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Reported Antimicrobial Resistance in Bloodstream Infections in Conflict-Affected Countries: A Cross-Sectional Analysis of 2023 Global Antimicrobial Resistance and Use Surveillance System Data From 99 Countries

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Reported Antimicrobial Resistance in Bloodstream Infections in Conflict-Affected Countries: A Cross-Sectional Analysis of 2023 Global Antimicrobial Resistance and Use Surveillance System Data From 99 Countries

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Abstract

Background

Armed conflict is believed to be linked to an increase in antimicrobial resistance (AMR), but available evidence driving this assumption is based on single hospitals or evacuated patients. National surveillance data from conflict-affected countries are rarely compared with those of other countries, partly because these countries are mostly low- or lower-middle-income and test fewer patients, so simple comparisons can be misleading. I compared reported AMR in bloodstream infections between conflict-affected and other countries, adjusting for national income and examining testing coverage.

Methods

I analyzed 2023 bloodstream infection data from the World Health Organization Global Antimicrobial Resistance and Use Surveillance System (GLASS), classifying countries by World Bank 2024 conflict and income lists, and repeated the analysis with 2021-2022 data. Six resistance outcomes in *Escherichia coli*, *Klebsiella pneumoniae*, *Acinetobacter* spp. and *Staphylococcus aureus* were compared using income-adjusted country-level regression.

Results

Ninety-nine countries, of which 13 were conflict-affected, reported testing coverage in 2023. Conflict-affected countries reported a median of 11.9 vs. 231.8 confirmed bloodstream infections per million population, with similar gaps in 2021-2022. Unadjusted resistance was higher for four of six outcomes, but most differences disappeared after income adjustment. Carbapenem-resistant *E. coli* remained higher in 2023 (adjusted odds ratio 3.17, 95% CI 1.82-5.52) and over 2021-2023 (2.23, 1.22-4.11), but varied on a yearly basis. Third-generation cephalosporin-resistant *K. pneumoniae* was modestly but consistently higher (1.64, 1.12-2.40). In all three years, lower testing coverage accompanied higher resistance for most outcomes.

Conclusions

Most of the higher resistance in conflict-affected countries was explained statistically by national income and limited testing. Carbapenem-resistant *E. coli* needs laboratory confirmation, and resistance figures from low-testing countries need cautious interpretation.

Keywords: antimicrobial resistance; armed conflict; bloodstream infection; carbapenem resistance; *Escherichia coli*; WHO GLASS; surveillance; selection bias

Background

Antimicrobial resistance (AMR) is a major threat to global health, and because treatment options are limited, it is important to understand the conditions under which it spreads. In 2019, bacterial AMR was directly responsible for an estimated 1.27 million deaths, and resistance in Gram-negative bacteria such as *Escherichia coli* and *Klebsiella pneumoniae* accounted for a large share of this burden [1]. Bloodstream infections caused by these organisms are especially dangerous because treatment usually has to start before culture tests yield any results.

Armed conflict is widely thought to make this problem worse. War damages hospitals and laboratories, interrupts the supply of antibiotics, and fills wards with patients who have contaminated wounds and long hospital stays [2,3]. Routine infectious disease surveillance is also disrupted, as described during the war in Ukraine [4]. Studies of war-wounded patients in Ukraine have reported highly multidrug-resistant Gram-negative bacteria [5,6], and carbapenemase-producing bacteria have been found in Ukrainian patients transferred to hospitals in other European countries [7-9]. Similar findings have been described in Iraq, Syria, Nigeria, and the Democratic Republic of the Congo [10-13].

Most of this evidence, however, comes from single hospitals, case series, or patients who were evacuated abroad. Fewer studies have compared national surveillance data from conflict-affected countries with data from other countries. A systematic review from the Middle East found that resistance among WHO priority pathogens was often higher in conflict-affected than in non-conflict settings [14], and a recent analysis from the Eastern Mediterranean Region found weaker surveillance and lower detection of bloodstream infections in countries affected by conflict [15]. Both were limited to one region.

Comparing countries is complicated by two main problems: first, most conflict-affected countries are low- or lower-middle-income countries, and resistance is generally higher in poorer countries regardless of conflict; second, when microbiology services are scarce, cultures tend to be taken only from the sickest patients and from those who have already failed empirical treatment. This can make reported resistance look higher than it really is.

The aim of this study was to compare reported resistance in bloodstream infections between conflict-affected and other countries worldwide using 2023 data from the World Health Organization (WHO) Global Antimicrobial Resistance and Use Surveillance System (GLASS), and to examine how much of any difference could be explained by national income and testing coverage.

Methods

Study Design and Data Source

This was a cross-sectional ecological study in which the unit of analysis was the country, territory, or area reporting to GLASS. Data for 2023 were downloaded from the public GLASS dashboard on 22 October 2026, and data for 2021 and 2022 on 24 October 2026 (dashboard last updated 25 September

2025) [16]; the export files and filter settings are listed in Additional file 2. I used two datasets for 2023, both restricted to bloodstream specimens: resistance to individual antibiotics by country, and testing coverage by country. For each country and antibiotic, the resistance dataset gives the number of isolates with an interpretable antimicrobial susceptibility testing (AST) result, the number resistant, and the percentage resistant. All counts used in the analysis were taken directly from these exports; none was derived from a rounded percentage.

Exposure and Covariates

Countries were classified using the World Bank fiscal year (FY) 2024 list of fragile and conflict-affected situations (FCS), which was issued in July 2023 and therefore covers the 2023 data year [17]. The list has two categories: countries affected by conflict and countries with high institutional and social fragility. In the primary analysis, countries in the conflict category were compared with countries on neither list, and countries in the fragility category were excluded. National income was classified using the World Bank FY24 income groups (low income, lower-middle income, upper-middle income, and high income) [18].

Outcomes

Six outcomes were chosen because they are WHO priority indicators and were reported by most countries: carbapenem resistance and third-generation cephalosporin resistance in *E. coli* and *K. pneumoniae*, carbapenem resistance in *Acinetobacter* spp., and methicillin resistance in *Staphylococcus aureus* (MRSA). For carbapenem resistance, the meropenem result was used, or the imipenem result if meropenem was not reported. For third-generation cephalosporin resistance, the ceftriaxone result was used, or cefotaxime or ceftazidime if ceftriaxone was not reported. In line with the GLASS dashboard, a country was included for an outcome only if at least 10 isolates had an interpretable AST result [16].

Testing coverage was defined as the number of bacteriologically confirmed bloodstream infections reported to GLASS per million population in 2023 [16].

Statistical Analysis

Resistance percentages and testing coverage were summarized as medians with interquartile ranges (IQRs) and compared between groups using the Mann-Whitney U test. To account for income, I fitted a country-level linear regression for each outcome, with the empirical log-odds of resistance, $\log[(R + 0.5) / (N - R + 0.5)]$, as the dependent variable, where R is the number of resistant isolates and N is the number tested. Conflict status and income group (four categories) were the independent variables, and heteroskedasticity-robust (HC3) standard errors were used. The exponentiated coefficient for conflict status was reported as an adjusted odds ratio (aOR) with a 95% confidence interval (CI). Because almost all conflict-affected countries were low- or lower-middle-income, I also compared conflict-affected and other countries within these two income groups only. Testing coverage was compared with the same approach after $\log_{10}$ transformation. The association between testing coverage and resistance across all countries was assessed using Spearman correlation.

Six sensitivity analyses were performed: (1) combining the conflict and fragility categories; (2) including only countries with at least 30 tested isolates; (3) using the World Bank FY25 income groups; (4) using the current World Bank FY27 income groups; (5) fitting a quasi-binomial regression weighted by the number of isolates tested; and (6) adding $\log_{10}$ testing coverage to the income-adjusted model, to

examine whether differences in testing explained the association with conflict. For carbapenem resistance in *E. coli*, the primary model was also repeated after removing each conflict-affected country in turn, and after removing every combination of two and of three conflict-affected countries. To test whether the findings were consistent over time, the main analyses were repeated with GLASS bloodstream data for 2021 and 2022, downloaded from the same dashboard and prepared in the same way. Conflict status and income were classified using the FY24 lists, as in the primary analysis, so that the same countries were compared in all years; the World Bank income groups for each data year (FY22 and FY23) were used in a sensitivity analysis. The three years were also combined in one model that included terms for year, with standard errors clustered by country, and interactions between conflict status and year were used to test whether the association differed between years. The leave-one-out analysis was repeated for outcomes that were significant in the combined model. Because the substitution of imipenem for meropenem, or of cefotaxime or ceftazidime for ceftriaxone, means that countries were not all compared on the same antibiotic, the main and combined models were also repeated using meropenem and ceftriaxone only. Two-sided p-values below 0.05 were considered statistically significant. Because six outcomes were tested, I also report whether results remained significant at a Bonferroni-corrected threshold of 0.0083. Analyses were performed in Python 3.13 using pandas and SciPy, and all results were checked independently in R.

Ethical Considerations

The study used only publicly available, aggregated, national-level data without individual patient information, so ethical approval was not required.

Use of Artificial Intelligence

Claude (Anthropic), a generative artificial intelligence tool, was used to assist with writing analysis code and figure preparation. The author ran, checked, and verified all analyses independently in Python and R, and takes full responsibility for the content of the published work.

Results

Countries and Testing Coverage

Ninety-nine countries reported bloodstream infection testing coverage to GLASS for 2023: 38 high-income, 20 upper-middle-income, 29 lower-middle-income, and 12 low-income countries. Thirteen were on the FY24 conflict list and four on the fragility list. Six of the 19 countries on the conflict list (Central African Republic, Niger, Somalia, South Sudan, Sudan, and Syria) did not report bloodstream infection data for 2023. Of the 13 conflict-affected countries, seven were low-income, four lower-middle-income, and two upper-middle-income; none was high-income. Afghanistan reported only two bloodstream isolates, so 12 conflict-affected countries contributed resistance data (Table 1).

Conflict-affected countries reported a median of 11.9 confirmed bloodstream infections per million population (IQR 2.4-18.5), compared with 231.8 (IQR 43.9-736.2) in other countries ($p < 0.001$; Figure 1). Within low- and lower-middle-income countries, the medians were 11.6 and 32.3 per million, respectively ($p = 0.013$). After adjustment for income group, testing coverage in conflict-affected countries was about half that of other countries, but the difference was not statistically significant (ratio 0.48, 95% CI 0.16-1.46; $p = 0.20$).

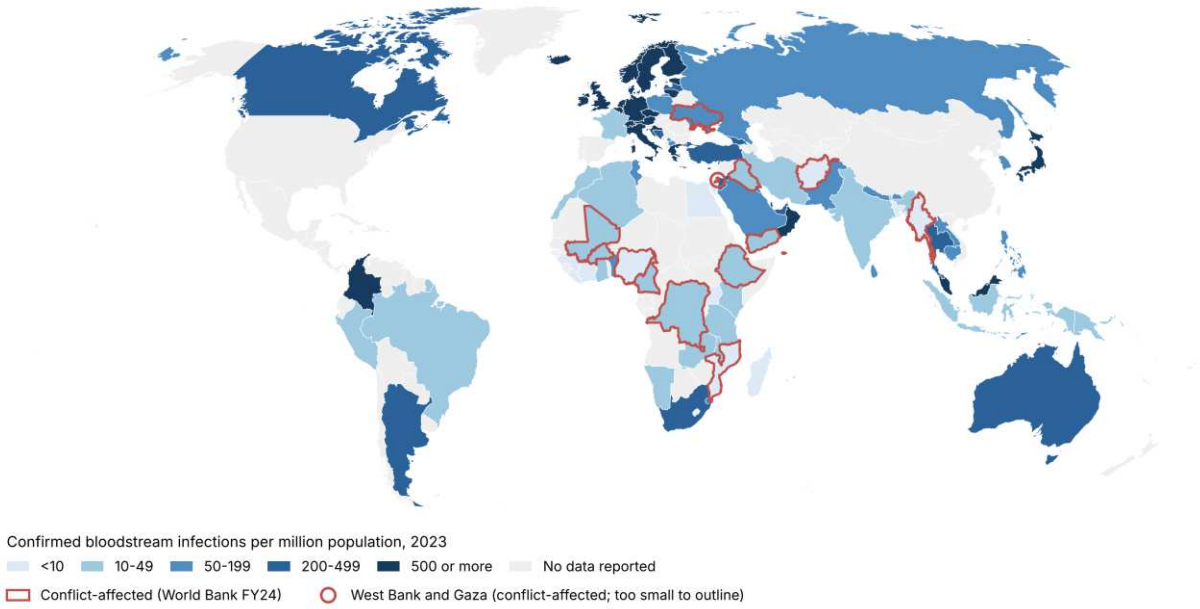


Figure 1: Testing coverage for bloodstream infections reported to GLASS, 2023. Shading shows the number of confirmed bloodstream infections per million population. Red outlines mark the 13 conflict-affected countries (World Bank FY24) that reported to GLASS; West Bank and Gaza is marked with a circle because it is too small to outline. Countries in grey did not report testing coverage for 2023, so conflict-affected countries that did not report are not outlined. Boundaries are from Natural Earth, with Crimea shown as part of Ukraine.

Country	WHO region	Income group	BSI per million	*E. coli* CR	*E. coli* 3GC-R	*K. pn.* CR	*K. pn.* 3GC-R	*Acin.* CR	MRSA
Afghanistan	EMR	Low	0.0	-	-	-	-	-	-
Burkina Faso	AFR	Low	11.9	20.0	88.5	19.0	96.8	63.6	22.0
Cameroon	AFR	Lower-middle	11.9	20.0	72.2	20.7	75.9	30.0	62.5
DR Congo	AFR	Low	10.8	18.2	73.1	15.7	90.2	76.2	90.4
Ethiopia	AFR	Low	13.7	17.9	77.1	40.7	93.1	45.7	50.0
Iraq	EMR	Upper-middle	48.0	16.9	84.6	61.8	84.3	72.7	89.7
Mali	AFR	Low	11.6	-	45.1	-	66.7	40.0	8.0
Mozambique	AFR	Low	1.5	-	40.0	17.6	82.4	-	16.7
Myanmar	SEAR	Lower-middle	2.4	23.3	76.5	63.0	93.1	33.3	40.0
Nigeria	AFR	Lower-middle	1.3	33.3	72.7	38.1	90.9	50.0	68.8

Country	WHO region	Income group	BSI per million	*E. coli* CR	*E. coli* 3GC-R	*K. pn.* CR	*K. pn.* 3GC-R	*Acin.* CR	MRSA
Ukraine	EUR	Lower-middle	50.3	10.7	52.9	70.1	84.5	79.3	13.5
Yemen	EMR	Low	18.5	24.2	83.3	48.5	95.5	68.5	79.0
West Bank and Gaza	EMR	Upper-middle	197.1	3.8	45.4	14.4	64.6	64.2	11.4
Other countries, median			231.8	0.8	38.9	15.4	54.8	58.6	32.5

Table 1: Testing coverage and reported resistance (%) in bloodstream isolates from conflict-affected countries, 2023. 3GC-R: third-generation cephalosporin resistance; *Acin.*: *Acinetobacter* spp.; AFR: African Region; BSI: confirmed bloodstream infections reported to GLASS; CR: carbapenem resistance; EMR: Eastern Mediterranean Region; EUR: European Region; GLASS: Global Antimicrobial Resistance and Use Surveillance System; *K. pn.*: *Klebsiella pneumoniae*; MRSA: methicillin-resistant *Staphylococcus aureus*; SEAR: South-East Asia Region. Conflict-affected countries are those on the World Bank FY24 conflict list that reported to GLASS in 2023. A dash indicates fewer than 10 isolates with an interpretable result. Data are from the WHO GLASS dashboard [16].

Resistance in Conflict-Affected and Other Countries

Without adjustment, conflict-affected countries reported higher resistance for four of the six outcomes (Table 2). The largest difference was for carbapenem-resistant *E. coli* (median 19.1% vs. 0.8%; $p < 0.001$). Third-generation cephalosporin resistance was also higher in both *E. coli* (72.9% vs. 38.9%; $p = 0.002$) and *K. pneumoniae* (87.4% vs. 54.8%; $p < 0.001$), as was carbapenem resistance in *K. pneumoniae* (38.1% vs. 15.4%; $p = 0.021$). There was no difference for carbapenem-resistant *Acinetobacter* spp. (63.6% vs. 58.6%; $p = 0.85$) or MRSA (45.0% vs. 32.5%; $p = 0.22$).

After adjustment for income group, most of these differences became small and were no longer significant (Figure 2). Carbapenem resistance in *E. coli* was the only outcome that remained higher in conflict-affected countries (aOR 3.17, 95% CI 1.82-5.52; $p < 0.001$), and this result remained significant after Bonferroni correction. Carbapenem resistance in *K. pneumoniae* showed a weaker, non-significant trend (aOR 2.29, 95% CI 0.94-5.62; $p = 0.069$). When the comparison was restricted to low- and lower-middle-income countries, carbapenem-resistant *E. coli* was again more common in conflict-affected countries (20.0% vs. 8.7%; $p = 0.010$; Figure 3), as was third-generation cephalosporin resistance in *K. pneumoniae* (90.6% vs. 81.5%; $p = 0.034$).

Outcome	Countries, conflict / other	Conflict, median % (IQR)	Other, median % (IQR)	p value	Crude OR (95% CI)	aOR (95% CI)	p value
E. coli, carbapenems	10 / 77	19.1 (17.1-22.4)	0.8 (0.0-6.2)	<0.001	18.38 (9.48-35.64)	3.17 (1.82-5.52)	<0.001

Outcome	Countries, conflict / other	Conflict, median % (IQR)	Other, median % (IQR)	p value	Crude OR (95% CI)	aOR (95% CI)	p value
E. coli, third-generation cephalosporins	12 / 77	72.9 (51.1-78.7)	38.9 (17.4-63.4)	0.002	3.60 (2.09-6.21)	1.18 (0.60-2.30)	0.63
K. pneumoniae, carbapenems	11 / 76	38.1 (18.3-55.1)	15.4 (1.4-36.6)	0.021	5.03 (2.38-10.65)	2.29 (0.94-5.62)	0.069
K. pneumoniae, third-generation cephalosporins	12 / 77	87.4 (80.7-93.1)	54.8 (21.4-78.3)	<0.001	5.85 (3.26-10.50)	1.47 (0.84-2.57)	0.18
Acinetobacter spp., carbapenems	11 / 71	63.6 (42.9-70.6)	58.6 (19.5-76.3)	0.85	1.68 (0.84-3.37)	0.68 (0.33-1.37)	0.28
S. aureus, methicillin (MRSA)	12 / 76	45.0 (15.9-71.4)	32.5 (13.6-47.9)	0.22	2.03 (0.73-5.63)	0.71 (0.17-2.94)	0.64

Table 2: Reported resistance in bloodstream isolates in conflict-affected and other countries, 2023. aOR: adjusted odds ratio; CI: confidence interval; IQR: interquartile range; MRSA: methicillin-resistant *Staphylococcus aureus*; OR: odds ratio. The first p value is from the Mann-Whitney U test. Odds ratios are from country-level linear regression of the empirical log-odds of resistance with heteroskedasticity-robust standard errors; the aOR is adjusted for World Bank income group, and the second p value refers to the aOR. Countries on the fragility list were excluded.

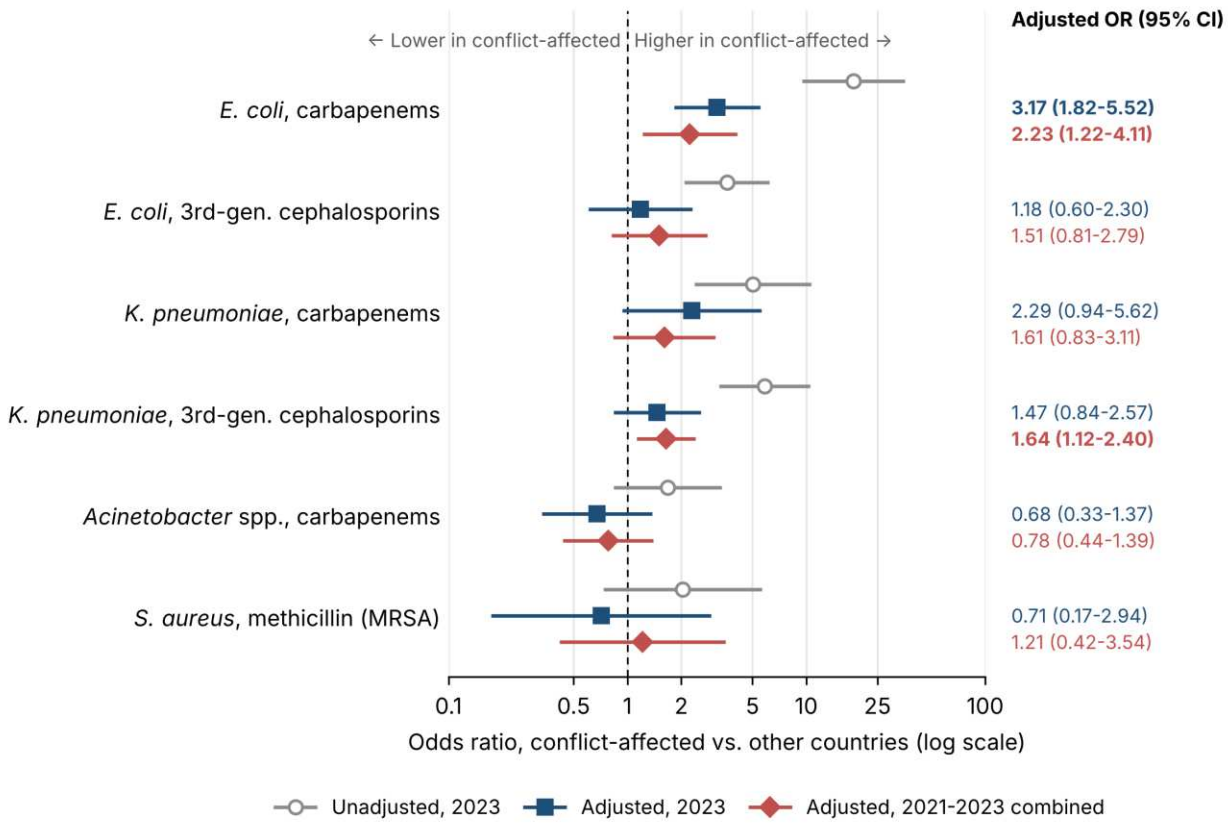


Figure 2: Odds ratios for resistance in conflict-affected compared with other countries, before and after adjustment for income group. Grey circles and blue squares show unadjusted and income-adjusted odds ratios for 2023 from country-level regression of the empirical log-odds of resistance with HC3 robust standard errors; red diamonds show income-adjusted odds ratios for 2021-2023 combined, with standard errors clustered by country. Lines show 95% confidence intervals, and the dashed line marks no difference. Adjusted odds ratios are listed on the right; bold indicates $p < 0.05$. Countries on the fragility list are excluded. MRSA: methicillin-resistant *Staphylococcus aureus*; OR: odds ratio; CI: confidence interval.

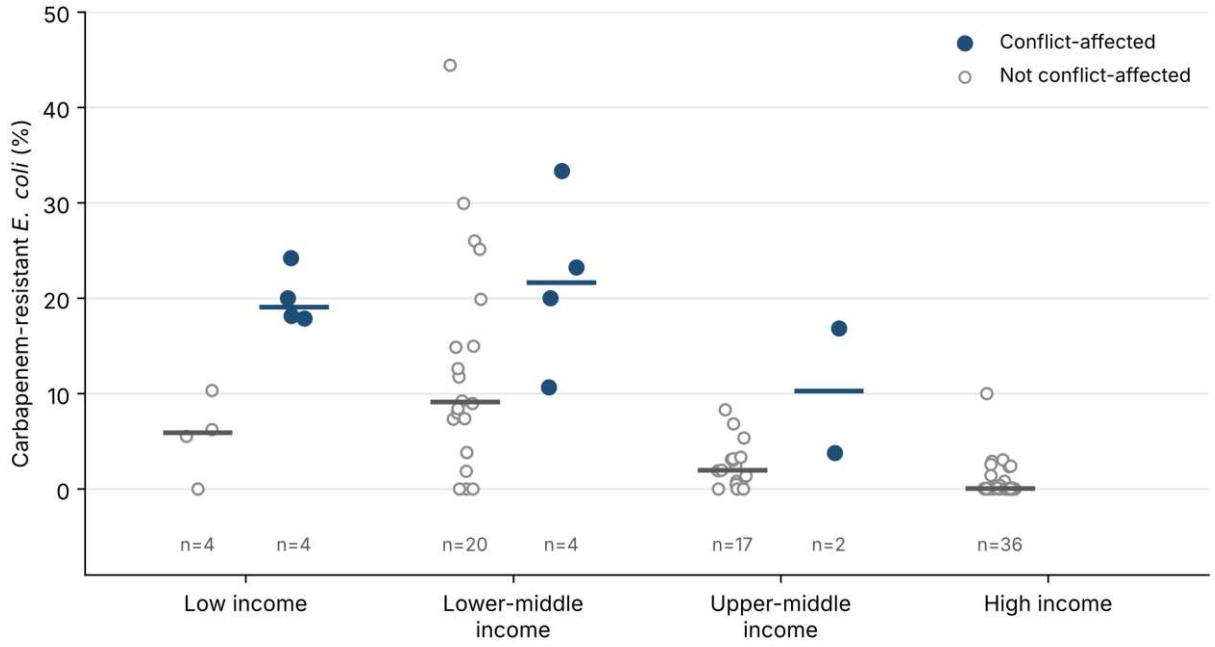


Figure 3: Carbapenem resistance in *Escherichia coli* bloodstream isolates by World Bank income group and conflict status, 2023. Each point is one country; horizontal lines show group medians. Countries on the fragility list are not shown.

Testing Coverage and Reported Resistance

Across all countries, lower testing coverage was associated with higher reported resistance for every outcome (Figure 4). The correlation was strongest for third-generation cephalosporin resistance in *E. coli* ($\rho = -0.76$, $p < 0.001$) and *K. pneumoniae* ($\rho = -0.75$, $p < 0.001$), followed by carbapenem resistance in *E. coli* ($\rho = -0.61$, $p < 0.001$), MRSA ($\rho = -0.55$, $p < 0.001$), carbapenem resistance in *K. pneumoniae* ($\rho = -0.42$, $p < 0.001$), and carbapenem resistance in *Acinetobacter* spp. ($\rho = -0.31$, $p = 0.004$). Within low- and lower-middle-income countries, the association remained significant only for third-generation cephalosporin resistance in *K. pneumoniae* ($\rho = -0.50$, $p = 0.002$).

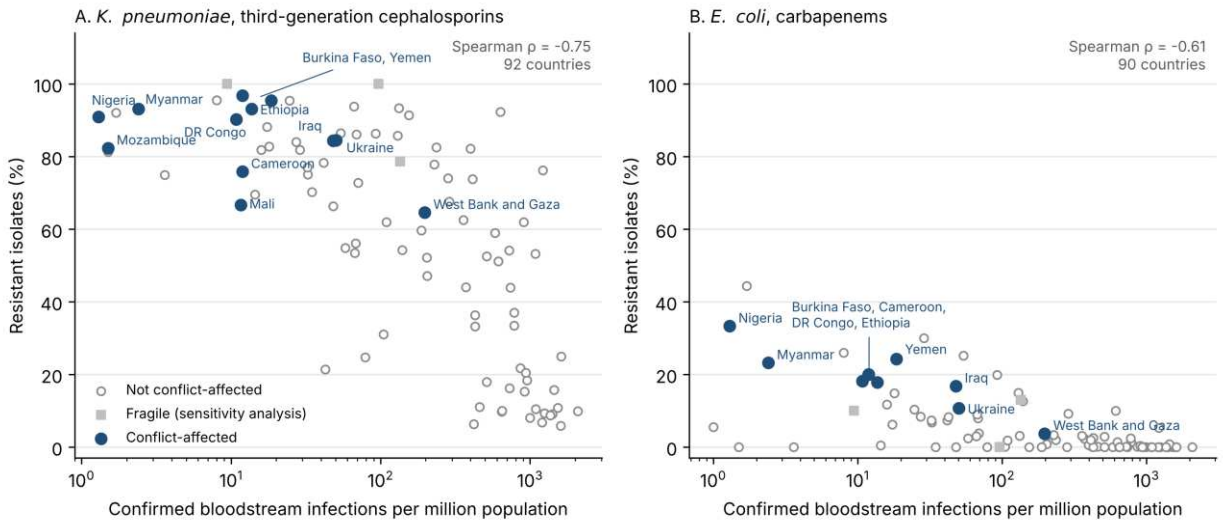


Figure 4: Testing coverage and reported resistance in bloodstream isolates, 2023. (A) Third-generation cephalosporin resistance in *Klebsiella pneumoniae*. (B) Carbapenem resistance in *Escherichia coli*. Testing coverage is the number of confirmed bloodstream infections reported to GLASS per million population (log scale).

Sensitivity Analyses

The higher carbapenem resistance in *E. coli* in conflict-affected countries was consistent when fragile states were included, when only countries with at least 30 tested isolates were included, and when FY25 or FY27 income groups were used (Table 3). It was not driven by any single country: when each conflict-affected country was removed in turn, the aOR ranged from 2.71 to 3.60 (all $p < 0.001$), and it remained significant at the Bonferroni-corrected threshold after removal of any two or three conflict-affected countries (aOR range 2.34-4.35; Additional file 1: Table S3). It was not statistically significant in the quasi-binomial model weighted by the number of isolates (aOR 1.69, 95% CI 0.36-7.89), in which countries testing many thousands of isolates, all of them not conflict-affected, carried most of the weight. Carbapenem resistance in *K. pneumoniae* was significantly higher in conflict-affected countries when FY25 or FY27 income groups were used, but not in the primary or other sensitivity analyses. None of the other outcomes was associated with conflict in any analysis. When testing coverage was added to the income-adjusted model, carbapenem resistance in *E. coli* remained higher in conflict-affected countries (aOR 2.58, 95% CI 1.44-4.63; $p = 0.001$), whereas the adjusted odds ratios for all other outcomes became smaller and none was significant. In this model, each tenfold increase in testing coverage was independently associated with lower odds of reported resistance for five of the six outcomes (odds ratios 0.40-0.58 per tenfold increase; $p < 0.05$), the exception being carbapenem resistance in *Acinetobacter* spp.

Outcome	Primary analysis	Conflict and fragile combined	At least 30 isolates	FY25 income groups	FY27 income groups	Isolate-weighted model	Adjusted for testing coverage
E. coli, carbapenems	3.17 (1.82-5.52)*	2.52 (1.48-4.28)*	2.91 (1.20-7.10)*	3.21 (1.51-6.83)*	3.05 (1.47-6.33)*	1.69 (0.36-7.89)	2.58 (1.44-4.63)*
E. coli, third-generation cephalosporins	1.18 (0.60-2.30)	0.88 (0.47-1.65)	1.13 (0.49-2.59)	1.28 (0.65-2.52)	1.21 (0.60-2.42)	1.91 (0.37-9.95)	0.99 (0.49-2.00)
K. pneumoniae, carbapenems	2.29 (0.94-5.62)	0.72 (0.18-2.96)	1.88 (0.63-5.61)	2.65 (1.24-5.66)*	2.82 (1.32-6.00)*	2.05 (0.30-14.03)	1.71 (0.56-5.25)
K. pneumoniae, third-generation cephalosporins	1.47 (0.84-2.57)	2.40 (0.99-5.81)	1.45 (0.78-2.72)	1.68 (0.95-2.95)	1.61 (0.90-2.89)	1.69 (0.22-12.94)	1.10 (0.58-2.08)
Acinetobacter spp., carbapenems	0.68 (0.33-1.37)	0.75 (0.36-1.57)	1.12 (0.52-2.39)	0.69 (0.35-1.40)	0.71 (0.34-1.49)	1.36 (0.30-6.12)	0.51 (0.20-1.27)
S. aureus, methicillin (MRSA)	0.71 (0.17-2.94)	0.79 (0.28-2.24)	0.97 (0.12-7.66)	0.68 (0.14-3.20)	0.65 (0.14-3.10)	0.89 (0.19-4.12)	0.49 (0.11-2.12)

Table 3: Sensitivity analyses: adjusted odds ratios (95% CI) for resistance in conflict-affected compared with other countries. CI: confidence interval; FY: fiscal year. All models are adjusted for World Bank income group; the primary analysis uses FY24 income groups. *$p < 0.05$. The isolate-weighted model is a quasi-binomial regression weighted by the number of isolates tested in each country. The model adjusted for testing coverage additionally includes $\log_{10}$ confirmed bloodstream infections per million population.

Replication in 2021 and 2022

Testing coverage was reported by 86 countries in 2021 and 92 countries in 2022, including 14 and 12 conflict-affected countries, respectively. In both years, conflict-affected countries again reported far fewer confirmed bloodstream infections per million population than other countries (median 4.4 vs. 263.6 in 2021 and 7.3 vs. 185.6 in 2022; both $p < 0.001$). Lower testing coverage was again associated with higher reported resistance for all six outcomes in 2022 (ρ -0.33 to -0.81, all $p < 0.01$) and for five of the six outcomes in 2021 (ρ -0.42 to -0.81, all $p < 0.001$), the exception being carbapenem resistance in *Acinetobacter* spp. (ρ -0.22, $p = 0.069$). Adjustment for income again reduced the unadjusted differences between conflict-affected and other countries (Table 4).

Carbapenem resistance in *E. coli* was higher in conflict-affected countries in all three years, but the difference was significant only in 2023 (aOR 2.17 in 2021, 1.41 in 2022, and 3.17 in 2023), and the size of

the association differed between years (p = 0.039). With the three years combined, the aOR was 2.23 (95% CI 1.22-4.11; p = 0.010; Figure 2). Conflict-affected countries that tested large numbers of isolates reported similar levels in 2022 and 2023 (Iraq 17.4% and 16.9%, Ethiopia 15.5% and 17.9%, Ukraine 10.5% and 10.7%, and Yemen 20.0% and 24.2%), whereas the largest changes were in Burkina Faso, Cameroon, and Myanmar, which each tested fewer than 50 isolates and reported 3.8-8.3% in 2022 and 20.0-23.3% in 2023. Third-generation cephalosporin resistance in *K. pneumoniae* was the most consistent finding across years: the aOR was 1.75, 1.83, and 1.47 in 2021, 2022, and 2023, did not differ between years (p = 0.95), and was significant when the three years were combined (aOR 1.64, 95% CI 1.12-2.40; p = 0.010; Figure 2). The association for third-generation cephalosporin resistance in *E. coli* differed between years (p = 0.011). Both combined estimates remained significant when each conflict-affected country was removed in turn (aOR 1.70-2.49 for carbapenem-resistant *E. coli* and 1.51-1.78 for third-generation cephalosporin-resistant *K. pneumoniae*), and neither changed materially when European countries were removed (Additional file 1: Table S4). When only countries reporting meropenem or ceftriaxone were included, carbapenem resistance in *E. coli* remained higher in conflict-affected countries in 2023 (aOR 3.06, 95% CI 1.65-5.68) and in 2021-2023 combined (aOR 2.14, 95% CI 1.01-4.53), as did third-generation cephalosporin resistance in *K. pneumoniae* in the combined model (aOR 1.55, 95% CI 1.03-2.31). Results were similar when income was classified using the World Bank groups for each data year, and the full results for 2021 and 2022 are shown in Additional file 1: Table S5.

Outcome	2021: countries, conflict / other	2021: aOR (95% CI)	2022: aOR (95% CI)	2023: aOR (95% CI)	All years: aOR (95% CI)	p value, difference between years
E. coli, carbapenems	7 / 65	2.17 (0.79-5.95)	1.41 (0.43-4.62)	3.17 (1.82-5.52)*	2.23 (1.22-4.11)*	0.039
E. coli, third-generation cephalosporins	8 / 66	1.15 (0.54-2.48)	2.66 (1.01-7.00)*	1.18 (0.60-2.30)	1.51 (0.81-2.79)	0.011
K. pneumoniae, carbapenems	9 / 65	1.22 (0.41-3.59)	1.31 (0.55-3.14)	2.29 (0.94-5.62)	1.61 (0.83-3.11)	0.11
K. pneumoniae, third-generation cephalosporins	8 / 66	1.75 (0.90-3.40)	1.83 (0.92-3.62)	1.47 (0.84-2.57)	1.64 (1.12-2.40)*	0.95
Acinetobacter spp., carbapenems	5 / 61	0.75 (0.18-3.09)	0.94 (0.26-3.34)	0.68 (0.33-1.37)	0.78 (0.44-1.39)	0.13
S. aureus, methicillin (MRSA)	11 / 64	2.08 (0.59-7.29)	1.24 (0.20-7.72)	0.71 (0.17-2.94)	1.21 (0.42-3.54)	0.097

Table 4: Adjusted odds ratios for resistance in conflict-affected compared with other countries, 2021-2023. aOR: adjusted odds ratio; CI: confidence interval; MRSA: methicillin-resistant *Staphylococcus*

aureus. All models use the World Bank FY24 conflict and income classifications, are adjusted for income group, and exclude countries on the fragility list. *p < 0.05. The combined model includes all three years, terms for year, and standard errors clustered by country; the p value for the difference between years is a joint test of the interactions between conflict status and year.

Discussion

In this global comparison of 2023 GLASS data, repeated with data for 2021 and 2022, conflict-affected countries reported much higher resistance in bloodstream infections than other countries, but most of this difference disappeared once national income was taken into account. Conflict-affected countries also reported far fewer confirmed bloodstream infections per million population, and across all countries lower testing coverage was associated with higher reported resistance. The one outcome that remained independently associated with conflict in 2023 was carbapenem resistance in *E. coli*, but it was weaker and not significant in 2021 and 2022, whereas the findings on income and testing coverage were similar in all three years.

This study adds to the existing evidence in three ways. First, it extends previous regional comparisons of national surveillance data to all WHO regions, covering 13 conflict-affected countries in four regions. Second, it shows how strongly simple comparisons depend on income: for the four outcomes that differed before adjustment, unadjusted odds ratios of 3.6 to 18.4 fell to between 1.2 and 3.2 after adjustment in 2023, and only one remained significant. Third, it shows that the findings on income and testing coverage were reproduced in two further years of data, whereas the association for carbapenem-resistant *E. coli* varied between years, which illustrates how unstable single-year estimates from countries with little testing can be. The linked country-level dataset and the analysis code are provided so that the analysis can be repeated as new GLASS data are released.

The finding that income explains most of the crude difference is important for how conflict-related AMR is described. All 13 conflict-affected countries in this dataset were low- or middle-income, and resistance to third-generation cephalosporins in particular is high across poorer countries whether or not they are at war. Comparing a country at war with high-income European countries, as is often done, will therefore make the difference associated with conflict appear larger than it is. Because no conflict-affected country was high-income, the adjusted estimates in this study compare conflict-affected countries only with countries in the same income groups; removing all 19 European Union countries from the analysis did not change the aOR for carbapenem-resistant *E. coli*. Income may, however, also lie partly on the causal pathway, because prolonged conflict lowers national income. Adjusting for income could therefore remove part of a genuine association with conflict, so the adjusted odds ratios are best regarded as conservative estimates and the unadjusted odds ratios as upper limits. My results agree with the regional analysis by Moghnieh et al., who found that conflict-affected countries in the Eastern Mediterranean had weaker surveillance and lower detection of bloodstream infections [15], and extend this to all WHO regions.

The strong inverse relationship between testing coverage and reported resistance supports the concern that national resistance figures from countries with limited testing are affected by selection bias. When only a few patients can be cultured, cultures are usually taken from patients with severe or treatment-resistant infections, and the percentage of resistant isolates will be higher than in the whole patient population. The GLASS dashboard itself acknowledges this by also presenting summary values restricted

to countries with testing coverage above the 75th percentile [16]. For conflict-affected countries, where testing coverage was around one-twentieth of that in other countries, this means that published national resistance percentages describe the patients who were tested rather than the population as a whole. Testing coverage remained associated with reported resistance after adjustment for income, which suggests that this effect is not only a consequence of poverty. In 2023, the excess of carbapenem-resistant *E. coli* in conflict-affected countries was only slightly reduced when testing coverage was taken into account.

Carbapenem resistance in *E. coli* stood out because it is normally rare: the median in countries not affected by conflict was below 1%, whereas nine of ten conflict-affected countries with data reported between 10% and 33%. The association was weaker and not significant in 2021 and 2022, although it pointed in the same direction in all three years. Countries that tested many isolates, including Iraq, Ethiopia, Ukraine, and Yemen, reported similar levels in 2022 and 2023, whereas the largest year-to-year changes were in countries testing fewer than 50 isolates, in which a few resistant isolates can change the national percentage considerably. The consistently high levels in the countries with larger numbers of isolates are still notable, given how rare carbapenem resistance in *E. coli* is elsewhere. This is concerning because *E. coli* causes bloodstream infections both in hospitals and in the community. GLASS data do not record where infections were acquired, however, so they cannot show whether resistant strains are spreading outside hospitals. Carbapenemase-producing Enterobacterales, including producers of New Delhi metallo-beta-lactamase (NDM-1) and oxacillinase-48 (OXA-48), have been found in Ukrainian hospitals and in Ukrainian patients treated in Germany and Poland [7-9,19]. Conflict-related care, including repeated surgery, prolonged hospital stays, and transfers between hospitals and across borders, provides many opportunities for such organisms to spread [20]. Antibiotic use may also contribute: in GLASS antibiotic use data for 2022, three of the four conflict-affected countries that reported (Mali, Ukraine, and West Bank and Gaza) did not reach the WHO target of at least 60% of total use from Access antibiotics, which suggests greater reliance on broader-spectrum Watch antibiotics [21].

Laboratory factors should also be considered before this result is accepted as a true difference. Carbapenem resistance in *E. coli* is rare enough that a small number of false-positive results can change a national percentage considerably, and few laboratories in conflict-affected settings are able to confirm carbapenemase production. Differences in breakpoints also matter. The current meropenem breakpoints for Enterobacterales of the European Committee on Antimicrobial Susceptibility Testing (EUCAST) and the Clinical and Laboratory Standards Institute (CLSI) differ, so an isolate with a meropenem minimum inhibitory concentration (MIC) of 4-8 mg/L is reported as resistant under CLSI but as "susceptible, increased exposure" under EUCAST [22,23] (Additional file 1: Tables S1 and S2). Laboratories that report only categorical results to GLASS cannot be re-interpreted against a common standard, whereas reporting raw MIC values or zone diameters to WHONET would make this possible [24]. Confirmatory testing of carbapenem-resistant *E. coli* isolates from conflict-affected countries, including molecular detection of carbapenemase genes, is therefore a priority.

Third-generation cephalosporin resistance in *K. pneumoniae* behaved differently. The difference from other countries was modest and not significant in any single year, but it was almost the same in 2021, 2022, and 2023, and it was significant when the years were combined. *K. pneumoniae* is a typical hospital-acquired pathogen, and resistance to third-generation cephalosporins is mostly caused by extended-spectrum beta-lactamases that spread readily within hospitals, so a small but stable excess

would be consistent with the crowding, interrupted infection control, and patient transfers described in conflict settings [20]. Because the effect was small, however, it could also reflect confounding that adjustment for income did not remove.

The absence of a difference for carbapenem-resistant *Acinetobacter* spp. and MRSA is also informative. *Acinetobacter* has long been linked to war wounds [3], but carbapenem resistance in this genus was already high in most countries, with a median of 58.6% in countries not affected by conflict, leaving little room for a difference to appear at national level. MRSA prevalence varied widely in both groups, which is consistent with the similar MRSA prevalence found in conflict and non-conflict settings in the Middle East [14].

These findings have practical implications. Improving testing coverage in conflict-affected countries is needed both for patient care and for producing resistance estimates that can be interpreted. Field microbiology approaches, such as the Médecins Sans Frontières (MSF) Mini-Lab, have shown that clinical bacteriology can be established in hospitals without a microbiology laboratory [25,26], and WHONET has been used to analyze resistance among war-wounded patients in humanitarian settings [24,27]. Surveillance reports from conflict-affected countries would also be easier to interpret if testing coverage, the types of facilities and patients sampled, and the breakpoint standard used were reported alongside resistance percentages.

Limitations

This study has several limitations. First, it is an ecological analysis of national aggregates, so the results describe countries rather than patients, and an association at country level does not show that conflict causes resistance. The data also cover bloodstream isolates only and do not describe wound or other infections. Second, the number of conflict-affected countries with data was small (10 to 12 per outcome in 2023 and 5 to 11 in 2021), several reported fewer than 30 isolates, and confidence intervals were wide. Third, six of the 19 conflict-affected countries did not report to GLASS, and countries that are able to report during conflict may be those with more stable or better-resourced laboratory systems, so the results may not represent conflict settings with the least laboratory capacity. Hospital studies from two of these countries suggest that resistance in such settings is substantial: carbapenem resistance was reported in 27% of *Klebsiella* isolates from hospital-acquired infections at a tertiary hospital in Mogadishu, Somalia [28], and in 41% of *K. pneumoniae* isolates from five hospitals in Khartoum, Sudan, collected before the current war [29]. These single-setting studies used different specimens and methods, however, and cannot be compared directly with national surveillance data. Fourth, conflict status was assigned to whole countries, although in several countries fighting was concentrated in particular regions and the reporting laboratories may have been located far from the conflict. Fifth, GLASS data depend on the number and type of participating laboratories, which differ between countries and were not available for this analysis. Testing coverage was also measured from the infections reported to GLASS, so it reflects the reach of the surveillance system rather than all blood cultures performed in a country. Sixth, six outcomes were tested, and although the analysis was repeated with 2021 and 2022 data, the years are not independent, because most countries reported in all of them, and the laboratories and hospitals reporting from each country may change between years, so year-to-year differences may reflect changes in who was tested rather than in resistance; in addition, the full-scale war in Ukraine began only in February 2022. Finally, the main result was not significant in

the isolate-weighted model, which gives most weight to a few countries with very large numbers of isolates.

Conclusions

Conflict-affected countries reported more antimicrobial resistance in bloodstream infections than other countries in each year from 2021 to 2023, but most of this difference was explained statistically by lower national income and very limited testing. Carbapenem-resistant *E. coli* was about twice as likely in conflict-affected countries over the three years combined, but the difference varied between years and should be investigated with confirmatory laboratory testing. National resistance figures from countries with low testing coverage, including countries at war, should be interpreted with caution, and surveillance reports should state testing coverage and the breakpoint standard used alongside resistance percentages.

Abbreviations

AMR: antimicrobial resistance

aOR: adjusted odds ratio

AST: antimicrobial susceptibility testing

CI: confidence interval

CLSI: Clinical and Laboratory Standards Institute

EUCAST: European Committee on Antimicrobial Susceptibility Testing

FCS: fragile and conflict-affected situations

FY: fiscal year

GLASS: Global Antimicrobial Resistance and Use Surveillance System

IQR: interquartile range

MIC: minimum inhibitory concentration

MRSA: methicillin-resistant *Staphylococcus aureus*

MSF: Médecins Sans Frontières

NDM: New Delhi metallo-beta-lactamase

OR: odds ratio

OXA: oxacillinase

WHO: World Health Organization

Declarations

Ethics approval and consent to participate: Not applicable. This study used only publicly available, aggregated national surveillance data that contain no individual patient information.

Consent for publication: Not applicable.

Availability of data and materials: The surveillance data analyzed in this study are publicly available from the World Health Organization Global Antimicrobial Resistance and Use Surveillance System (GLASS) dashboard (https://worldhealthorg.shinyapps.io/glass-dashboard/). The World Bank classifications are publicly available from the World Bank. The country-level dataset generated for this analysis is included in Additional file 2, and the analysis code in Python and R, which reproduces all results, is included in Additional file 3.

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Authors' contributions: SJ conceived and designed the study, obtained and analyzed the data, interpreted the results, and wrote the manuscript. The author read and approved the final manuscript.

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Supplementary Information

Additional file 1: Supplementary Tables S1-S5. Tables S1 and S2: comparison of current EUCAST and CLSI clinical MIC breakpoints for Enterobacterales and *Pseudomonas aeruginosa*. Table S3: leave-one-out analysis for carbapenem resistance in *Escherichia coli*, 2023. Table S4: leave-one-out analysis of the combined 2021-2023 estimates. Table S5: reported resistance in conflict-affected and other countries, 2021 and 2022 (DOCX).

Additional file 2: Country-level datasets for 2021, 2022, and 2023 used in the analysis: outcome, antibiotic used, number of isolates tested, number resistant, percentage resistant, conflict status, income group, and testing coverage (XLSX).

Additional file 3: Analysis code: Python script that reproduces all results in the paper and R script that independently checks them (ZIP).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Code.zip
- AdditionalFile1.docx
- AdditionalFile2.xlsx