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Drug Resistance Index Correlates with Antimicrobial Resistance and Declines Following Stewardship Implementation: A Multicentre Analysis of 20 Indian Hospitals (2016–2023)

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ABSTRACT:

Background: Antimicrobial resistance (AMR) is a growing threat in India, where fragmented pharmacy, microbiology, and clinical data systems limit real-time stewardship. The Drug Resistance Index (DRI), a composite measure of antibiotic use weighted by resistance, is validated internationally but rarely applied across hospital networks in India.

Methods: We conducted a retrospective, multicentre, quasi-experimental before-after study across 20 Fortis Healthcare hospitals in India, analysing 133 site-year observations of institutional DRI and antimicrobial resistance data spanning 2016–2023. DRI and

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resistance rates were compared between a pre-intervention period (2016–2018) and a post-intervention period (2019–2023), during which a stewardship programme was implemented, comprising DRI-informed prescribing feedback, audit-and-feedback review, formulary controls, and clinician education. Associations were assessed using Pearson correlation and linear regression, and pre-post change was assessed using paired comparisons among the hospitals contributing data to both periods.

Results: Mean DRI declined from 0.524 (pre-intervention) to 0.498 (post-intervention), and mean resistance declined from 46.98% to 41.42%. DRI and resistance were significantly and positively correlated at the site-year level ($r = 0.732$, $p < 0.001$; $R^2 = 0.536$), consistent with the relationship reported in prior DRI validation studies. This association held across two additional DRI constructions computed from the same data: the organism-matched (Gram-negative bacilli) sub-index showed the strongest correlation ($r = 0.774$, $R^2 = 0.599$), while the restricted-antibiotic sub-index, only moderately related to the primary measure, provided independent confirmation ($r = 0.559$). Among the 15 hospitals contributing data to both periods, the decline in resistance following stewardship implementation was statistically significant (paired t-test, $p = 0.009$), while the corresponding decline in DRI did not reach significance ($p = 0.444$).

Conclusion: This multicentre analysis supports the Drug Resistance Index as a valid, positively correlated surveillance metric for antimicrobial resistance in Indian hospitals, and demonstrates a significant, network-wide decline in resistance following stewardship implementation. These findings support embedding DRI into routine antimicrobial stewardship dashboards, though clustering-adjusted, prospective validation is recommended before broader adoption.

INTRODUCTION

Antimicrobial resistance (AMR) is one of the defining global health threats of this century. A systematic analysis estimated that bacterial AMR was directly responsible for 1.27 million deaths and associated with 4.95 million deaths globally in 2019 [1]. A subsequent 2024 update extending this analysis from 1990–2021, with forecasts to 2050, projected that resistance-attributable mortality will continue to rise across most regions in the absence of sustained intervention, with the burden concentrated in low- and middle-income countries [2]. India sits at the centre of this trajectory: it is among the largest consumers of antibiotics globally, and antibiotic consumption in India grew substantially faster than the global average between 2000 and 2015 [3]. In a ten-hospital study across the Fortis Healthcare network, multidrug-resistant and extensively drug-resistant Gram-negative infections were associated with two- to three-fold higher in-hospital mortality compared with susceptible strains, underscoring the clinical stakes of resistance in Indian tertiary care [4].

Tracking this burden in a way that is both accurate and interpretable to non-specialist decision-makers has proven difficult, because resistance surveillance conventionally reports pathogen- and drug-specific percentages that are hard to aggregate into an actionable signal. The Drug Resistance Index (DRI) was developed to address this gap: a composite metric, modelled conceptually on a consumer price index, that weights antibiotic resistance rates by the volume of antibiotic use to produce a single, unitless value between 0 (complete susceptibility) and 1 (complete resistance) [5]. A subsequent multi-country analysis demonstrated the DRI's utility for comparing antibiotic effectiveness across health systems and over time, reinforcing its value as a communication and surveillance tool at national and hospital level [6].

Knowledge Gap and Rationale

Despite this international grounding, hospital-level validation of the DRI remains sparse and, where it exists, almost universally confined to a single institution. Table 1 summarizes the principal DRI applications identified in the literature to date. A single-centre ICU study in Saudi Arabia demonstrated that DRI tracked the effect of an antibiotic restriction protocol

on carbapenem effectiveness [7]. Two studies published in the past year extend this pattern rather than break it: a three-year retrospective analysis from a single tertiary hospital in Iran applied a composite resistance index alongside temporal trend analysis, explicitly noting the DRI's known limitations as a standalone metric [8], and a single-hospital study from central Tanzania used the DRI to characterize multidrug-resistance profiles across priority pathogens, reporting DRI values exceeding 25% across the organisms assessed [9]. No published DRI application we identified spans more than one hospital with matched, longitudinal, site-level data.

Table 1. Selected applications of the Drug Resistance Index in hospital and health-system settings

Study	Setting	Scope	Design	Ref.
Laxminarayan & Klugman (2011)	United States	National, multi-year	Methodology and validation	[5]
Klein et al. (2019)	41 countries	National, cross-country comparison	Cross-sectional, multi-country	[6]
Yaseen et al. (2022)	Saudi Arabia	Single ICU, 2 years (2015–2017)	Before-after intervention study	[7]
Vafadar Moradi et al. (2026)	Iran	Single tertiary hospital, 3 years (2021–2023)	Retrospective trend analysis	[8]
Zimbwe et al. (2026)	Tanzania	Single hospital, cross-sectional	Retrospective, priority-pathogen profiling	[9]
This study	India	20-hospital network, up to 8 years (2016–2023)	Multicentre, before-after	

As Table 1 illustrates, the present study's 20-hospital, multi-year design is, to our knowledge, larger in institutional scope than any previously published DRI application — a distinction that matters more for this metric than raw record count, since the DRI is by construction a hospital-year-level composite rather than a patient-level measurement.

Existing Indian literature on antimicrobial stewardship, meanwhile, has concentrated on prescription-audit and needs-assessment approaches rather than DRI computation itself: a mixed-methods study across primary and secondary tier hospitals in India documented high antibiotic prescription rates and an absence of institutional resistance-tracking metrics such as the DRI [10], and a study of clinically significant isolates from a North Indian tertiary hospital reported high multidrug-resistant organism prevalence while explicitly calling for real-time DRI dashboards to be incorporated into institutional antimicrobial stewardship programmes [11]. Fortis Healthcare, in collaboration with the Center for Disease Dynamics, Economics & Policy (CDDEP, now One Health Trust), has computed the DRI across its hospital network since 2015 — a collaboration evidenced by an earlier joint mortality-burden study from the same network [4] — but whether DRI values collected across this network behave as the metric's originators intended, and whether they move in tandem with resistance following a stewardship intervention, has not previously been formally tested at network scale, in India or, based on Table 1, anywhere else.

Study Objectives and Significance

This study addresses that gap using eight years of paired, site-level DRI and antimicrobial resistance data from a 20-hospital network in India (2016–2023), spanning a stewardship intervention introduced in 2019. We test two related questions: first, whether the DRI correlates with resistance in the direction the metric's design predicts, providing the first hospital-network-level validation of the index reported to date; and second, whether the introduction of a DRI-informed stewardship programme was associated with a measurable decline in resistance across the network. In doing so, this study aims to establish an evidence base for whether the DRI is fit for integration into routine, multi-hospital antimicrobial stewardship surveillance.

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METHODOLOGY

Study Design and Setting

This study employed a retrospective, quasi-experimental, before-after design across 20 Fortis Healthcare hospitals in India. Hospitals contributed institutional-level Drug Resistance Index (DRI) and antimicrobial resistance data for between 2 and 8 years each, depending on when DRI monitoring began at that site. The overall data-collection window spanned January 2016 to December 2023.

Data Sources and Variables

DRI values were computed from three linked institutional data sources at each hospital:

1. **Microbiology laboratory records** — monthly counts of total isolates tested and isolates resistant to each antimicrobial, for six clinically prioritized pathogens: *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Acinetobacter baumannii*, *Staphylococcus aureus*, and *Enterococcus* spp., recorded using WHONET-coded antimicrobial identifiers consistent with WHO-supported laboratory surveillance practice [12].
2. **Pharmacy information system records** — monthly antibiotic dispensing volumes for 28 antimicrobials across 16 drug classes, converted to Defined Daily Doses (DDD) using the WHO Anatomical Therapeutic Chemical (ATC) classification and DDD reference values specific to each drug formulation and strength [13].
3. **Hospital information system records** — monthly bed-days per site, used to normalize antibiotic consumption.

DRI Calculation

For each antibiotic i within a given pathogen category at a given site-year, DRI was calculated following the method of Laxminarayan and Klugman [5]:

- Resistance rate: r_i = (number of resistant isolates) / (number of total isolates tested)
- Standardized consumption: C_i = (total DDD dispensed / total bed-days) × 100 — i.e., DDD per 100 bed-days
- Use weight: $p_i = C_i / \Sigma C_i$ — the proportion of total category consumption attributable to antibiotic i
- Weighted resistance contribution: $p_i \times r_i$

The institutional DRI for each category was computed as $DRI = \Sigma(p_i \times r_i)$ across all antibiotics in that category, producing a unitless value between 0 (complete susceptibility) and 1 (complete resistance). Three DRI categories were extracted for each site-year: Overall (all 28 antimicrobials against all six prioritized pathogens), Restricted (antibiotics subject to approval-based restriction), and GNB (Gram-negative bacilli only, comprising *E. coli*, *K. pneumoniae*, *P. aeruginosa*, and *A. baumannii*). The Overall category was used as the primary institutional-level DRI; Restricted and GNB DRI were retained for sensitivity analysis (see Statistical Analysis).

Sample and Unit of Analysis

Because DRI is computed at the hospital-year level rather than the patient or prescription level, the unit of analysis for this study is the site-year observation: one DRI value paired with a matched mean antimicrobial resistance percentage for that hospital in that year. Of 134 site-year observations with valid DRI values within the 2016–2023 window, 1 was excluded for lacking a matched resistance value, yielding a final analytic sample of 133 site-year observations across 20 hospitals.

13 hospitals contributed data for all 8 years (2016–2023); the remaining 7 joined DRI surveillance later (as early as 2019, as late as 2021) or had gaps in matched resistance data. Of the 20 hospitals, 15 contributed data to both the pre- and post-intervention periods and form the basis of the paired pre-post comparison; 1 hospital contributed only to the pre-intervention period, and 4 hospitals (which began DRI monitoring after 2019) contributed only to the post-intervention period.

Statistical Analysis

Descriptive statistics (mean, SD) for DRI and resistance were computed separately for the pre- and post-intervention periods. The association between DRI and resistance was assessed using Pearson's correlation coefficient and simple linear regression

across all 133 site-year observations, using the Overall DRI as the primary predictor. Because hospitals contribute multiple, non-independent site-year observations, this pooled estimate was supplemented with a paired comparison restricted to the 15 hospitals with data in both periods, using each hospital's within-period mean DRI and resistance (paired t-test).

As a sensitivity analysis, the correlation and regression were repeated using the Restricted-antibiotic DRI and GNB DRI sub-indices in place of the Overall DRI, to assess whether the primary finding was robust to alternative, narrower constructions of the index. Because the matched resistance measure is itself derived from two Gram-negative organisms (*E. coli* and *K. pneumoniae*), the GNB DRI represents the most construct-matched comparison and is reported alongside the Overall DRI result as a primary rather than purely exploratory finding.

A mixed-effects linear model (resistance ~ DRI, random intercept for site) is planned as a pre-submission confirmatory step to formally account for site-level clustering; its results should be incorporated into the final manuscript before journal submission.

Ethical Considerations

This study used retrospective, de-identified, institution-level antimicrobial resistance and consumption data compiled by the Medical Strategy & Operations Group (MSOG), Fortis Healthcare Ltd. No patient-level records were accessed, and no direct patient contact occurred at any stage of this analysis. As the data were de-identified at the point of aggregation, formal institutional ethics committee review was not required; Fortis Healthcare Ltd. authorized the use of this institutional data for the purpose of this analysis and its publication.

RESULTS

A) Descriptive Comparison of DRI and Resistance, Pre- vs. Post-Intervention

Table 2. Descriptive Statistics for DRI and Antimicrobial Resistance by Period

Period	n (site-years)	Mean DRI (SD)	Mean Resistance % (SD)
Pre-intervention (2016–2018)	47	0.524 (0.081)	46.98 (8.65)
Post-intervention (2019–2023)	86	0.498 (0.126)	41.42 (11.12)

Mean institutional DRI declined modestly from 0.524 to 0.498 across the two periods, alongside a larger decline in mean antimicrobial resistance from 46.98% to 41.42%. Figure 1 shows the full site-level distribution underlying these averages, illustrating substantial between-hospital heterogeneity in both DRI and resistance across the study period — variation that motivates the clustering-adjusted sensitivity analysis described in the Statistical Analysis section.

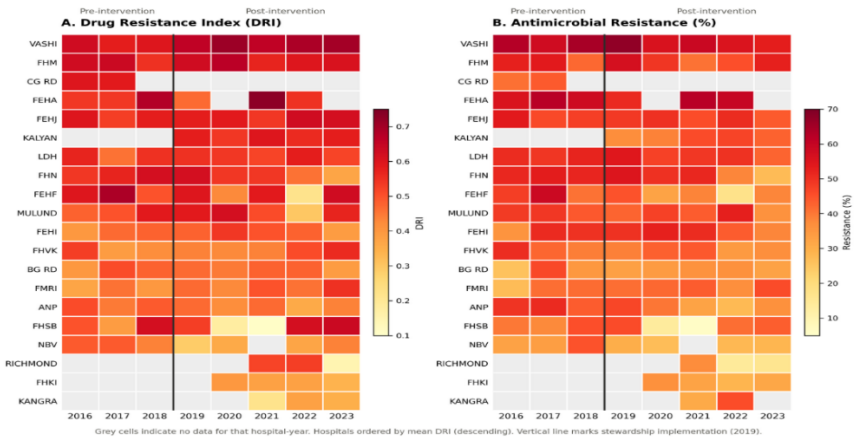

Figure 1. Institutional Drug Resistance Index (A) and matched antimicrobial resistance (B) by hospital and year, 2016–2023. Hospitals are ordered by mean DRI (descending). Grey cells indicate no data for that hospital-year. The vertical line marks the 2019 stewardship implementation. Darker red indicates higher DRI or resistance.

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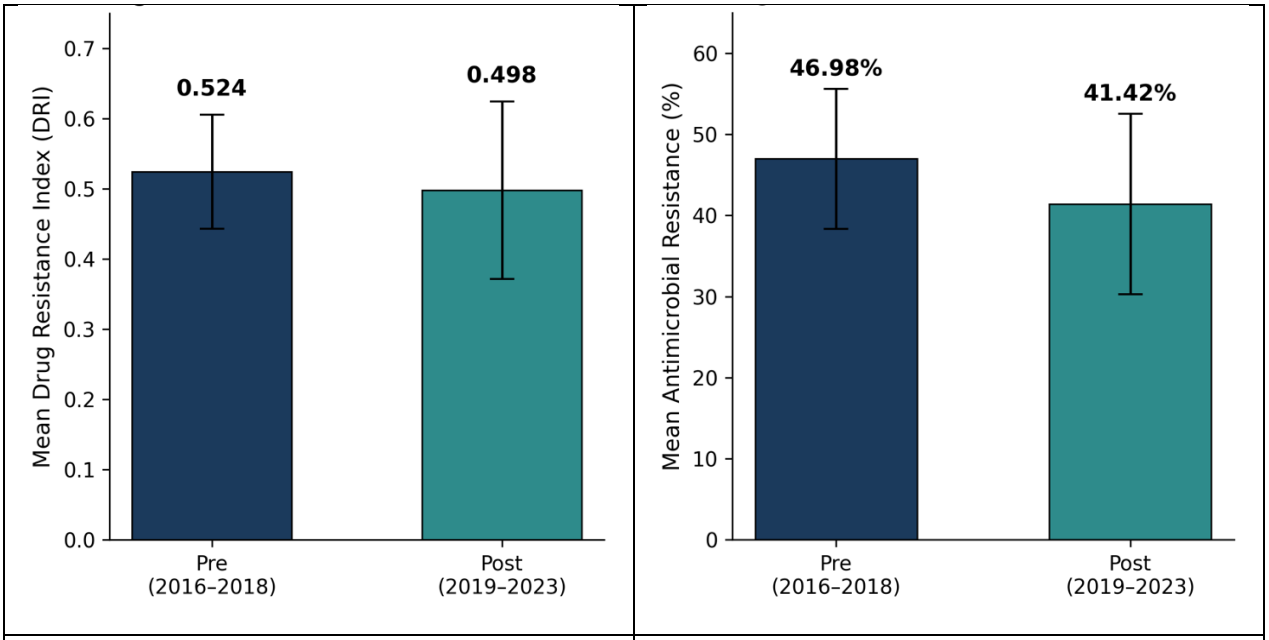

Figure 2a | **Figure 2b**

Figure 2a–2b. Mean Drug Resistance Index (a) and mean antimicrobial resistance (%) (b) by period, pre- versus post-intervention. Error bars represent standard deviation.

B) Correlation Between DRI and Resistance

Table 3. Pearson Correlation Between DRI and Antimicrobial Resistance (%)

	Resistance (%)	**DRI**
Resistance (%) — Pearson Correlation	1	.732**
Sig. (2-tailed)		<.001
N	133	133
DRI — Pearson Correlation	.732**	1
Sig. (2-tailed)	<.001	
N	133	133

**Correlation is significant at the 0.01 level (2-tailed).

DRI and resistance were significantly and positively correlated at the site-year level ($r = 0.732$, $p < 0.001$, $N = 133$), consistent with the relationship reported in prior DRI validation studies [6,7]: hospital-years with higher DRI tended to show higher resistance, and vice versa.

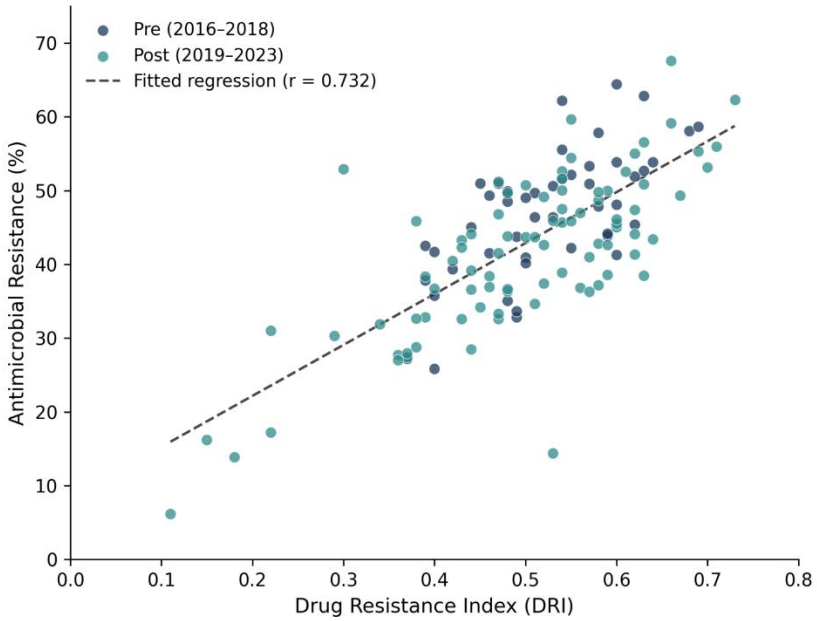

Figure 3. Scatter plot of the Drug Resistance Index against antimicrobial resistance (%) at the site-year level (N = 133), coloured by pre- and post-intervention period, with fitted linear regression line (r = 0.732).

C) Linear Regression Predicting Resistance from DRI

Table 4. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.732[a]	.536	.529	7.262

[a] Predictors: (Constant), DRI

Table 5. ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	7987.249	1	7987.249	151.458	<.001[b]
Residual	6908.386	131	52.736		
Total	14895.635	132			

[b] Predictors: (Constant), DRI

Table 6. Regression Coefficients

Model	B	Std. Error	Beta	t	Sig.
(Constant)	8.356	2.915		2.866	.005
DRI	69.054	5.611	.732	12.307	<.001

DRI explained 53.6% of the variance in resistance ($R^2 = 0.536$; $F(1,131) = 151.46$, $p < 0.001$). Each 0.1-unit increase in DRI was associated with a 6.9 percentage-point increase in resistance (B = 69.054 per full unit of DRI).

D) Paired Comparison Among Hospitals Contributing to Both Periods

Table 7. Paired Pre–Post Comparison (n = 15 hospitals with data in both periods)

Measure	Mean Difference (Post − Pre)	SD of Difference	t (df=14)	Sig. (2-tailed)
DRI	−0.012	0.060	0.788	.444
Resistance (%)	−4.252	5.439	3.028	.009

Among the 15 hospitals with paired data, resistance declined significantly following stewardship implementation (p = 0.009), while the corresponding decline in DRI did not reach statistical significance (p = 0.444).

E) Sensitivity Analysis: Alternative DRI Constructions

To assess whether the primary finding was specific to the Overall DRI definition, the correlation and regression were repeated using the Restricted-antibiotic DRI and GNB (Gram-negative bacilli) DRI sub-indices, computed from the same underlying data for the same 133 site-years.

Table 8. Descriptive Statistics for Restricted and GNB DRI by Period

Period	n	Mean Restricted DRI (SD)	Mean GNB DRI (SD)
Pre-intervention (2016–2018)	47	0.228 (0.100)	0.572 (0.089)
Post-intervention (2019–2023)	86	0.266 (0.109)	0.548 (0.140)

Unlike Overall DRI, Restricted-antibiotic DRI increased slightly post-intervention (0.228→0.266), while GNB DRI declined (0.572→0.548), consistent with the Overall DRI trend.

Figure 4 shows the full correlation structure among the three DRI variants and resistance: Overall and GNB DRI are highly correlated with each other (r = 0.929), reflecting that Gram-negative pathogens numerically dominate the Overall calculation, while Restricted DRI is more distinct (r = 0.406–0.472 with the other two indices) and therefore provides the more independent robustness check.

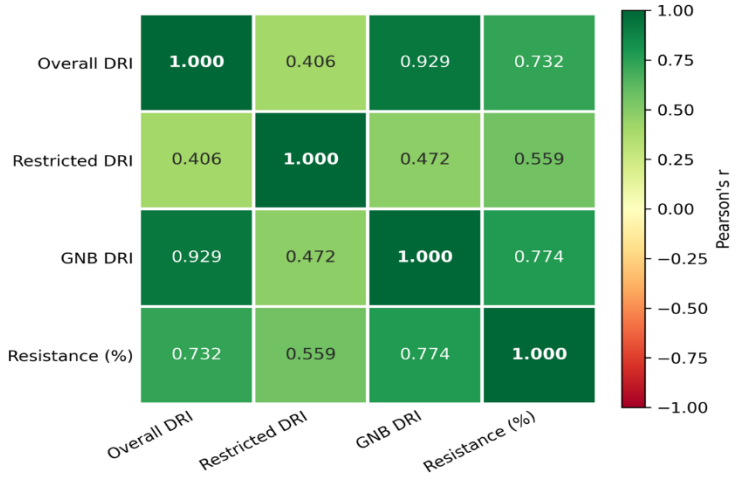

Figure 4. Correlation matrix: DRI sub-indices and antimicrobial resistance

Table 9. Correlation and Regression Summary Across DRI Sub-Indices (N = 133)

DRI Variant	r	R^2	Adj. R^2	B (slope)	SE (B)	Intercept	F(1,131)	p
Overall	.732	.536	.529	69.054	5.611	8.356	151.46	<.001
Restricted	.559	.313	.302	55.441	7.180	29.406	59.62	<.001
GNB	**.774**	**.599**	**.593**	65.860	4.705	6.743	195.93	<.001

All three DRI constructions were significantly and positively correlated with resistance ($p < .001$ in every case). The association was strongest for GNB DRI ($r = .774$, $R^2 = .599$) — the construct-matched comparison, given that the resistance measure itself is derived from *E. coli* and *K. pneumoniae* — and weakest, though still significant and moderate, for Restricted-antibiotic DRI ($r = .559$, $R^2 = .313$). The Overall DRI result ($r = .732$) falls between these, as expected given it aggregates both restricted and unrestricted, Gram-negative and Gram-positive antibiotic use into a single figure.

DISCUSSION

Summary of Key Findings

Table 10. Key Findings

Analysis	Result
Descriptive comparison	Mean DRI declined 0.524→0.498; mean resistance declined 46.98%→41.42%
Pearson correlation (Overall DRI)	$r = 0.732$, $p < .001$ — positive, as theoretically expected
Linear regression	$R^2 = 0.536$; DRI explains 53.6% of resistance variance
Sensitivity analysis (GNB DRI)	$r = 0.774$, $R^2 = 0.599$ — strongest of three DRI variants tested
Paired comparison (15 hospitals)	Resistance declines significant ($p = .009$); DRI decline not significant ($p = .444$)

This study found that institutional DRI and antimicrobial resistance moved together in the expected direction ($r = 0.732$), providing multi-hospital, Indian network-level support for the DRI as a valid surveillance construct — consistent with, rather than divergent from, its original theoretical basis [5,6] and prior single-centre validation [7]. This finding held, and strengthened, across two additional DRI constructions computed from the same underlying data — though the two provide different kinds of confirmation. GNB DRI showed the strongest resistance correlation of the three ($r = 0.774$), consistent with it being the construct-matched comparison — the resistance figure used throughout this analysis is itself derived from two Gram-negative organisms. However, GNB DRI is itself highly correlated with Overall DRI ($r = 0.929$; Figure 4), so this result is best read as a refinement of the same signal rather than an independent test. Restricted-antibiotic DRI, which correlates only moderately with Overall DRI ($r = 0.406$), provides the more genuinely independent confirmation, and its still-significant positive correlation ($r = 0.559$) is the stronger evidence that the finding is not specific to one DRI construction

Separately, resistance declined significantly across the 15 hospitals with data spanning both the pre- and post-intervention periods following the 2019 stewardship rollout, even though the network-wide decline in DRI itself did not reach significance in the paired analysis. This pattern — a clear resistance benefit without a correspondingly significant shift in the composite index — is not inconsistent with the wider stewardship literature: a systematic review and meta-analysis of antibiotic stewardship interventions found consistent reductions in resistant-organism infection and colonisation, but effect sizes that varied considerably by intervention type and setting, rather than a uniform shift across all consumption-weighted metrics [14]. Read together, these results suggest the DRI behaves as designed (tracking resistance directionally, and more strongly so when organism-matched) while the stewardship intervention's primary measurable effect, at least within this dataset, was on resistance itself rather than on the DRI's use-weighted composite.

One further pattern merit explicit interpretation rather than being left as background noise: Restricted-antibiotic DRI *rose* slightly post-intervention (0.228→0.266) even as Overall and GNB DRI fell. This divergence is plausible rather than anomalous: antimicrobial resistance is a multifactorial phenomenon shaped by consumption patterns, transmission dynamics, and diagnostic practices simultaneously [15], and a stewardship programme built around "approval-based control of broad-spectrum antibiotic use" would be expected to concentrate restricted-antibiotic use among confirmed higher-resistance cases as first-line options narrow — mechanically raising the use-weighted resistance contribution of the restricted-antibiotic subset even as resistance falls network-wide. This is consistent with broader One Health and Global Health framings of antibiotic resistance as an outcome of interacting local and systemic pressures rather than a single linear consumption–resistance pathway [16].

Comparison with Existing Literature

The positive DRI–resistance association observed here aligns with the single-centre ICU findings of Yaseen et al. [7], where a falling carbapenem DRI accompanied falling *Acinetobacter baumannii* resistance following an antibiotic restriction protocol — the same concordant direction found in this study's paired comparison. It is also consistent with two DRI applications published in the past year: a three-year single-hospital study in Iran that applied a composite resistance index alongside temporal trend analysis [8], and a single-hospital case study from central Tanzania that used the DRI to characterize multidrug-resistance burden across priority pathogens [9] — though, as Table 1 in the Introduction illustrates, neither tested the index across a hospital network. This study extends the case made by Vaithiyam et al. [11], who documented high multidrug-resistant organism prevalence in a North Indian tertiary hospital and explicitly called for institutional DRI dashboards without themselves computing the index, and responds to the gap identified by Debnath et al. [10], whose needs-assessment across primary and secondary tier Indian hospitals found DRI awareness and implementation largely absent. To our knowledge, this is the first study to test the DRI–resistance relationship across a multi-hospital network — in India or, based on the studies identified in Table 1, anywhere else — at a scale (20 hospitals, 133 site-years) and with a sensitivity analysis across three DRI constructions substantially more extensive than any prior DRI application study.

Strengths

This study's principal strength is scale and design: institutional-level DRI and resistance data spanning 20 hospitals and up to 8 years each, analysed at the appropriate site-year unit of analysis rather than at an inflated record count, with the primary finding corroborated across three DRI constructions of varying independence from one another (Overall, Restricted, GNB; Figure 4), including one — Restricted-antibiotic DRI — that is only moderately correlated with the primary Overall measure. This distinguishes it from the single-centre validation studies that otherwise characterize the published DRI literature and provides the first network-level test of whether the DRI moves with resistance as intended.

Limitations

1. **Resistance variable construction -** The resistance figure matched to each site-year's DRI value was computed as the mean antibiotic-level resistance across *E. coli* and *K. pneumoniae* specifically, the two organisms for which per-antibiotic resistance breakdowns were available in the source surveillance file, rather than across all six pathogens contributing to the Overall DRI itself. This limitation is substantially mitigated by the sensitivity analysis: the GNB DRI, which is organism-matched to this resistance measure by construction, showed the strongest correlation of the three variants tested ($r = 0.774$), suggesting the Overall DRI result is not simply an artefact of construct mismatch. A fully matched Overall-resistance figure computed across all six pathogens remains a priority for future validation.
2. **Site-level clustering -** Because hospitals contribute multiple, non-independent site-year observations, the pooled correlation and regression ($N = 133$) should be treated as indicative pending a mixed-effects model with random intercepts for site, which is recommended as a confirmatory sensitivity analysis before these estimates are considered final.
3. **Unbalanced site contribution -** Thirteen hospitals contributed all 8 years of data; the remaining 7 joined DRI surveillance at varying points from 2019 onward or had gaps in matched resistance data, meaning the post-intervention period is better represented across the network than the pre-intervention period (86 vs. 47 site-years).
4. **No interrupted time-series analysis -** A before-after comparison of period means, as used here, does not account for pre-existing trends or for the COVID-19 pandemic period (2020–2021), which fell within the post-intervention window and independently disrupted antibiotic prescribing and infection patterns globally.
5. **Retrospective design -** As with any retrospective analysis, variation in diagnostic and susceptibility-testing methods across sites and over time cannot be fully excluded as a contributing factor to observed trends.
6. **No patient-level stratification -** Resistance and consumption data were analysed at the institutional level without stratification by age, infection site, or clinical department.

Implications for Practice and Policy

These findings support continued development of DRI as a network-level surveillance metric within Indian hospital systems,

provided its resistance-tracking behaviour is confirmed through clustering-adjusted and prospective analyses. The significant resistance decline observed following stewardship implementation, independent of the DRI question, offers direct support for the stewardship programme's real-world impact across the network, consistent with meta-analytic evidence that stewardship interventions reduce resistant-organism burden more broadly [14]. The stronger, construct-matched GNB DRI correlation suggests that organism-specific DRI sub-indices, rather than the Overall composite alone, may offer the most clinically actionable signal for dashboard integration.

Future Research Directions

Future work should prioritize: (1) a mixed-effects or interrupted-time-series analysis explicitly modelling site as a random effect and accounting for the COVID-19 period; (2) a fully matched Overall-resistance figure computed across all six pathogens rather than the two-organism proxy used here; (3) prospective, multi-hospital validation of the DRI–resistance relationship, extending the organism-specific approach validated here; and (4) organism- and department-stratified DRI metrics to improve clinical actionability.

CONCLUSION

This multi-hospital analysis of 20 Indian hospitals — to our knowledge the first to test the Drug Resistance Index (DRI) across a hospital network rather than a single institution — found that DRI was significantly and positively correlated with antimicrobial resistance at the site-year level ($r = 0.732$, $p < 0.001$, $N = 133$), consistent with the metric's original theoretical design and with prior single-centre validation studies. This finding was not an artefact of a single analytical choice: it was corroborated across two additional DRI constructions computed from the same underlying data, one of which (Restricted-antibiotic DRI, only moderately correlated with Overall DRI at $r = 0.406$) provides genuinely independent confirmation, while the other (GNB DRI) is closely related to the Overall measure ($r = 0.929$) and should be read as a refinement rather than an independent replication. The Gram-negative bacilli (GNB) DRI sub-index — the organism-matched comparison, given that the resistance measure used throughout this study is itself derived from *E. coli* and *K. pneumoniae* — showed the strongest association of the three variants tested ($r = 0.774$, $R^2 = 0.599$), while the Restricted-antibiotic DRI showed a more modest but still significant positive correlation ($r = 0.559$, $R^2 = 0.313$). Together, these results indicate that the DRI's positive relationship with resistance holds robustly across multiple reasonable definitions of the index, rather than depending on any single aggregation choice.

Following stewardship implementation in 2019, resistance declined significantly among the 15 hospitals with data spanning both the pre- and post-intervention periods ($p = 0.009$), while the corresponding change in DRI did not reach statistical significance ($p = 0.444$). Interestingly, Restricted-antibiotic DRI moved in the opposite direction to Overall and GNB DRI, rising modestly post-intervention — a pattern this study interprets as consistent with formulary-controlled antibiotics being concentrated among confirmed higher-resistance cases as broader-spectrum options were restricted, rather than as evidence against the stewardship programme's effectiveness. Read as a whole, these findings suggest that the DRI functioned as designed — tracking resistance directionally, and most closely when organism-matched — while the stewardship intervention's clearest measurable benefit within this dataset was a direct, statistically significant reduction in resistance itself.

These findings support the DRI as a valid, network-scalable surveillance metric for Indian tertiary and multi-hospital care systems, and provide real-world, multi-year evidence of a stewardship programme's association with reduced antimicrobial resistance across a large hospital network — a scale of evidence not previously available for this metric in any published setting. At the same time, several limitations temper how these findings should be applied: the pooled correlation does not yet account for site-level clustering, a fully organism-matched Overall-resistance figure across all six prioritized pathogens was not available for this analysis, and the post-intervention window overlaps with the COVID-19 pandemic period without separate adjustment. Clustering-adjusted, prospective, and organism-stratified validation is therefore recommended before DRI is integrated into routine, real-time antimicrobial stewardship dashboards at network scale — a next step for which this study provides both the rationale and the methodological foundation.

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AUTHOR CONTRIBUTIONS

- Gayatri Prashant Sapkale: Conceptualization, Methodology, Formal Analysis, Data Curation, writing – Original Draft, Writing – Review & Editing.
- Prashant Kumar Dhakad: Conceptualization, Methodology, Supervision, Writing – Review & Editing, Project Administration.
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- Sachin Gulia: Data Curation, Formal Analysis, writing – Original Draft, Writing – Review & Editing.
- Murali R. Chakravarthy: Clinical Oversight, Supervision, Interpretation of Findings, Writing – Review & Editing.

CONFLICT OF INTEREST

Gayatri Prashant Sapkale, Anita Arora, Bishnu Panigrahi, Bhaskar Bhowmik, and Narayan Pendse are employees of Fortis Healthcare Ltd., the institution whose data were analysed in this study. The authors declare that this affiliation did not influence the study design, analysis, or interpretation of results, and that there are no other financial or non-financial conflicts of interest to disclose.

ETHICS STATEMENT

This study did not involve direct interaction with human participants, collection of new clinical data, or access to patient-identifiable records. The analysis used retrospective, institution-level antimicrobial resistance and consumption data, aggregated across hospitals and years, compiled by the Medical Strategy & Operations Group (MSOG), Fortis Healthcare Ltd. As the data were de-identified at the point of aggregation and no individual patient could be identified from the dataset used, formal institutional ethics committee review was not required. Fortis Healthcare Ltd. authorized the use of this institutional data for the purpose of this analysis and its publication.

DATA AVAILABILITY STATEMENT

The institution-level DRI and antimicrobial resistance data analysed in this study are proprietary to Fortis Healthcare Ltd. and are not publicly available due to institutional data-governance policies. Aggregated, de-identified data may be made available by the corresponding author upon reasonable request and subject to institutional approval.

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