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Trends in the Composite Antimicrobial Resistance Index of Healthcare-Associated Infections in Türkiye: A National Surveillance Study, 2015–2024

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Abstract

Purpose

Antimicrobial resistance (AMR) in healthcare-associated infections (HAIs) represents a growing global public health threat. Composite AMR indices derived from national surveillance systems offer a standardized tool for monitoring resistance trends at the population level. This study aimed to evaluate ten-year trends in the Composite AMR Index and the Standardized Composite AMR Index of HAIs reported to the Turkish National Healthcare-Associated Infection Surveillance Network (INFLINE) between 2015 and 2024.

Methods

This nationwide ecological descriptive study analysed annual aggregate data from INFLINE. The Composite AMR Index was defined as the proportion of resistant isolates among six priority pathogens: *Escherichia coli*, *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Enterococcus faecium/faecalis*. Temporal trends were assessed using the Mann-Kendall non-parametric trend test, Spearman rank correlation, and segmented regression analysis with a pre-specified inflection point at 2021.

Results

During the pre-pandemic period (2015–2020), both indices remained stable between 46.0% and 50.4%, with no statistically significant trend ($p = 0.45$ and $p = 0.57$, respectively). A sharp inflection was observed in 2021, with the Composite AMR Index increasing by 14.1 percentage points in a single year (from 49.3% to 63.4%). Both indices continued to rise, reaching 67.1% and 70.6% by 2024. Overall, both indices demonstrated statistically significant increasing trends (Mann-Kendall: $\tau = 0.78$, $p = 0.002$ and $\tau = 0.76$, $p = 0.003$, respectively). Segmented regression confirmed a structural break at 2021, with a near-flat pre-pandemic slope (+ 0.39%/year) followed by an abrupt level shift of + 14.2 percentage points ($R^2=0.99$).

Conclusions

The Composite AMR Index of HAIs in Türkiye demonstrated a stable pre-pandemic plateau followed by a sharp and sustained post-pandemic escalation, with both indices reaching approximately 65–70% by 2024. These findings suggest a structural shift in the national AMR burden associated with the COVID-19 pandemic and underscore the need for reinforced infection prevention and control measures, targeted antimicrobial stewardship, and continued national surveillance investment.

1. Introduction

The global burden of antimicrobial resistance (AMR) continues to escalate, with resistant pathogens causing healthcare-associated infections (HAIs) linked to excess mortality, prolonged hospitalization, and substantial economic costs [1, 2]. Recognising AMR as a critical public health priority, the World Health Organization has called for systematic surveillance of resistance trends in healthcare settings as a cornerstone of effective infection prevention and control programs [3].

Monitoring temporal changes in the proportion of resistant isolates within national HAI surveillance systems provides a valuable tool for evaluating the effectiveness of antimicrobial stewardship and IPC interventions at the population level. Composite indices that aggregate resistance across multiple priority pathogens offer a standardized approach to tracking the overall burden of resistant HAI, enabling longitudinal comparisons that individual pathogen-level data cannot readily provide [4, 5].

Türkiye operates one of the largest mandatory national HAI surveillance networks in the region, Turkish National Healthcare-Associated Infection Surveillance Network (INFLINE), which captures microbiological data from secondary and tertiary hospitals across all 81 provinces. Within this framework, a Composite AMR Index — defined as the proportion of resistant isolates among first-level AMR marker organisms — has been calculated annually since 2015. However, no longitudinal analysis of this index has been published to date. The present study aimed to evaluate ten-year trends in the Composite AMR Index and the Standardized Composite AMR Index in Türkiye between 2015 and 2024, with particular focus on the impact of the COVID-19 pandemic on national AMR burden.

2. Materials and Methods

2.1 Study Design and Data Source

This nationwide ecological descriptive study analyzed annual aggregate data from INFLINE, covering the period from January 2015 to December 2024. INFLINE operates under the coordination of the General Directorate of Public Health, Ministry of Health of the Republic of Türkiye, and serves as the mandatory national platform for healthcare-associated infection reporting. The system aggregates standardized surveillance data from secondary and tertiary hospitals across Türkiye.

2.2 Composite AMR Index

The Composite AMR Index was defined as the proportion of resistant isolates among bacteria included in the first-level AMR marker organisms within INFLINE. The index incorporated resistance profiles of six priority pathogens: *Escherichia coli*, *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Enterococcus faecium/faecalis*.

The Standardized Composite AMR Index applied a standardization procedure to adjust for annual variation in the distribution of reported pathogens. This approach was used to enable a more

comparable longitudinal assessment of the overall AMR burden by reducing the influence of changes in pathogen composition over time.

2.3 Statistical Analysis

Temporal trends in the Composite AMR Index and the Standardized Composite AMR Index were assessed using the Mann-Kendall non-parametric trend test. Kendall's tau (τ) was reported as a measure of trend direction and strength. Spearman's rank correlation coefficient (rs) was calculated to quantify the association between calendar year and annual index values.

Period-specific analyses were conducted separately for the pre-pandemic period (2015–2020) and the post-pandemic period (2021–2024) to characterize phase-specific trend dynamics. Given the observed epidemiological transition around the COVID-19 pandemic period, segmented regression analysis was performed using 2021 as the candidate inflection point. The segmented regression model included an intercept, a linear time term, a level-change term at 2021, and a post-inflection slope-change term. Model fit was assessed using the coefficient of determination (R^2).

Changes in index values were reported as percentage points where applicable. Sen's slope estimates were expressed as percentage points per year. All analyses were performed using Python version 3.12.3 with the pymannkendall, scipy, and numpy libraries.

3. Results

3.1 HAI Burden and Coverage of the Composite AMR Index

Over the ten-year study period, the total number of healthcare-associated infections reported to INFLINE ranged from 41,847 in 2020 to 61,026 in 2017, with an overall mean of approximately 53,000 HAIs per year. A transient decline in total HAI numbers was observed in 2020 and 2021, likely reflecting the impact of the COVID-19 pandemic on surveillance participation and hospital activity. Total HAI counts recovered to pre-pandemic levels by 2022, reaching 55,477, and continued to increase to 59,844 in 2024.

The proportion of HAIs caused by bacteria included in the Composite AMR Index, defined as the percentage of AMR index pathogens among all reported HAI-causing organisms, fluctuated between 57.1% in 2016 and 68.8% in 2017 across the study period, without a consistent directional trend. This proportion remained above 57% in all years, indicating that the Composite AMR Index consistently captured the majority of HAI-causing pathogens during the observation period. The highest coverage values were observed in 2017 (68.8%), 2018 (67.7%), and 2020 (68.6%), while the lowest values were recorded in 2016 (57.1%) and 2021 (57.8%).

3.2 Distribution of Priority Pathogens

Among the six priority pathogens included in the Composite AMR Index, *Klebsiella pneumoniae* was the most frequently isolated organism throughout the study period, accounting for 12.4% to 19.1% of all

HAIs. Its proportional contribution peaked in 2020 (19.1%) before declining to 12.4% by 2024. *Pseudomonas aeruginosa* was consistently one of the leading pathogens, ranging from 12.5% to 18.6%, with its highest contribution observed in 2017 (18.6%) and 2018 (17.8%).

Acinetobacter baumannii demonstrated notable temporal variation, peaking at 10.7% in 2017 and showing a relative decline in subsequent years, stabilizing at 8.2% to 8.8% between 2022 and 2024. *Escherichia coli* showed a gradual increase over the study period, rising from 5.1% in 2015 to 12.6% in 2024. This pattern suggested a progressive shift in the HAI pathogen profile toward Gram-negative Enterobacterales. *Staphylococcus aureus* remained a relatively minor contributor, ranging from 3.5% to 5.3%, while *Enterococcus faecium/faecalis* accounted for 4.7% to 7.8% of HAIs throughout the observation period.

A notable redistribution of pathogen contributions was observed in 2020, with simultaneous increases in the proportional share of *K. pneumoniae* (19.1%), *P. aeruginosa* (18.5%), and *E. coli* (9.8%). This redistribution coincided with the first year of the COVID-19 pandemic and may have reflected changes in hospital case-mix, critical care burden, and mechanically ventilated patient populations. The pattern partially reversed in subsequent years (Fig. 2).

3.3 Trends in the Composite AMR Index

During the pre-pandemic period (2015–2020), both the Composite AMR Index and the Standardized Composite AMR Index remained relatively stable, fluctuating between 46.0% and 49.6%, and between 46.0% and 50.4%, respectively. The two indices tracked closely throughout this period, diverging by no more than 1.1 percentage points in any given year. This suggests that year-to-year variations in pathogen distribution did not substantially influence the overall resistance burden during the pre-pandemic phase.

A marked epidemiological change was observed in 2021. The Composite AMR Index increased from 49.3% in 2020 to 63.4% in 2021, representing a 14.1 percentage-point increase and the largest single-year change recorded across the observation period. The Standardized Composite AMR Index showed a more gradual initial rise, increasing from 49.6% in 2020 to 51.5% in 2021, before increasing sharply to 64.7% in 2022. The divergence between the two indices in 2021 suggests that the abrupt increase in the unstandardized Composite AMR Index during that year was partly influenced by changes in pathogen distribution, rather than reflecting a uniform increase in resistance across all priority organisms.

From 2022 onward, both indices converged again and continued to increase in parallel. The Composite AMR Index and the Standardized Composite AMR Index reached 66.3% and 69.5% in 2023, and 67.1% and 70.6% in 2024, respectively. By the end of the study period, both indices had stabilized at levels approximately 20 percentage points above their pre-pandemic baseline, suggesting a sustained increase in the AMR burden within healthcare settings in Türkiye.

3.4 Statistical Trend Analysis

Over the full ten-year observation period (2015–2024), both the Composite AMR Index and the Standardized Composite AMR Index demonstrated statistically significant increasing trends by Mann-Kendall analysis. The Composite AMR Index showed a significant upward trend ($\tau = 0.78$, $p = 0.002$), as did the Standardized Composite AMR Index ($\tau = 0.76$, $p = 0.003$). Strong positive correlations were also observed between calendar year and annual index values for both measures (Composite AMR Index: $r_s = 0.87$, $p = 0.001$; Standardized Composite AMR Index: $r_s = 0.86$, $p = 0.001$).

Period-specific analyses indicated two distinct temporal phases. During the pre-pandemic period (2015–2020), neither index exhibited a statistically significant trend (Composite AMR Index: $\tau = 0.33$, $p = 0.45$; Standardized Composite AMR Index: $\tau = 0.27$, $p = 0.57$), supporting the visual impression of a stable pre-pandemic plateau. During the post-pandemic period (2021–2024), both indices showed a monotonic increasing tendency ($\tau = 1.00$ for both indices); however, these period-specific trends did not reach conventional statistical significance ($p = 0.09$), likely reflecting the limited number of annual observations in this shorter interval.

Segmented regression analysis supported a structural change around 2021. For the Composite AMR Index, the model estimated a near-flat pre-2021 slope of + 0.39 percentage points per year, followed by a level change of + 14.2 percentage points at the inflection point and continued post-inflection increase. The model demonstrated excellent fit ($R^2 = 0.991$). For the Standardized Composite AMR Index, segmented regression showed a more gradual transition, with a pre-2021 slope of + 0.43 percentage points per year and an estimated level change of + 4.7 percentage points at the inflection point. The model fit was also high ($R^2 = 0.942$).

The mean Composite AMR Index increased from 48.2% during 2015–2020 to 65.5% during 2021–2024, corresponding to a relative increase of 36.0%. The corresponding values for the Standardized Composite AMR Index were 48.3% and 65.1%, reflecting a relative increase of 34.8% (Table 1, Fig. 4).

Table 1
Statistical trend analysis of Composite and Standardized Composite AMR Indices, Türkiye, 2015–2024

Index	Period / comparison	Analysis	Main estimate	p-value / model fit	Main finding
Composite AMR Index	2015–2024	Mann-Kendall trend test	τ = 0.78	p = 0.002	Significant increasing trend
Standardized Composite AMR Index	2015–2024	Mann-Kendall trend test	τ = 0.76	p = 0.003	Significant increasing trend
Composite AMR Index	2015–2024	Spearman correlation with calendar year	rs = 0.87	p = 0.001	Strong positive correlation
Standardized Composite AMR Index	2015–2024	Spearman correlation with calendar year	rs = 0.86	p = 0.001	Strong positive correlation
Composite AMR Index	2015–2020	Mann-Kendall trend test	τ = 0.33	p = 0.45	No significant pre-pandemic trend
Standardized Composite AMR Index	2015–2020	Mann-Kendall trend test	τ = 0.27	p = 0.57	No significant pre-pandemic trend
Composite AMR Index	2021–2024	Mann-Kendall trend test	τ = 1.00	p = 0.09	Non-significant increasing tendency
Standardized Composite AMR Index	2021–2024	Mann-Kendall trend test	τ = 1.00	p = 0.09	Non-significant increasing tendency
Composite AMR Index	2015–2024	Segmented regression	Pre-2021 slope: +0.39 pp/year; level change at 2021: +14.2 pp	R^2 = 0.99	Pattern consistent with structural change around 2021
Standardized Composite AMR Index	2015–2024	Segmented regression	Pre-2021 slope: +0.43 pp/year; level change at 2021: +4.7 pp	R^2 = 0.97	Pattern consistent with structural change around 2021
Composite AMR Index	2015–2020 vs. 2021–2024	Period mean comparison	48.2% to 65.5%	Relative increase: 36.0%	Higher mean AMR burden after 2021
Standardized Composite	2015–2020 vs. 2021–	Period mean comparison	48.3% to 65.1%	Relative increase:	Higher standardized

Index	Period / comparison	Analysis	Main estimate	p-value / model fit	Main finding
AMR Index	2024			34.8%	AMR burden after 2021

Abbreviations: AMR, antimicrobial resistance; τ, Kendall's tau; rs, Spearman rank correlation coefficient; pp, percentage points; R^2, coefficient of determination.

4. Discussion

This ten-year national surveillance analysis demonstrated two epidemiologically distinct phases in the AMR burden of HAIs in Türkiye. Between 2015 and 2020, both the Composite AMR Index and the Standardized Composite AMR Index remained stable at approximately 47–50%, with no statistically significant trend. Following 2020, a sharp and sustained increase was observed, with both indices reaching approximately 65–70% by 2024 — a level approximately 20 percentage points above the pre-pandemic baseline. To our knowledge, this represents the first longitudinal analysis of a national composite AMR index derived from a mandatory HAI surveillance system, offering a population-level perspective on resistance trends that complements existing pathogen-specific surveillance data.

The pre-pandemic stability observed between 2015 and 2020 is consistent with findings from other national surveillance systems reporting plateau phases in HAI-related resistance during this period [4, 5]. The absence of a significant trend during this phase may reflect the combined effect of progressive standardization of infection control practices, the widespread implementation of antimicrobial stewardship programs, and the maturation of the INFLINE surveillance network itself. The Standardized Composite AMR Index, which adjusts for annual variation in pathogen distribution, tracked the Composite AMR Index closely throughout this period, suggesting that the observed stability reflected genuine epidemiological stasis rather than shifts in the case mix.

The sharp inflection observed at 2021 warrants careful interpretation. Several factors may have contributed to this increase, though causal attribution is not possible from aggregate surveillance data alone. First, the COVID-19 pandemic imposed substantial pressure on infection control capacity globally, including redeployment of infection control personnel, relaxation of contact precaution protocols, and increased use of broad-spectrum antimicrobials in critically ill patients [6, 7]. Second, the pandemic-associated surge in mechanically ventilated patients with severe respiratory failure may have created conditions favourable for the emergence and transmission of resistant organisms, particularly carbapenem-resistant *Acinetobacter baumannii* and *Klebsiella pneumoniae*, which were observed to increase proportionally in 2020 in our data. Third, disruptions to routine microbiological testing and surveillance reporting during pandemic peaks may have introduced selective reporting bias, with sicker patients — who are more likely to harbour resistant organisms — remaining under surveillance while less complex cases were under-reported. The observed divergence between the Composite AMR Index and the Standardized Composite AMR Index in 2021 supports this interpretation, suggesting that shifts in

pathogen distribution, rather than a uniform increase in resistance rates across all organisms, partly drove the abrupt rise in the composite measure.

The persistence of elevated AMR index values through 2022–2024, with both indices stabilising at 65–70%, suggests that the post-pandemic period has been characterised by a new, higher baseline rather than a transient disruption. Similar post-pandemic escalation in AMR burden has been documented in other national surveillance datasets [6, 7], though the magnitude and persistence of the increase observed in Türkiye warrants particular attention given the country's large and rapidly expanding HAI surveillance network. The convergence of the Composite and Standardized indices from 2022 onward further supports the hypothesis that the post-pandemic elevation reflects a genuine and sustained increase in resistance prevalence across priority pathogens, rather than a distribution effect.

These findings have direct implications for national infection prevention and antimicrobial stewardship policy. The identification of 2021 as a structural inflection point highlights the need for targeted AMR containment strategies in the post-pandemic period, including reinforcement of contact precautions, optimisation of carbapenem-sparing regimens, and enhancement of diagnostic stewardship to reduce the selective pressure driving resistance. The sustained divergence of AMR index values from pre-pandemic levels also underscores the importance of continued longitudinal monitoring through INFLINE, as single time-point assessments would fail to capture the dynamic trajectory documented here. Future analyses incorporating patient-level data — including severity scores, prior antimicrobial exposure, and clinical outcomes — would substantially strengthen the interpretability of national AMR index trends and enable more targeted policy responses.

5. Limitations

This study has several limitations inherent to its ecological design and reliance on aggregate national surveillance data. First, patient-level clinical variables — including severity scores, prior antimicrobial exposure, underlying comorbidities, and clinical outcomes — were not available within the aggregate INFLINE dataset, precluding risk-adjusted analyses and limiting causal inference. Second, the ecological study design does not allow attribution of observed AMR index trends to specific clinical, microbiological, or policy-related determinants. Third, while the 2021 inflection point was supported by statistical evidence from period-specific Mann-Kendall analyses and segmented regression modelling, formal joinpoint regression analysis — which would allow estimation of annual percent change and more rigorous identification of change points — could not be conducted due to software accessibility constraints. Fourth, changes in surveillance participation and reporting completeness across years may have influenced aggregate index values, particularly during the COVID-19 pandemic period when some hospitals temporarily suspended or reduced HAI surveillance activities. Fifth, the Composite AMR Index as defined within INFLINE captures resistance among six priority pathogens only; emerging resistant organisms not included in the index — such as *Candida auris* or carbapenem-resistant *Enterobacterales* beyond the defined marker criteria — are not reflected in the composite measure. Despite these limitations, the large scale of the national dataset, the ten-year observation period, and the consistency

of findings across both the Composite and Standardized indices strengthen the validity and interpretability of the reported trends.

6. Conclusions

Between 2015 and 2024, the Composite AMR Index of healthcare-associated infections in Türkiye demonstrated a biphasic trajectory: a stable pre-pandemic plateau between 2015 and 2020, followed by a sharp and sustained increase from 2021 onward, with both indices reaching approximately 65–70% by 2024. Statistical analyses confirmed the absence of any significant trend during the pre-pandemic period and identified 2021 as a structural inflection point, with a level shift of more than 14 percentage points in a single year and a model fit of R^2=0.99. These findings suggest that the COVID-19 pandemic was associated with a structural and potentially sustained escalation in the AMR burden of HAIs in Türkiye, consistent with post-pandemic AMR trends reported from other national surveillance systems. The sustained divergence from pre-pandemic levels underscores the urgent need for reinforced infection prevention and control measures, targeted antimicrobial stewardship interventions, and continued investment in national HAI surveillance infrastructure. Longitudinal monitoring of composite AMR indices through INFLINE will be essential for tracking the long-term trajectory of resistance and evaluating the impact of national containment strategies.

Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

E.A.B. conceived and designed the study, accessed and analysed the national surveillance data, performed the statistical analyses, interpreted the results, and wrote the original draft. C.H.H., E.B., and D.A. contributed to data acquisition, analysis, and interpretation. M.B. contributed to epidemiological interpretation of the data. E.Ö. and M.E.D. provided administrative supervision and critically reviewed the manuscript. Ü.Ç. contributed microbiological expertise and critically revised the manuscript for important intellectual content. All authors read and approved the final version.

Ethics Approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Yüksek İhtisas University Health Sciences Research Ethics Committee (Date: 05.06.2026, Decision No: 449, Meeting No: 24).

Consent to Participate

This study was based on retrospective analysis of anonymised aggregate national surveillance data obtained through INFLINE. No individual patient data were collected or processed. In accordance with national regulations, individual informed consent was not required.

Data Availability

The data that support the findings of this study are derived from the Turkish National Healthcare-Associated Infection Surveillance Network (INFLINE), which is managed by the General Directorate of Public Health, Republic of Türkiye Ministry of Health. The aggregate surveillance data used in this study are not publicly available as they constitute institutional surveillance records, but may be available from the corresponding author upon reasonable request and subject to institutional approval.

Declaration of AI-Assisted Technologies

During the preparation of this manuscript, AI-assisted tools were used to support language editing, translation, manuscript refinement, statistical code review, and formatting of tabular and graphical outputs. Claude and ChatGPT were used for language refinement, structural editing, analytical workflow checking, and assistance in preparing table and figure formats. DeepL was used for translation and language polishing. The final statistical analyses and figures were generated from the underlying study data using Python version 3.12.3, including the pymannkendall, scipy, numpy, and matplotlib libraries. All statistical outputs, data interpretation, manuscript content, tables, and figures were reviewed, verified, and approved by the authors. No AI-assisted tool was listed as an author, and the authors take full responsibility for the accuracy, validity, and integrity of the submitted work.

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Figures

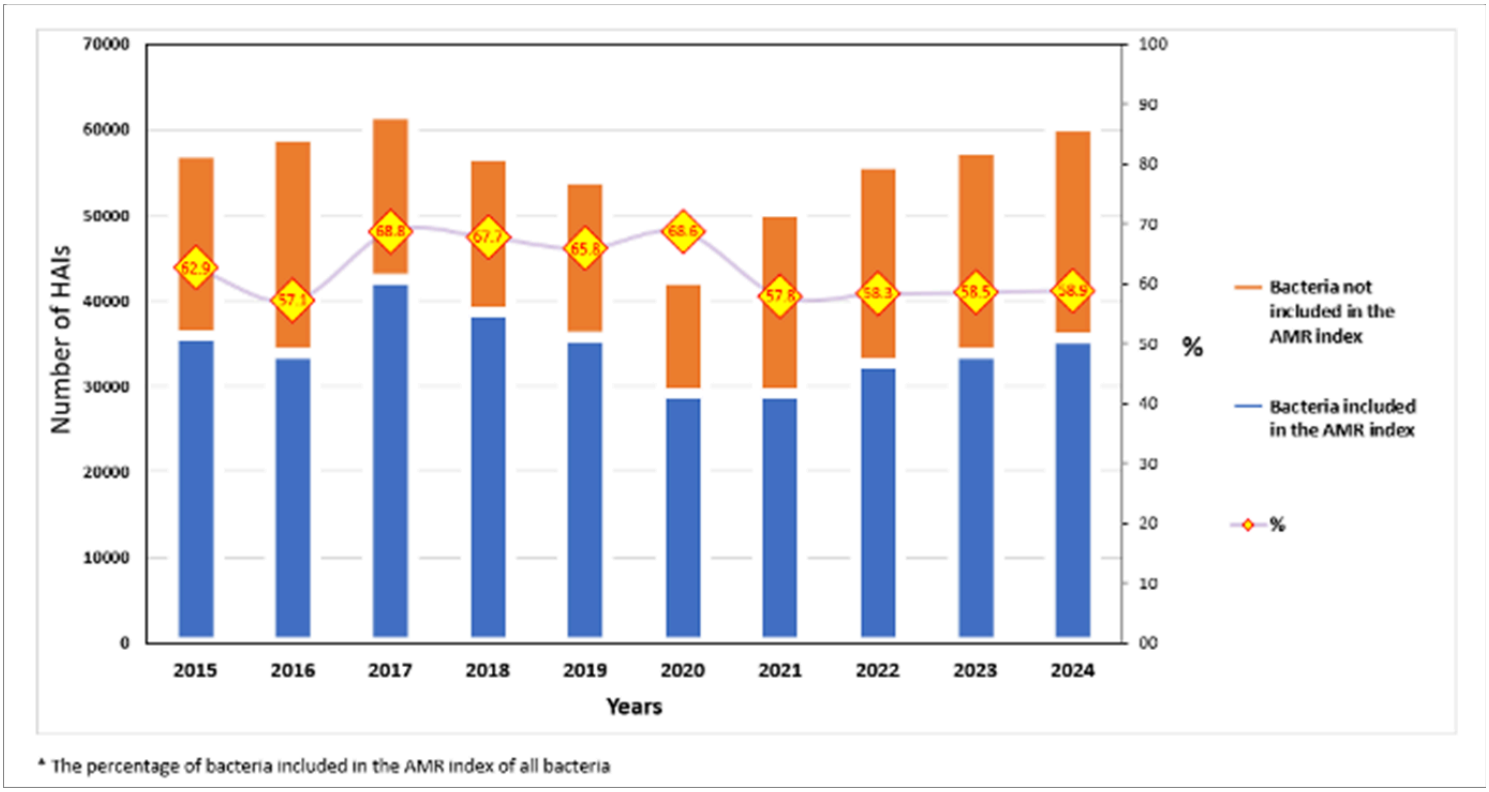


Figure 1

Distribution of bacteria in the composite AMR index by years.

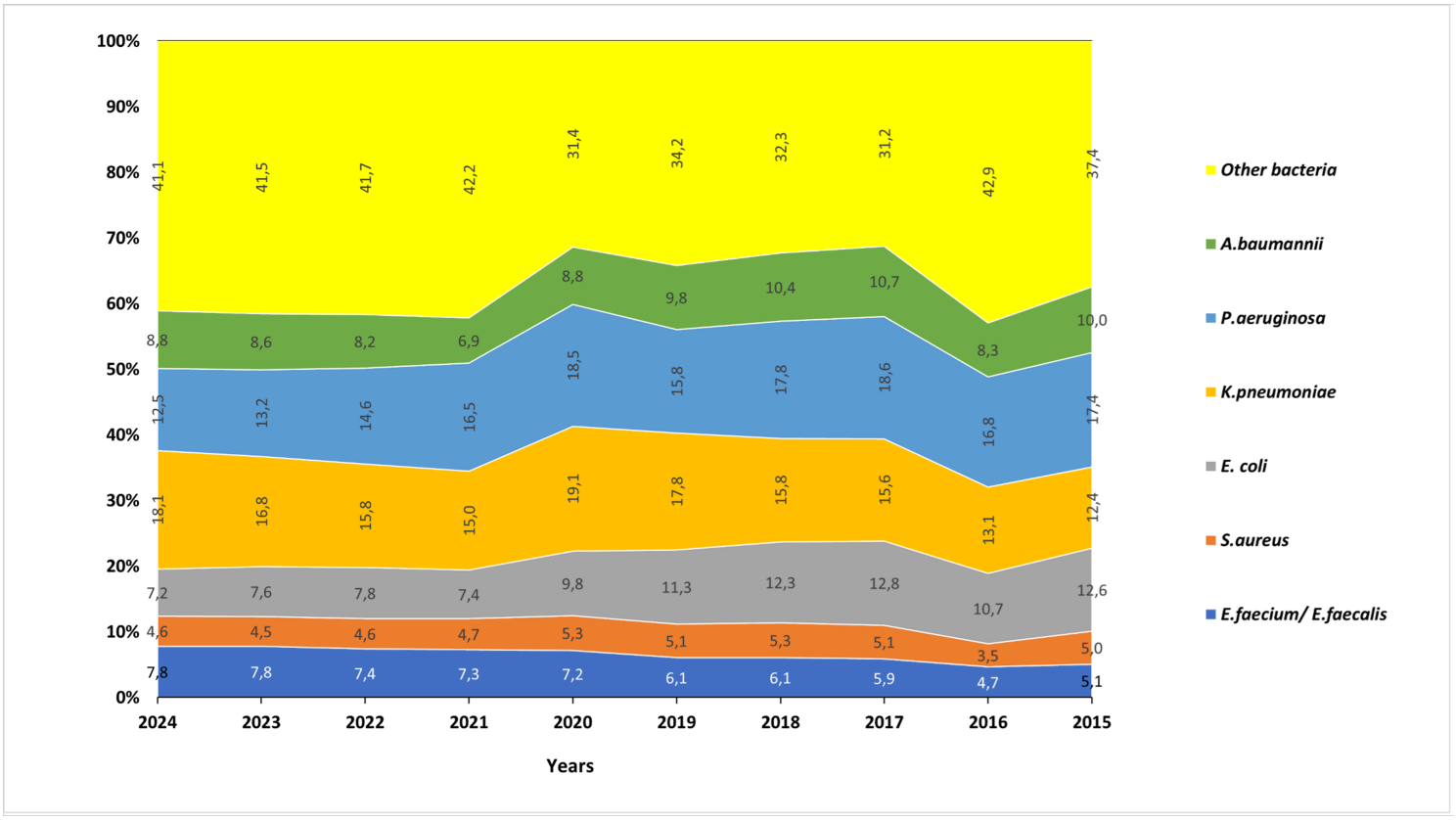


Figure 2

Percentages of bacteria in the composite AMR index by years.

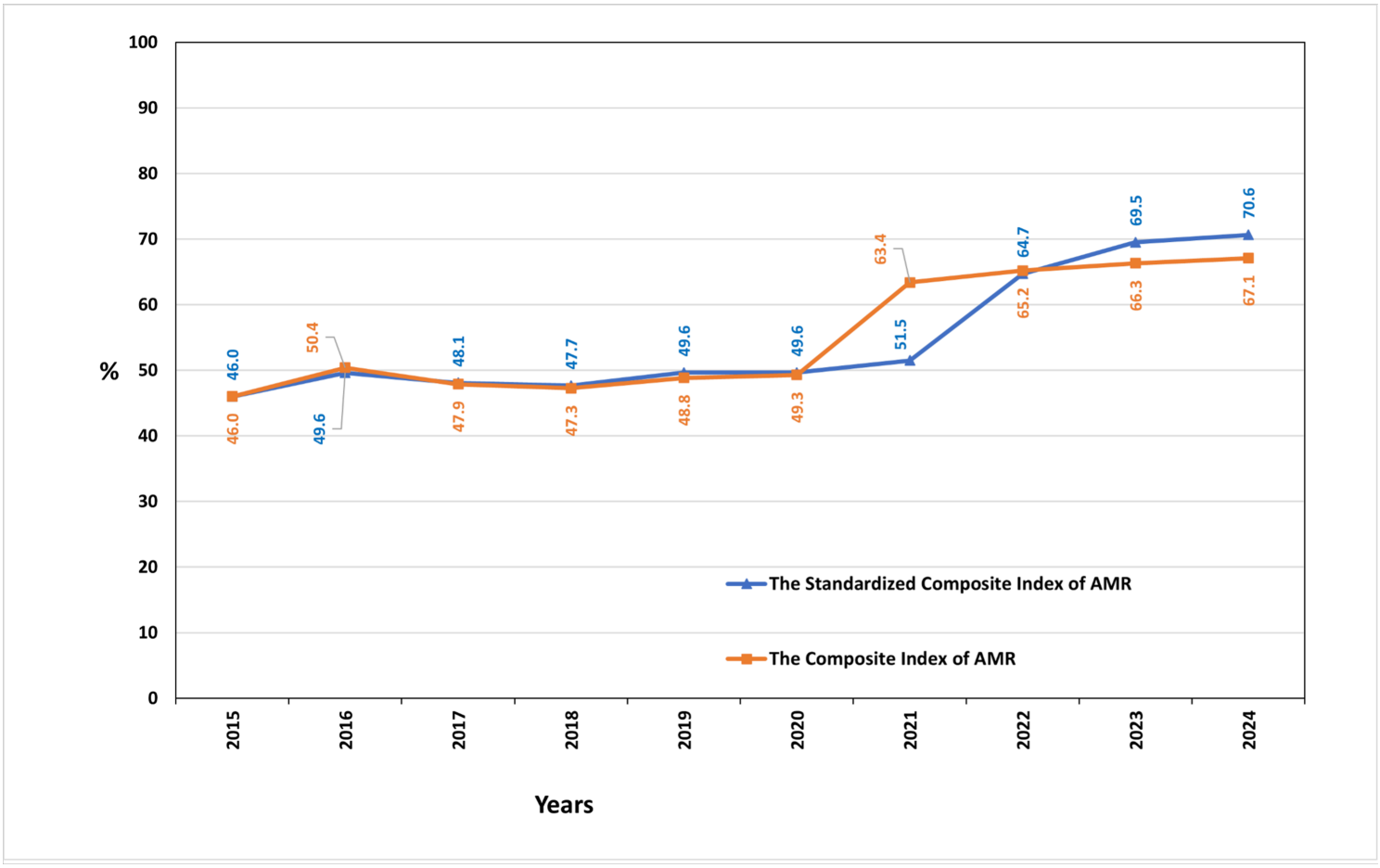


Figure 3

The Composite AMR Index and the Standardized Composite AMR Index by years.

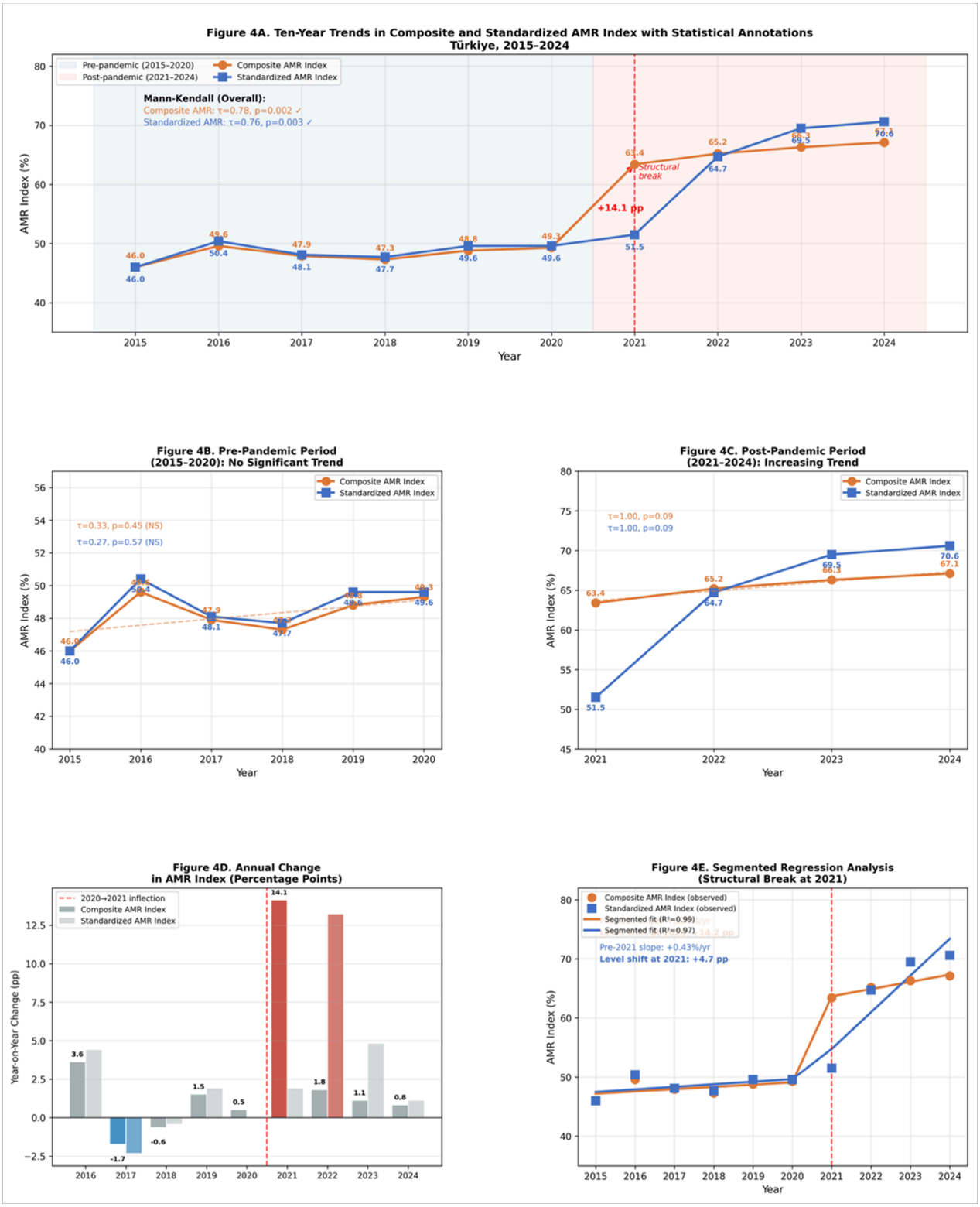


Figure 4

Statistical analysis of Composite and Standardized Composite AMR Index trends, Türkiye, 2015-2024.