–39 | 19 | 84 | 123 | 226 | 154.4 |
| 40–49 | 14 | 80 | 102 | 196 | 169.9 |
| 50–59 | 20 | 115 | 159 | 294 | 182.0 |
| 60–69 | 8 | 136 | 184 | 328 | 379.6 |
| 70+ | 7 | 92 | 161 | 260 | 379.6 |
| **Total** | **178** | **844** | **1076** | **2098** | |
| **Combined age groups (shown in Supplementary Figure S1)** | | | | | |
| 0–19 | 87 | 261 | 260 | | 72.9 |
| 20–39 | 42 | 160 | 210 | | 123.6 |

| Age category (years) | 2022 (n) | 2023 (n) | 2024 (n) | Total (n) | Compound annual growth rate, 2022–2024 (%) |
|---|---|---|---|---|---|
| 40–59 | 34 | 195 | 261 | | 177.1 |
| ≥60 | 15 | 228 | 345 | | 379.6 |

*CAGR = (n2024 / n2022) ^ (1/2) − 1, calculated from the 2022 and 2024 counts only.*

Also, considerable growth was seen in the 40-59 years category, with a CAGR of 177.1%, the 20-39 years category, with a CAGR of 123.6% and 0-19 years (72.9%). The younger age groups grew more slowly (0–19 years: 72.9% per year).

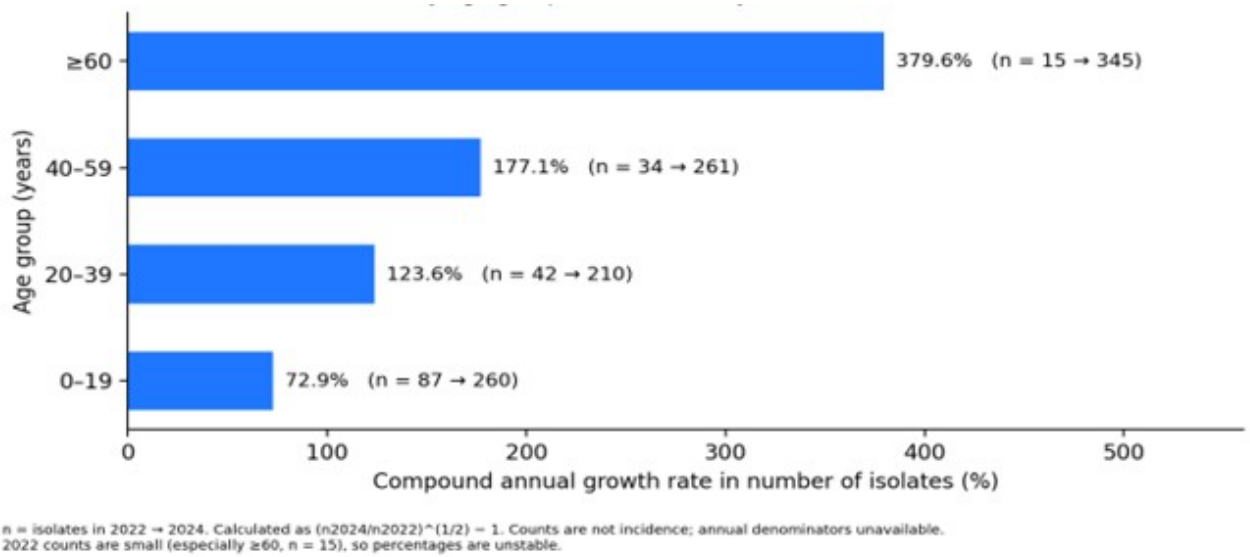


**Figure 1.** Compound annual percentage change in the number of LRTI isolates by age group, Astana and Shymkent, 2022–2024.

The number of isolates increased in all age groups from 2022 to 2024 (Figure 1). Growth was most pronounced with the age group 60 years and over, where the number of isolates rose from 15 in 2022 to 345 in 2024 (a compound annual growth rate of 379.6%). The 40–59-year group rose from 34 to 261 isolates (177.1% per year), the 20–39-year group from 42 to 210 (123.6%), and the 0–19-year group from 87 to 260 (72.9%).

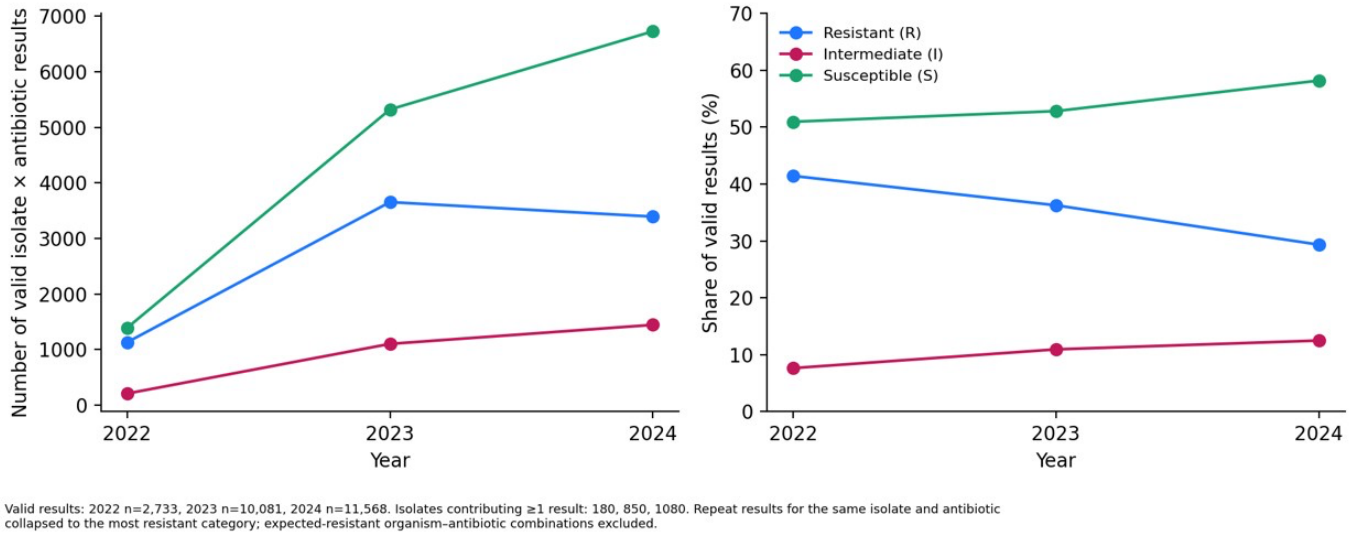


**Figure 2.** Antimicrobial susceptibility results by category (R, I, S) and by year in Astana and Shymkent.

Across the three years, 24,382 valid susceptibility results were recorded (2,733 in 2022, 10,081 in 2023 and 11,568 in 2024), from 2,110 isolates in 2,098 patients (Figure 2). The number of results far exceeds the number of patients because each isolate was tested against several antibiotics (median 12; IQR 7–14), resulting in a large number of results compared to the number of patients. In keeping with the number of isolates, there were increases in the absolute numbers of resistant, intermediate and susceptible results. Resistant results fell from 41.4% in 2022 to 36.3% in 2023 and 29.3% in 2024. Intermediate results were achieved at 7.6% and then 10.9% and finally 12.5%. Susceptible results rose from 50.9% to 52.8% and then 58.2%. These shares pool all organisms and antibiotics and depend on which antibiotics were tested each year. They therefore describe the testing data and should not be read as a true trend in resistance.

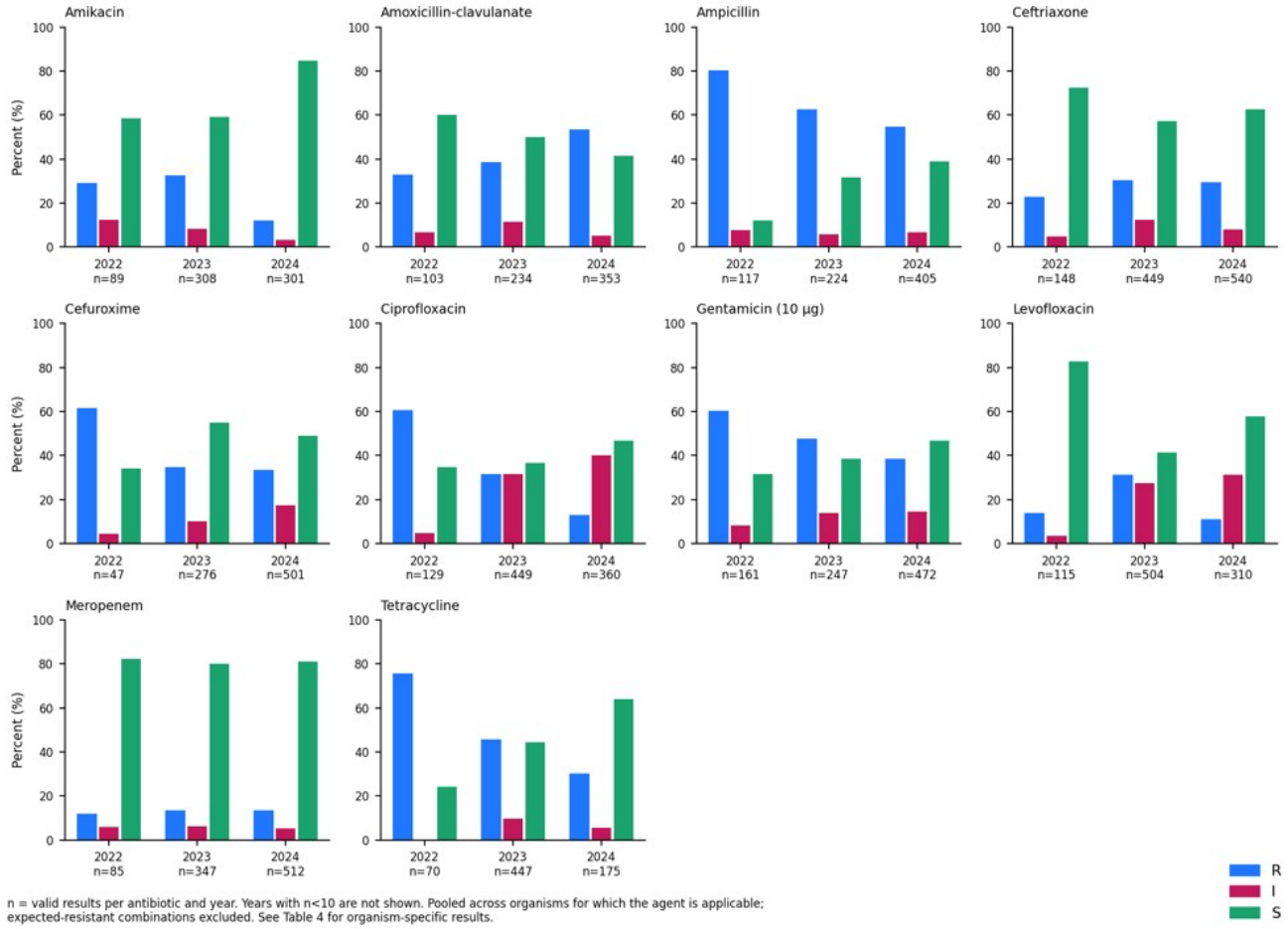


**Figure 3.** Susceptibility results for the ten most frequently tested antibiotics by year in Astana and Shymkent, 2022–2024.

This figure 3 shows the Antibiotic susceptibility of the 10 most commonly tested antibiotics over the years. The distribution of resistant, intermediate and susceptible data for each antibiotic is displayed in the Figure by year. Each bar is based on at least 47 results, and the number of results (n) is shown below each year. Trends were different for each drug. Falling resistance: ampicillin 80.3% in 2022 to 54.6% in 2024, tetracycline 75.7% to 30.3%, ciprofloxacin 60.5% to 13.1%, gentamicin 60.2% to 38.6%, and amikacin 29.2% to 12.0%. Resistance increased: amoxicillin-clavulanate 33.0% - 53.5%. Ceftriaxone rose from 23.0% to 30.3% and then held at 29.4% in 2024. Stability of resistance: meropenem remained in the 12–14% range in all 3 years. Fluoroquinolones (ciprofloxacin and levofloxacin): these had the most significant shift in intermediate category. The rates for Ciprofloxacin intermediate results increased from 4.7% to 40.0%, and Levofloxacin from 3.5% to 31.3%. The maximum level of resistance was 31.2% for levofloxacin in 2023.

**Table 3.** Resistance and intermediate susceptibility for ten most frequently tested antimicrobials within each organism group, in Astana and Shymkent, 2022–2024.

| Organism group | Antimicrobial | n tested | R, n | I, n | S, n | % R (95% CI) | % I | % R+I (95% CI) |
|---|---|---|---|---|---|---|---|---|
| **Gram-negative** | Meropenem | 668 | 87 | 43 | 538 | 13.0 (10.7–15.8) | 6.4 | 19.5 (16.6–22.6) |
| | Ciprofloxacin | 578 | 136 | 158 | 284 | 23.5 (20.3–27.2) | 27.3 | 50.9 (46.8–54.9) |
| | Amikacin | 569 | 118 | 29 | 422 | 20.7 (17.6–24.3) | 5.1 | 25.8 (22.4–29.6) |
| | Levofloxacin | 527 | 112 | 95 | 320 | 21.3 (18.0–24.9) | 18.0 | 39.3 (35.2–43.5) |
| | Ceftriaxone | 524 | 160 | 62 | 302 | 30.5 (26.7–34.6) | 11.8 | 42.4 (38.2–46.6) |
| | Gentamicin (10 µg) | 450 | 172 | 45 | 233 | 38.2 (33.9–42.8) | 10.0 | 48.2 (43.6–52.8) |
| | Tobramycin | 431 | 146 | 25 | 260 | 33.9 (29.6–38.5) | 5.8 | 39.7 (35.2–44.4) |
| | Piperacillin-tazobactam | 389 | 103 | 52 | 234 | 26.5 (22.3–31.1) | 13.4 | 39.8 (35.1–44.8) |
| | Amoxicillin-clavulanate | 365 | 193 | 37 | 135 | 52.9 (47.8–57.9) | 10.1 | 63.0 (57.9–67.8) |
| | Cefuroxime | 357 | 146 | 80 | 131 | 40.9 (35.9–46.1) | 22.4 | 63.3 (58.2–68.1) |
| **Gram-positive** | **Ceftriaxone** | **607** | **169** | **44** | **394** | **27.8 (24.4–31.5)** | **7.2** | **35.1 (31.4–39.0)** |
| | Benzylpenicillin (penicillin G) | 560 | 376 | 62 | 122 | 67.1 (63.1–70.9) | 11.1 | 78.2 (74.6–81.4) |
| | Azithromycin | 550 | 263 | 63 | 224 | 47.8 (43.7–52.0) | 11.5 | 59.3 (55.1–63.3) |
| | Vancomycin† | 538 | 236 | 50 | 252 | 43.9 (39.7–48.1) | 9.3 | 53.2 (48.9–57.3) |
| | Clindamycin | 512 | 219 | 18 | 275 | 42.8 (38.6–47.1) | 3.5 | 46.3 (42.0–50.6) |
| | Oxacillin | 484 | 331 | 49 | 104 | 68.4 (64.1–72.4) | 10.1 | 78.5 (74.6–81.9) |
| | Ampicillin | 475 | 272 | 32 | 171 | 57.3 (52.8–61.6) | 6.7 | 64.0 (59.6–68.2) |
| | Tetracycline | 466 | 201 | 29 | 236 | 43.1 (38.7–47.7) | 6.2 | 49.4 (44.8–53.9) |
| | Erythromycin | 463 | 253 | 38 | 172 | 54.6 (50.1–59.1) | 8.2 | 62.9 (58.4–67.1) |
| | Cefuroxime | 463 | 146 | 36 | 281 | 31.5 (27.5–35.9) | 7.8 | 39.3 (35.0–43.8) |
| **Fungi** | **Clotrimazole** | **355** | **69** | **67** | **219** | **19.4 (15.7–23.9)** | **18.9** | **38.3 (33.4–43.5)** |
| | Fluconazole | 352 | 77 | 44 | 231 | 21.9 (17.9–26.5) | 12.5 | 34.4 (29.6–39.5) |
| | Itraconazole | 339 | 81 | 101 | 157 | 23.9 (19.7–28.7) | 29.8 | 53.7 (48.4–58.9) |
| | Ketoconazole | 288 | 83 | 41 | 164 | 28.8 (23.9–34.3) | 14.2 | 43.1 (37.5–48.8) |
| | Nystatin | 197 | 20 | 28 | 149 | 10.2 (6.7–15.2) | 14.2 | 24.4 (18.9–30.8) |
| | Amphotericin B | 83 | 3 | 2 | 78 | 3.6 (1.2–10.1) | 2.4 | 6.0 (2.6–13.3) |
| | Miconazole | 61 | 0 | 3 | 58 | 0.0 (0.0–5.9) | 4.9 | 4.9 (1.7–13.5) |
| | Voriconazole | 48 | 0 | 0 | 48 | 0.0 (0.0–7.4) | 0.0 | 0.0 (0.0–7.4) |

***Source:*** *Hospital Lab Report, 2026*

***Note:*** *R = resistant; I = intermediate; S = susceptible; CI = 95% confidence interval. Resistance estimates are pooled by organism groups. Intrinsic or expected resistance and non-applicable organism–antimicrobial combinations were excluded. one result per patient, organism and antibiotic; median 12 antibiotics tested per isolate (IQR 7–14)*

Table 3 presents susceptibility testing data for antimicrobial agents which yielded 24,382 valid isolates-antibiotic results from 2,110 isolates in 2,098 patients. Each isolate was tested against a median of 12 antibiotics (Median 12 antibiotic per isolates; IQR 7-14; maximum 35). The table shows the differences in antimicrobial resistance across Gram-negative bacteria, Gram - positive bacteria and fungi in Astana and Shymkent, 2022–2024. Among the 2,098 patients, gram-negative bacteria (43.6%), gram-positive bacteria (39.1%) and fungi (17.3%) were the most common groups. The ten most commonly tested agents on Gram-negative isolates (Table 3) were most resistant to amoxicillin-clavulanate (52.9%), followed by cefuroxime (40.9%) and gentamicin (38.2%) and lowest to meropenem (13.0%). When results of resistance and

intermediate were grouped together, the highest percentages of non-susceptibility were for cefuroxime (63.3%) and amoxicillin-clavulanate (63.0%), with ciprofloxacin achieving the highest percentage (50.9%) primarily due to intermediate results (27.3%). The frequency of resistance among Gram-positive isolates was highest for oxacillin (68.4%), benzylpenicillin (67.1%) and ampicillin (57.3%) with high resistance also to erythromycin (54.6%) and azithromycin (47.8%) and lowest to ceftriaxone (27.8%). The highest rates of combined non-susceptibility were seen against oxacillin (78.5%) and benzylpenicillin (78.2%).

These estimates are amalgamated species estimates and give only a general indication: the results will vary by organism, Resistance was highest to ketoconazole (28.8%), followed by itraconazole (23.9%) and fluconazole (21.9%). The lowest resistance was observed with amphotericin B (3.6%). Resistance to miconazole and voriconazole was not observed for the samples tested. Considering intermediate and resistant together the highest was seen with itraconazole (53.7%), followed by ketoconazole (43.1%) and clotrimazole (38.3%). Because pooled estimates mix species with different intrinsic resistance, organism-specific results are given in Table 4. This table shows that resistance varies across organisms and antibiotics.

**Table 4.** Antimicrobial resistance by organism–antibiotic pair for the main pathogens, Astana and Shymkent, 2022–2024.

| Organism (N isolates) | Antimicrobial | n tested | R, n | I, n | % R (95% CI) | % R+I (95% CI) |
|---|---|---|---|---|---|---|
| **Staphylococcus aureus (174)** | Oxacillin | 150 | 94 | 11 | 62.7 (54.7–70.0) | 70.0 (62.2–76.8) |
| | Tetracycline | 150 | 51 | 8 | 34.0 (26.9–41.9) | 39.3 (31.9–47.3) |
| | Clindamycin | 145 | 50 | 2 | 34.5 (27.2–42.5) | 35.9 (28.5–43.9) |
| | Azithromycin | 139 | 58 | 7 | 41.7 (33.9–50.0) | 46.8 (38.7–55.0) |
| | Ceftriaxone | 136 | 58 | 9 | 42.6 (34.6–51.0) | 49.3 (41.0–57.6) |
| | Levofloxacin | 126 | 24 | 72 | 19.0 (13.1–26.8) | 76.2 (68.0–82.8) |
| | Erythromycin | 122 | 41 | 7 | 33.6 (25.8–42.4) | 39.3 (31.1–48.2) |
| | Ciprofloxacin | 120 | 25 | 70 | 20.8 (14.5–28.9) | 79.2 (71.1–85.5) |
| **Klebsiella pneumoniae (121)** | Ceftriaxone | 109 | 38 | 14 | 34.9 (26.6–44.2) | 47.7 (38.6–57.0) |
| | Meropenem | 96 | 2 | 5 | 2.1 (0.6–7.3) | 7.3 (3.6–14.3) |
| | Amikacin | 95 | 2 | 3 | 2.1 (0.6–7.4) | 5.3 (2.3–11.7) |
| | Cefuroxime | 76 | 37 | 33 | 48.7 (37.8–59.7) | 92.1 (83.8–96.3) |
| | Ciprofloxacin | 74 | 6 | 10 | 8.1 (3.8–16.6) | 21.6 (13.8–32.3) |
| | Levofloxacin | 71 | 5 | 9 | 7.0 (3.0–15.4) | 19.7 (12.1–30.4) |
| | Piperacillin-tazobactam | 69 | 18 | 2 | 26.1 (17.2–37.5) | 29.0 (19.6–40.6) |
| | Ertapenem | 66 | 4 | 3 | 6.1 (2.4–14.6) | 10.6 (5.2–20.3) |
| **Acinetobacter baumannii (59)** | Meropenem | 53 | 14 | 2 | 26.4 (16.4–39.6) | 30.2 (19.5–43.5) |
| | Gentamicin (10 μg) | 46 | 14 | 5 | 30.4 (19.1–44.8) | 41.3 (28.3–55.7) |
| | Ciprofloxacin | 39 | 14 | 24 | 35.9 (22.7–51.6) | 97.4 (86.8–99.5) |
| | Tobramycin | 37 | 11 | 1 | 29.7 (17.5–45.8) | 32.4 (19.6–48.5) |
| | Levofloxacin | 36 | 11 | 4 | 30.6 (18.0–46.9) | 41.7 (27.1–57.8) |

| Organism (N isolates) | Antimicrobial | n tested | R, n | I, n | % R (95% CI) | % R+I (95% CI) |
|---|---|---|---|---|---|---|
| | Amikacin | 35 | 10 | 1 | 28.6 (16.3–45.1) | 31.4 (18.6–48.0) |
| | Imipenem | 35 | 11 | 3 | 31.4 (18.6–48.0) | 40.0 (25.6–56.4) |
| | Ceftazidime | 32 | 26 | 0 | 81.2 (64.7–91.1) | 81.2 (64.7–91.1) |
| **Streptococcus mitis group (134)** | Azithromycin | 118 | 71 | 10 | 60.2 (51.2–68.5) | 68.6 (59.8–76.3) |
| | Ampicillin | 114 | 67 | 9 | 58.8 (49.6–67.4) | 66.7 (57.6–74.7) |
| | Vancomycin | 113 | 17 | 0 | 15.0 (9.6–22.8) | 15.0 (9.6–22.8) |
| | Clindamycin | 111 | 44 | 1 | 39.6 (31.0–48.9) | 40.5 (31.9–49.8) |
| | Erythromycin | 110 | 71 | 10 | 64.5 (55.3–72.9) | 73.6 (64.7–81.0) |
| | Ceftriaxone | 109 | 28 | 3 | 25.7 (18.4–34.6) | 28.4 (20.8–37.5) |
| | Benzylpenicillin (penicillin G) | 105 | 67 | 19 | 63.8 (54.3–72.4) | 81.9 (73.5–88.1) |
| | Clarithromycin | 103 | 67 | 5 | 65.0 (55.4–73.6) | 69.9 (60.5–77.9) |
| **Candida albicans (147)** | Clotrimazole | 143 | 37 | 38 | 25.9 (19.4–33.6) | 52.4 (44.3–60.5) |
| | Fluconazole | 143 | 47 | 13 | 32.9 (25.7–40.9) | 42.0 (34.2–50.2) |
| | Itraconazole | 143 | 44 | 39 | 30.8 (23.8–38.8) | 58.0 (49.8–65.8) |
| | Ketoconazole | 133 | 41 | 25 | 30.8 (23.6–39.1) | 49.6 (41.3–58.0) |
| | Nystatin | 96 | 6 | 19 | 6.2 (2.9–13.0) | 26.0 (18.3–35.6) |
| | Amphotericin B | 38 | 2 | 0 | 5.3 (1.5–17.3) | 5.3 (1.5–17.3) |
| | Voriconazole | 37 | 0 | 0 | 0.0 (0.0–9.4) | 0.0 (0.0–9.4) |
| **Escherichia coli (64)** | Ampicillin | 52 | 41 | 0 | 78.8 (66.0–87.8) | 78.8 (66.0–87.8) |
| | Ceftriaxone | 52 | 32 | 1 | 61.5 (48.0–73.5) | 63.5 (49.9–75.2) |
| | Amikacin | 49 | 3 | 2 | 6.1 (2.1–16.5) | 10.2 (4.4–21.8) |
| | Meropenem | 47 | 3 | 1 | 6.4 (2.2–17.2) | 8.5 (3.4–19.9) |
| | Cefuroxime | 39 | 26 | 10 | 66.7 (51.0–79.4) | 92.3 (79.7–97.3) |
| | Ciprofloxacin | 34 | 12 | 0 | 35.3 (21.5–52.1) | 35.3 (21.5–52.1) |
| | Ertapenem | 30 | 4 | 1 | 13.3 (5.3–29.7) | 16.7 (7.3–33.6) |
| | Amoxicillin-clavulanate | 30 | 19 | 1 | 63.3 (45.5–78.1) | 66.7 (48.8–80.8) |
| **Pseudomonas aeruginosa (59)** | Meropenem | 48 | 11 | 4 | 22.9 (13.3–36.5) | 31.2 (19.9–45.3) |
| | Amikacin | 43 | 6 | 0 | 14.0 (6.6–27.3) | 14.0 (6.6–27.3) |
| | Ciprofloxacin | 41 | 7 | 24 | 17.1 (8.5–31.3) | 75.6 (60.7–86.2) |
| | Cefepime | 40 | 8 | 25 | 20.0 (10.5–34.8) | 82.5 (68.0–91.3) |
| | Gentamicin (10 μg) | 38 | 13 | 10 | 34.2 (21.2–50.1) | 60.5 (44.7–74.4) |
| | Tobramycin | 37 | 7 | 1 | 18.9 (9.5–34.2) | 21.6 (11.4–37.2) |
| | Levofloxacin | 36 | 4 | 25 | 11.1 (4.4–25.3) | 80.6 (65.0–90.2) |

| Organism (N isolates) | Antimicrobial | n tested | R, n | I, n | % R (95% CI) | % R+I (95% CI) |
|---|---|---|---|---|---|---|
| | Imipenem | 36 | 10 | 18 | 27.8 (15.8–44.0) | 77.8 (61.9–88.3) |

***Note:*** *R = resistant; I = intermediate; CI = 95% confidence interval. Only organism–antimicrobial pairs with ≥30 tests are shown. Pairs with 10–29 tests are provided in the supplementary data. Intrinsic or expected resistance was excluded.*

The highest level of resistance was seen with oxacillin among the Staphylococcus aureus (62.7%). For the klebsiella pneumoniae, the highest level of resistance was seen against cefuroxime (48.7%) and the lowest against meropenem and amikacin (2.1%). Acinetobacter baumannii was especially highly resistant to ceftazidime (81.2%). In streptococci of the mitis group, the highest rates of resistance were observed against clarithromycin (65.0%), and erythromycin (64.5%). The highest level of resistance was observed with fluconazole (32.9%) and voriconazole was not detected in the samples tested for Candida albicans. The resistance rates for Escherichia coli were 78.8% to ampicillin, 66.7% to cefuroxime and 61.5% to ceftriaxone. Resistance to amikacin (6.1%) and meropenem (6.4%) was low, in contrast. The highest resistance rate of Pseudomonas aeruginosa was to gentamicin (34.2%) and the lowest to levofloxacin (11.1%).

## Discussion

This study provides valuable insights into the epidemiology of LRTIs in hospitalized individuals in Astana and Shymkent, Kazakhstan, from 2022 to 2024. The results show an increase in recorded LRTI cases over the course of the study. Gram-negative bacteria were the predominant pathogens, accounting for 43.61% of all isolates. Common pathogens identified included Staphylococcus aureus, Klebsiella pneumoniae, Streptococcus mitis, Acinetobacter baumannii, and Candida albicans. Antimicrobial susceptibility results indicated resistance to commonly used antibiotics, including ampicillin, gentamicin, and azithromycin. This study provides baseline information on the distribution of pathogens and organism-specific resistance patterns in bacterial resistance and distribution patterns in hospitalized patients with LRTIs, which extends the existing evidence on patterns of antimicrobial resistance (AMR) in Kazakhstan. The results highlight the importance of strengthening antimicrobial stewardship programs, regular monitoring, and optimizing antibiotic prescribing to address the challenges posed by AMR and ultimately enhance patient health results.

**Comparison with Regional and Global Studies**

The predominance of Gram-negative bacteria, including Klebsiella pneumoniae, Acinetobacter baumannii, and Pseudomonas aeruginosa, in the results agreed with regional and global trends. This concordance highlights the importance of these pathogens in lower respiratory tract infections (LRTIs), consistent with a study in northern Vietnam (2022–2024), in which these three Gram-negative bacteria were the most common causes of hospital-acquired pneumonia (16). In the same vein, an observational study in China before the pandemic demonstrated that Gram-negative pathogens, especially P. aeruginosa, K. pneumoniae, and E. coli, were the primary causes of ICU infections (12). This geographical consistency indicates that homogeneous healthcare challenges are experienced; therefore, the need to strengthen infection control is supported by a national assessment in which only 55% of hospitals conducted IPC monitoring and only 9% used the results to improve practice (22).

Additionally, these findings were supported by a cohort study of elderly patients with pneumonia in Thailand, in which K. pneumoniae (20.4%) and P. aeruginosa (15.5%) were the most prevalent etiological agents among hospitalized patients (14). These trends suggest a global transformation towards Gram-negative organisms, which are slowly replacing conventional community pathogens, such as Streptococcus pneumoniae, especially among vulnerable patient groups. The World Health Organization (WHO) and the Centers for Disease Control and Prevention (CDC) have also recognized these organisms as priority pathogens, the report by the WHO in 2025 highlights the increasing threat of drug-resistant Gram-negative pathogens, and the K. pneumoniae and E. coli exhibit over 40-55% rates of resistance to first-line cephalosporins in addition to rapidly increasing rates of carbapenem resistance (13).

**Antimicrobial Resistance Trend**

The observed high resistance rates, especially to broad-spectrum penicillins, including ampicillin, and to aminoglycosides, such as gentamicin, support the view that β-lactamase and other resistance mechanisms are prevalent among these hospital isolates. Similar findings, including an alarming rise in carbapenemase-producing K. pneumoniae and P.

aeruginosa, have been reported in Eastern Europe and Central Asia (16, 17), further adding to the challenges in the management of these infections. Another area of concern was resistance to azithromycin, which was also prominent. Although it is considered a community pathogen, the recent rise in azithromycin use, partly due to its use in treating COVID-like pneumonia, has led to higher resistance rates worldwide. For example, a study from India reported a resistance rate of about 22% to azithromycin among clinical pathogens, most of which were classified as multidrug-resistant (18). The observed resistance rates to ampicillin (78.8%) and cefuroxime (66.7%) in E. coli and to oxacillin (62.7%) in S. aureus exceeded 50%, whereas resistance to carbapenems and amikacin in Enterobacterales stayed below 10%. This suggests the ineffectiveness of many traditional antibiotics used against the current hospital strains (19).

Our results are also consistent with a systematic review and meta-analysis of pneumonia cases in hospital setting in the country of Kazakhstan from 2008 to 2022 (23) of which 48% of the isolates were hospital-acquired pathogens. In that review, K. pneumoniae showed relatively low resistance, as in our series (meropenem 2.1%); E. coli resistance to β-lactams exceeded 66%, comparable to our ampicillin (78.8%) and cefuroxime (66.7%) results; and P. aeruginosa carbapenem resistance was 27%, close to our imipenem result (27.8%). Our E. coli fluoroquinolone resistance (ciprofloxacin 35.3%) and A. baumannii carbapenem resistance (26.4–31.4%) were lower than the 63% and above 70% reported there, which may reflect differences in time period, population, specimen type or testing methods.

Notably, our study's finding of substantial fungal representation (17.3% of isolates, predominantly Candida albicans) parallels (22)'s observation of an 'unexpected prevalence' of Candida spp. among pneumonia isolates nationally, which they attributed in part to the inclusion of COVID-19 patients in underlying studies. This study period (2022–2024) overlaps with the pandemic recovery phase, and we similarly cannot exclude the influence of post-COVID immune or comorbidity factors on fungal isolate prevalence.

**Age-related vulnerability**

The age-related vulnerability observed in this study aligns with international patterns in which elderly patients commonly account for the most severe cases of pneumonia. In Italy, for instance, adults over 75 years constituted more than 50% of hospitalized LRTI cases in one retrospective study, while in Thailand, Gram-negative organisms predominated LRTIs in patients aged 60 and older (20; 21). Given that LRTIs are recognized as leading causes of death among older adults, the disproportionate impact of these infections on patients aged ≥60 in this present study underscores the need for tailored interventions, such as aggressive vaccination strategies and the careful de-escalation of invasive devices (15).

In this study, between 2022 and 2024, the number of recorded cases among patients aged ≥60 increased from 15 isolates to 345 isolates. The proportion of annual cases involving this age group also increased substantially, from 8.4% to 32.1%.

**Antimicrobial Resistance Surveillance Effort in Kazakhstan**

Surveillance of antimicrobial resistance (AMR) initiative is a recent trend in Kazakhstan, which is both developing and changing quickly as the nation attempts to find its way in the post-Soviet healthcare sector. The AMR statistics in Kazakhstan and the comparison with other Central Asian states can be of great interest, given the obstacles to modernizing the post-Soviet healthcare system. Despite attempts to create an effective system of AMR monitoring, numerous challenges remain, and these barriers are rooted in the history of Soviet systems of labs and their infrastructure. The Republican Center of Healthcare Development (RCHD) is the largest organization that monitors AMR in Kazakhstan, and it operates within the Ministry of Health. Additionally, Kazakhstan has pledged commitment to standardized surveillance of resistance by collecting data on a systematic basis, based on designated sentinel sites, since participating in the World Health Organization Global Antimicrobial Resistance and Use Surveillance System (GLASS) (22; 27). However, the enforcement of these efforts has been characterized by geographical gaps and a slow pace of implementation, resulting in significant operational challenges that hinder optimal effectiveness. The national AMR surveillance system of Kazakhstan has about 40-50 microbiological laboratories, most of which are situated in the largest urban centers, including Astana, Almaty, and Shymkent. It is the mandate of these laboratories to transmit resistance information through a systematic reporting system that ultimately reports to the National Reference Center of Microbiology in Almaty. However, recent data on the prevalence of the automated antimicrobial susceptibility testing systems with international quality assurance standards show that only a subset of surveillance laboratories in low- and middle-income countries have this system in place, which limits the reliability and comparability of data. National guidelines based on the WHO core components of IPC and systematic monitoring of IPC practice have been proposed as the first steps (22).

**Evidence from Central Asia and a similar Health Systems**

Central Asia as a region has been grossly underserved in terms of research regarding antimicrobial resistance (AMR), and information published in other neighboring countries of Kazakhstan, such as Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan, is remarkably limited. Although it shows that there are regional trends in AMR, the existing gaps in data make it impossible to conduct comprehensive comparative assessments that are essential in formulating efficient avenues of public health. The AMR situation in Central Asia has a range of common characteristics between the countries of the region. The existing body of practices regarding antibiotic prescription, which has mostly been shaped by the traditions of the Soviet era, is inclined towards the application of broad-spectrum antibiotics and a longer duration of treatment. According to (24), the recommended 7-10 days of antibiotic treatment for hospital-acquired pneumonia in Kazakhstan, Uzbekistan, and Kyrgyzstan is exceeded by 14 days in most cases. This is possibly one of the most significant factors contributing to the increased rate of resistant bacterial strains arising from such long exposure. Additionally, antibiotic sales are a major challenge in Central Asia. Prescription-less availability of many antibiotics at local pharmacies, despite different regulations, does exist. Studies show that antibiotics have been bought without a prescription for years in Eurasian countries; in Kazakhstan and Kyrgyzstan this includes fluoroquinolones (24, 25). This unregulated access promotes inappropriate self-medication.

**Geographic Disparities between Astana and Shymkent**

This study shows a large burden of lower respiratory tract infection (LRTI) cases among hospitalized patients in Shymkent (n=1,819, 86.7%) compared to Astana (n=279, 13.3%). Such a large disparity cannot be accounted for solely by population differences, as Shymkent's population (1.2 million) is only slightly smaller than Astana's (1.6 million). There are Several factors contributing to this geographic distribution. The participating hospitals in Shymkent may have a larger coverage area or serve as the main referral center for a larger patient population than in Astana, where multiple tertiary care centers may share the burden of LRTI cases. However, differences in the testing patterns for microbiological confirmation, such as specimen submission criteria, laboratory capacity, and testing priorities, may lead to biased detection, resulting in higher case identification in Shymkent. Also, there may be real differences in the infection control resources, antibiotic stewardship program development, healthcare worker-to-patient ratio, and hospital capacity that may lead to a higher LRTI burden in the hospital in Shymkent. The persistent temporal trends observed in both cities, with a similar increase in number of isolates, suggest that the underlying causes are at the national or systemic level rather than limited to a specific location.

This trend indicates that interventions should aim to address national practices in prescribing, formulary regulations, stewardship frameworks, and infection control protocols, rather than focusing solely on improvements at individual facilities. Nonetheless, the considerable size of the disparity suggests that Shymkent could benefit from targeted investigations to determine whether local conditions (including staffing, infrastructure quality, patient severity, and patterns of antibiotic use) contribute to the increasing risk of LRTI among hospitalized patients, and whether such challenges could be addressed through targeted facility-level interventions.

**Public Health Implications**

The results of the study show substantial resistance to several frontline antibiotics, with marked differences by organism. Third generation of cephalosporin resistance was common in Enterobacterales (ceftriaxone: K. pneumoniae 34.9%, E. coli 61.5%), and amoxicillin-clavulanate resistance exceeded 50% among Gram-negative isolates (52.9%). Carbapenem resistance, by contrast, was low in K. pneumoniae (meropenem 2.1%) and E. coli (6.4%) but appreciable in A. baumannii (26.4%) and P. aeruginosa (22.9%). Because these resistances differ a lot between organisms, empirical regimens for LRTIs in hospitalized patients should be guided by local, organism-specific antibiograms and reviewed regularly against current susceptibility data. These reasons highlight the importance of immediate changes in clinical practice and population health policy to improve the control of lower respiratory tract infections (LRTIs) among hospitalized patients. Given the increasing resistance levels, especially to widely used antibiotics, there is a strong need for clinicians to use local antibiograms to guide therapeutic choices. Local antibiograms should guide when broader-spectrum agents such as carbapenems or β-lactam/β-lactamase inhibitor combinations are justified for empirical treatment of Gram-negative LRTI (26). The changes in resistance patterns require regular updating of clinical guidelines, and empirical treatment regimens for lower respiratory tract infection (LRTIs) should be regularly reviewed against the current local epidemiology and antimicrobial susceptibility data (5; 13)

The experience of educational and stewardship interventions in Kazakhstan highlights the possibility

of the benefits of such programs. An example was seen in a comprehensive stewardship intervention, carried out in hospitals in the Aktobe region, resulting from 75% to 93% rise in the adherence rates to the antibiotic prescribing guidelines for pneumonia, and a dramatic improvement in the diagnostic stewardship, as evidenced by the rise in microbiological testing (6). In Astana and Shymkent, such programs might be useful for reducing the overuse and inappropriate use of antibiotics such as ampicillin, gentamicin, and azithromycin, as well as for enhancing timely de-escalation of antibiotics based on culture results.

**Strengths and Limitations**

This current study has shown noticeable strengths. It evaluated three years of microbiological data from two large cities in Kazakhstan, facilitating strong trend analysis and geographic variation. The demographic data, especially age, were included, enabling the identification of vulnerable groups at higher risk of lower respiratory tract infections (LRTIs) and of susceptible bacterial strains, especially among older adults. The study fills an important gap in local surveillance of antimicrobial resistance by focusing on lower respiratory tract infections (LRTIs) among hospitalized patients. As one of the first multicenter studies in Astana and Shymkent, it provides a broader view of the world than past reports that covered isolated hospitals. Furthermore, the positioning of LRTIs within the broader framework of respiratory infections, such as community-acquired pneumonia (CAP), enhances the study's applicability to the population's overall health.

Several limitations have been identified in this study. Firstly, the retrospective laboratory design did not provide sufficient clinical information, including patient outcomes, comorbidities, and prior antibiotic exposure. Although cases were classified as hospital-acquired, some misclassification between community-acquired and hospital-acquired LRTI could not be excluded because clinical timing data were unavailable. In addition, there is limited publicly available data on antimicrobial resistance trends in Kazakhstan, which restricts comparative analysis and broader contextual interpretation of the findings. Also, Antibiotic panels were not standardized across isolates or laboratories, so the proportions resistant may not represent all LRTI isolates. Results for some organism–antibiotic pairs are based on fewer than 30 isolates. Despite these constraints, the study provides valuable baseline evidence and underscores the urgent need for strengthened, integrated AMR surveillance systems in the country.

## Conclusion

This research provides valuable multicenter evidence on the distribution of bacterial pathogens and trends in antimicrobial resistance among hospitalized patients with lower respiratory tract infections in Astana and Shymkent, Kazakhstan. The three-year review of microbiological results provides a useful picture of city-level resistance among hospitalized patients with respiratory infections. Resistance differed by organism and antibiotic. Third-generation cephalosporin resistance was common in Enterobacterales (ceftriaxone: K. pneumoniae, E. coli), carbapenem resistance was low in K. pneumoniae, but appreciable in Acinetobacter baumannii and Pseudomonas aeruginosa, macrolide resistance was high in viridans streptococci (azithromycin 60.2%), and fluconazole resistance in C. albicans was 32.9%. Several pairs rest on modest numbers of isolates, and local antibiograms by organism, rather than pooled figures, should guide empirical therapy. Also, the number of isolates from older adults, especially those aged 60 and above, is rising, underscoring the growing clinical and public health significance of LRTIs in vulnerable groups. These findings have tremendous clinical practice and health policy implications. The empirical treatment guidelines must be adjusted based on local resistance patterns, and antimicrobial stewardship programs, infection prevention policies, and national surveillance systems must be reinforced. The success of implementing the National AMR Action Plan in Kazakhstan will require long-term institutional commitment, improved data systems, and the specific allocation of resources. Therefore, future research, including genomic investigation and outcome measurements, will be required to make national AMR policies more precise. In general, this innovative multicenter research generated important evidence at the local level at an opportune moment. Going forward, evidence-based interventions are required at a coordinated level to avert further emergence of antimicrobial resistance; counter further spread and ensure the success of current treatment tools for respiratory infections among hospitalized patients.

## Supplementary Materials

Supplementary file available via:
https://www.journalehdi.com/suppfile/809/ehdi066_Supplementary_Table_S1_revised.pdf

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