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Antimicrobial resistance in Malaysia: a cross-sectional study analysing trends and economic impacts

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ABSTRACT

Objective This national study assessed the economic impact of treating patients with antimicrobial resistance (AMR) pathogens within Malaysia's Ministry of Health (MoH) hospitals.

Design A cross-sectional study design and top-down costing approach, analysing Malaysian diagnosis-related group (DRG) data for AMR patients admitted to MoH hospitals from 2017 to 2020.

Setting and participants A total of 1190 cases were identified using International Statistical Classification of Diseases-10 version 2010 codes for AMR pathogens.

Outcome measures The study aims to estimate direct healthcare costs for treating AMR patients. Costs per admission were calculated based on each patient's length of stay (LOS). A binary logistic regression model identified cost determinants, with significant factors ($p<0.05$) further analysed using a multivariate multiple logistic regression. ORs with 95% CIs were determined, and treatment costs were categorised as above or below the annual national base rate.

Results Findings showed that costs are influenced by the volume of cases identified through DRG codes and LOS, which averaged between 21.7 and 36.4 days. Median admission costs for AMR patients ranged from RM12 476.28 (IQR RM 15 655.93) to RM19 295.11 (IQR RM20 200.28). Both LOS and total costs increased annually, from RM3 711 046.10 in 2017 to RM9 700 249.08 in 2019. Patients over 56 years old and those with severity levels II and III were more likely exceeding the national base rate.

Conclusions These findings, explaining 9.3% of the variance in the regression model, can inform policies to reduce the economic burden of AMR and improve patient outcomes, highlighting the need for a comprehensive strategy to address this global health threat.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ National-level study with a prominent sample size representative of the population of patients infected with antimicrobial resistance (AMR) pathogens in hospital settings in the public healthcare sector of a developing nation.

⇒ The study data extraction using centralised data from the federal government provides a comprehensive analysis and essentially reduces bias.

⇒ Causal relationships cannot be derived from the cross-sectional analysis as exposure and outcome were evaluated at the same time.

⇒ Coding error leading to casemix cost that engenders the potential for bias in data collection and the difficulty of accurately estimating the economic burden of AMR.

⇒ The study is limited to focusing on hospitals and special medical institutions; does not include other healthcare settings where AMR may also have significant economic impacts.

INTRODUCTION

Antimicrobial resistance (AMR) is at a worrying level worldwide, with 700 000 deaths annually, and is projected to increase to 10 million people per year by 2050 due to the frequent and widespread use and abuse of antimicrobials.[1] AMR occurs when bacteria develop the ability to survive and multiply despite antimicrobials exposure, making these drugs ineffective in the treatment of bacterial infections. Infections resulting from organisms resistant to multiple drugs (MDR) have been documented globally, undermining our ability to effectively manage infectious diseases.

Failure to appreciate the economic consequences of AMR can be devastating in the long run. AMR has been projected to cost from US$300 billion to more than US$1 trillion annually by 2050 worldwide.[2] The impacts of AMR on human health will be increased morbidity (illness) and mortality.[3] When pathogens are drug-resistant, such treatment will invariably be more costly and produce worse outcomes for patients and the community. These give rise to the direct and indirect costs of illness. Direct costs of illness are the resources used to treat or cope with the disease, including hospitalisation costs and medication. The indirect costs of disease comprise the present and future costs to society of morbidity, disability and premature death, particularly the loss of production caused by a reduced adequate labour supply (due to lower productivity and the deaths of workers).

Accurate diagnosis and careful administration of antimicrobials are crucial in addressing the problem of AMR. When bacteria resist common antimicrobials, more expensive medications are necessary for treatment. This leads to longer periods of illness, increased hospitalisation, higher mortality and morbidity rates, increased healthcare costs, and economic burdens on individuals and society.[4] This study uses data from various sources, including hospital records, medical literature, government reports and MalaysianDRG or 'casemix' to investigate the economic burden and health implications due to the appearance of difficult-to-treat bacterial diseases in public hospitals in Malaysia.

To our knowledge, this is the first nationwide study that estimates the economic cost of AMR, patient length of stay (LOS) in hospitals and patient clinical outcome (death or alive or discharged well) in Malaysia. Understanding the economic burden of AMR in hospitals is crucial for developing effective strategies to combat this global health threat. In addressing the growing national health threat posed by the AMR pandemic, this study emphasises healthcare financing and aims to ensure access to safe, effective, high-quality and affordable essential medicines for everyone. This approach aligns with Sustainable Development Goal 3, which focuses on ensuring good health and well-being without compromising the quality of healthcare delivery services. The insights presented by integrating economic data into current and future AMR statistics will prove pivotal for future modelling of AMR emergence and managing the anticipated pandemic.

MATERIAL AND METHODS

A national-level cross-sectional and a top-down costing approach study was conducted involving all public hospitals in Malaysia (excluding university teaching hospitals) where data are captured in the casemix system (MalaysianDRG) managed by the Medical Development Division, Ministry of Health (MoH) Malaysia. Data from 2017 to 2020 were included in the study. However, we approached the year 2020 data cautiously as the pandemic period does not reflect the actual costs that were accrued in non-pandemic duration. The minimum sample size required to answer the question about contributing factors is 713 patients diagnosed with AMR, calculated using the two population proportion formulas. Nevertheless, we extracted all available data in the casemix system to more accurately estimate the country's economic cost of treating patients infected with AMR and the factors contributing to the treatment cost. The number of each pathogen is not equally weighted as this sample size was based on samples admitted during the study duration. AMR treatment cost is the economic cost borne by providers for the infection of AMR pathogens and the management of concurrent comorbidities.

The patients admitted to the study were coded with the WHO version of the 10th International Statistical Classification of Diseases and Related Health Problems (ICD-10). Codes in ICD-10 are coded according to the diagnosis of the patient at discharge. Codes are characteristics of a patient's condition and procedures performed during admission. The ICD-10 codes were then abstracted into MalaysianDRG software, and the new diagnosis-related group (DRG) codes were churned out. These DRG codes consist of multiple severity of illness (SOI) levels (I, II and III), with each patient's LOS, and the cost of stay during that admission. The SOI Index is a three-tiered system (ranging from level 1 to level 3) that evaluates a patient's illness burden based on multiple dimensions. This index provides an overall severity score at discharge, which is derived from clinically significant factors, including complications, comorbidities, the number of procedures, intensive care unit (ICU) stays and age categories.[5]

ICD codes were helpful in abstracting keywords of interest and were required for the study. Codes for specific purposes and the inclusion of keywords—such as methicillin-resistant *Staphylococcus aureus* (MRSA), ESBL-producing *Klebsiella pneumoniae*, ESBL-producing *Escherichia coli* and multidrug-resistant *Mycobacterium tuberculosis* (U80–U89: Bacterial agents resistant to antimicrobials) were examined and abstracted from the casemix data system. Casemix data such as cost per admission, LOS and discharge status (discharged well, referred out and died) were obtained from the Medical Services Development Branch—Hospital Management Services Unit, Medical Development Division of the MoH. The extracted data were cleaned and arranged into desirable variables before analysis. Data analyses were carried out using IBM Statistical Package for Social Sciences (SPSS) V.26 with a p value less than 0.05 considered statistically significant.

Lastly, to demonstrate the process of determining the cost per case, each coded instance incorporated into the MalaysianDRG casemix system results in a distinct DRG associated with an assigned cost group weight (CGW). This CGW is determined by considering the average input expenses for necessary medical procedures and diagnostic services essential for achieving optimal patient results. Multiplying all CGWs with the latest annual national base rate yields the price per cost for each DRG. The cost per admission or the actual price per patient was estimated considering the actual patient's stay length.

A binary logistic regression model was performed for the analysis of determinants of the cost of AMR treatment in MoH hospitals. Using simple logistic regression to estimate the factors associated with AMR pathogen infections, and then, significant factors with a $p<0.05$ at the univariate level were entered into the multivariate multiple logistic regression to predict factors for the cost of AMR treatment. ORs using 95% CIs were calculated for all variables. The treatment cost that suffices as the dependent variable was adapted into dichotomous over or below the annual national base rate. Consequently, the independent variables were transmuted into categorical data and the presence of multicollinearity was assessed to satisfy the assumptions for the regression model.

Table 1 Overview characteristics of AMR patients from public hospitals in Malaysian DRG and its effect on the economic cost of AMR treatment (2017–2020*)

Variable		N	%	Median (IQR) (RM)	P value
Hospital category					0.127
	Major specialist hospital	254	21.3	14827.50 (18 180.58)	
	Minor specialist hospital	45	3.8	9949.84 (13 867.19)	
	Non-specialist hospital	24	2.0	17746 (19 161.91)	
	Special medical institution	6	0.5	16743 (526 583.48)	
	State hospital	861	72.4	**17403.47** (**20 796.27**)	
Gender					0.935
	Male	738	62.0	16148.15 (18 344.34)	
	Female	452	38.0	**17398.39** (**21 528.58**)	
Age					0.007
	0–10	34	2.9	13910.94 (26 617.72)	
	11–20	22	1.8	15910.33 (27 132.20)	
	21–30	62	5.2	13045.34 (25 432.59)	
	31–40	100	8.4	18213.84 (20 138.87)	
	41–50	158	13.3	17292.16 (20 317.15)	
	51–60	282	23.7	**18480.40** (**20 017.05**)	
	61–70	300	25.2	17279.30 (20 941.38)	
	71–80	170	14.3	14978.11 (14 098.97)	
	81–90	56	4.7	13265.78 (12 342.92)	
	91–100	6	0.5	14233.57 (22 960.27)	
Disciplines					0.147
	Medical	983	82.6	15,71517 (18 147.81)	
	Surgical	207	17.4	21498.55 (**27 116.81**)	
Severity of Illness					<0.001
	I	181	15.2	12406.08 (16 469.26)	
	II	290	24.4	12924.91 (16 663.49)	
	III	719	60.4	**18853.76** (**20 553.17**)	
Intensive care unit (ICU) admission					0.068
	Yes	139	11.7	24239.29 (**26 960.47**)	
	No	1051	88.3	15682.96 (18 364.37)	
Discharge outcome					0.381
	Alive	233	19.6	14376.59 (14 206.62)	
	Dead	957	80.4	**17393.32** (**21 531.68**)	
LOS†		26.8 (79.9)			<0.001

Bold values indicate the highest cost in each respective category
*The pandemic might cause the costs to be higher/lower than what is reflected.
†LOS is described as mean (SD).
AMR, Antimicrobial resistance; DRG, diagnosis-related group; LOS, length of stay.

Patient and public involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

RESULTS

A total of 1190 cases (2017–2020) of the 146 MoH hospitals were extracted, and table 1 provides demographic information. These cases comprise all available data retrieved from the MalaysianDRG software based on the ICD-10 version 2010 codes for AMR pathogens following thorough data cleaning processes. In our study, readmission cases are treated as distinct and independent cases. This approach is justified as each readmission is assigned its own unique set of ICD codes, reflecting the specific clinical conditions and diagnoses associated with that admission. By counting readmissions separately, we ensure accurate representation and analysis of the data.

Most of the cases were from state hospitals (72.4%), followed by major specialist hospitals with 21.3%, minor specialist hospitals (3.8%), non-specialist hospitals (2.0%) and special medical institutions (0.5%). Patients infected with AMR pathogens in state hospitals contribute to the highest median cost (RM17 403.47 with an IQR of RM20 796.27) between hospital categories. The gender distribution was 62.0%–38.0% males to females, although female patients recorded a higher median cost than males with RM17 398.39 (IQR RM21 528.58). The mean age of the cases was 56.0 years with an SD of 18.4 years. The lowest age of the patient was found to be less than 1 year old, while the highest age was 96.9 years old. The age was divided into 10 groups for analysis purposes and the majority of patients were in the age group 51–70 years. Patients in the 51–60 age group had the highest median cost with RM18 480.40 (IQR RM 20 017.05).

Patients admitted to medical disciplines make up more than 80% of all samples. However, the opposition (surgical disciplines) accorded a higher median cost (RM21 498.55, IQR RM27 116.81). As high as 719 (60.4%) of the cases had the highest severity level of illness (SOI) and accounted for the highest median cost of AMR treatment with RM18 853.76 (IQR RM20 553.17). Just over 10% of the patients were admitted to the ICU and put-up median cost of RM24 239.29 (IQR RM26 960.47). Of the 1190 cases, 957 (80.4%) patients died during hospitalisation, while 233 (19.6%) patients had a favourable discharge outcome. The deceased contributed to a higher median cost than the survived patients (RM17 393.32, IQR 21 531.68 and RM 14 376.59, IQR RM14 206.62, respectively). Overall, the patients had an average LOS (ALOS) of 26.8±79.9 days.

Cost of treatment

Table 2 exhibits the median cost compared with the national base rate cost. These costs correspond to the volume of cases that were conveyed through the number of DRG codes and LOS. The cases by DRG codes gradually increase each year, while the range of ALOS is 21.7–36.4. The median cost per admission for patients with AMR in public hospitals ranges between RM13 710.91 (IQR 19 440.04) and RM19 295.11 (IQR RM20 200.28).

Table 3 visualises the total cost for patients with AMR in public hospitals from 2017 to 2020. Both the LOS and the total cost continuously increased annually. The total cost per admission rose from RM3 711 046.10 in 2017 to RM 9 700 249.08 in 2019. The total cost in 2020 is RM8 871 374.88 although it should be kept in mind that the unprecedented period of COVID-19 pandemic may not reflect actual costs.

Table 3 Total cost per case and total cost per admission for AMR patients in public hospitals (2017–2020*)

Year	ALOS (days)	Total cost per case (RM)	Total cost per admission (RM)
2017	24.1	1 556 938.66	3 711 046.10
2018	36.4	2 060 027.27	7 491 391.30
2019	26.4	3 425 132.07	9 700 249.08
2020*	21.7	3 905 580.89	8 871 374.88
	Grand total	10 947 678.89	29 774 061.36

*The pandemic might cause the costs to be higher/lower than what is reflected.
ALOS, average length of stay; AMR, antimicrobial resistance.

Before carrying out the multivariate analysis of the treatment cost, we evaluated the data for the presence of multicollinearity. The correlation coefficients between each independent variable were first calculated (table 4). Apart from LOS, the correlation matrix showed no sign of pairwise collinearity as all correlation coefficients were below 0.7, multicollinearity was not a concern. Subsequently, we conducted a multivariate analysis to determine the effect between the demographics of the patients and the hospital characteristics on the treatment cost per AMR admission using the constant national base rate.

The results of the Pearson correlation analysis revealed a remarkably strong positive linear relationship between the LOS and cost per admission, as evidenced by a correlation coefficient of 0.969. This value, which is close to 1, indicates that increases in one admission day are closely associated with proportional increases in the cost. Furthermore, the statistical significance of this relationship is underscored by a p value of less than 0.05, suggesting that the observed correlation is highly unlikely to be due to random chance. These findings demonstrate a robust and meaningful connection, providing strong evidence for a significant and consistent association between the variables.

All variables were included in the multivariate logistic regression to determine the predictors of high or low cost of AMR treatment (table 5). Based on the results, the odds that patients with a younger age than

Table 2 Median cost of AMR patients in public hospitals (2017–2020*)

Year	No. of DRG codes	Total LOS (days)	Case group weight	National base rate (RM)	Cost per case (RM)		Cost per admission (RM)	
					Median	IQR	Median	IQR
2017	204	4919	1.95	3992.53	7403.72	1973.68	12476.28	15655.93
2018	258	9360	1.98	4063.10	7393.39	3360.56	13710.91	19440.04
2019	386	10172	2.18	4132.24	8381.42	3462.31	18334.36	20533.80
2020*	374	8248	2.53	4359.39	10435.99	4527.66	19295.11	20200.28

*The pandemic might cause the costs to be higher/lower than what is reflected.
AMR, antimicrobial resistance; DRG, diagnosis-related group; LOS, length of stay.

Table 4 Pearson correlation between variables and cost per admission

Variable	Correlation coefficient	P value*
Hospital category	0.074	0.010
Gender	−0.410	0.155
Age	−0.026	0.369
Disciplines	0.108	<0.05
LOS	**0.969**	**<0.05**
SOI	0.108	<0.05
Intensive care unit (ICU) admission	0.147	<0.05
Discharge outcome	−0.059	0.043

The bold value indicates a remarkably strong positive linear relationship between the length of stay (LOS) and cost per admission.
*Significance was determined at the 0.05 level.
LOS, length of stay; SOI, severity of illness.

the mean age of the samples (56.0 years old) were 2.5 more likely to drive the cost of AMR treatment more than the national annual base rate. Patients categorised as severity level of illness II and III have the odds of 2.0 more likely to topple the cost of AMR treatment into the higher than annual national base rate bracket as opposed to the least severe patients. Furthermore, the probability of increasing the cost of AMR treatment higher than the annual national base rate is 69.9% if patients survive and discharge. These results were significantly associated with the cost of AMR treatment (p<0.05) and were 9.3% explained by this regression model.

DISCUSSION

AMR has significant negative impacts on patients, healthcare providers and national healthcare systems.[6–9] In this study, 72.4% of 1190 AMR cases were from state hospitals, contributing to the highest median total expenditure. This is consistent with other studies and reports, although the WHO Global Antimicrobial Resistance and Use Surveillance System report in 2022 noted a skew towards major healthcare facilities due to the convenience of data collection.[10–12] State hospitals, being large tertiary facilities with more than ten specialties and 20 or more subspecialties,[13] show higher resistance profiles in infections than in other settings. A 2012 study found that 24% of AMR cases were caused by the hospital environment.[14] Consequently, the WHO Southeast Asia Region launched a Patient Safety Strategy in 2015 to improve infection prevention and control among its member states, including Malaysia.

In this study, female patients had almost half the cases of AMR compared with male patients but incurred slightly higher median costs. Patients aged 51–70 years had the highest median costs, though drug-resistant infections in children are a concern. The selective pressure of isolates from children is distinct due to their immature immune system with a slightly different set of antimicrobials, or overall antimicrobial exposure.[15 16] A US study reported a 700% increase in paediatric infections by multidrug-resistant pathogens over 8 years.[17] Nevertheless, AMR isolates were generally higher in adults.[18] The disability-adjusted life-years for AMR infections were also higher in older age groups.[19] Another study echoes our findings, suggesting that carbapenem-resistant *Acinetobacter baumannii* is on the rise in adults.[20] On the other hand, there is a decrease in the resistance trend of children after 2018 that can be attributed to the expert guidance issued by the Infectious Diseases Society of America and the Society for Healthcare Epidemiology in 2007 that recommended the implementation of antimicrobial stewardship programmes (ASP) in acute care settings to combat AMR infections. Malaysia adopted its first ASP in 2014 across public hospitals to tackle AMR. The success of the programme depends on the local administration and enforcement of the relevant agencies.

Global health expenditures hit US$9.8 trillion in 2021, 10.3% of global GDP. Health expenditure per capita rose for all income groups, except low-income countries.[21] Malaysia's health expenditure as a percentage of GDP upsurged from 3.7% in 2017 to 4.1% in 2020. The cost of AMR treatment per admission in Malaysia rose from RM3 711 046.10 in 2017 to RM9 700 249.08 in 2019, with health expenditure as a percentage of GDP escalating from 0.0073% in 2017 to 0.0169% in 2019, with a faint drop in 2020. This increase from 2017 to 2019 exceeds 130% and corresponds to the WHO Western Pacific Region's projection of 0.060%–0.079% of Malaysia GDP for AMR treatment from 2020 to 2030.[22] The cost inflation for the treatment of AMR in Malaysia is in tandem with the LOS of the patients and the number of DRG codes. DRG codes classify hospital cases by clinical characteristics and costs, ensuring payment is based on patient conditions rather than services provided. An increase in DRG codes signals a rise in AMR infections regardless of comorbidities. Therefore, a high number of DRG codes and high LOS amount to a high healthcare payment.

Table 5 Association between demographic and hospital characteristics with the national base rate

Variable	OR	95% CI (OR)	X^2 stat. (df)	P value*
Hospital category	1.47	(1.07, 3.72)	1	0.391
Gender	1.23	(0.71, 2.14)	1	0.453
Age	2.51	(1.44, 4.38)	1	**0.001**
Disciplines	1.34	(0.58, 3.11)	1	0.487
LOS	2 (10^8)	(0.00, 0.00)	1	0.991
SOI	2.00	(1.07, 3.72)	1	**0.028**
ICU admission	1.74	(0.51, 5.93)	1	0.373
Discharge outcome	2.33	(1.10, 4.89)	1	**0.026**

Bold values indicate a significant association between demographic and hospital characteristics with the national base rate.
*Significance was determined at the 0.05 level.
LOS, length of stay; SOI, severity of illness.

This study indicates that older patients and those with higher SOI levels are more likely to drive AMR treatment costs above the annual national base rate. The national base rate is defined as the average cost of admission of the patient per admission episode. This rate is generated annually at the MoH.[23] This finding aligns with multiple nationwide studies linking AMR to numerous negative consequences, including longer hospital stays, increased morbidity, mortality, ICU admissions and hospital costs.[1 9 23–25] The SOI index scores patients at discharge based on illness burden, including complications, comorbidities, procedures, ICU stays and age distribution. As disease complications worsen, the patient will stay longer in the hospital, requiring more extensive care and using more resources than cases in the lower severity level or 'mild' cases.[26] Rapid molecular-based detection techniques have proven cost-effective by facilitating earlier correct antimicrobial prescriptions, shortening hospital stays and reducing costs.[27] Studies show switching from intravenous to oral antimicrobials is cost-effective, though more research is needed to assess AMR selection impact based on antimicrobial types used.

The study population consists of patients admitted to public hospitals within the specified study period. The scope of the study is limited to individuals identified with special-purpose codes in the ICD-10 classification (U80–U89), signifying cases of MDRO bacterial infections. These patients, on discharge, not only faced MDRO infections but also dealt with additional comorbidities or conditions treated during their hospitalisation. In Malaysia, with a population exceeding 34 million, the mortality rate in 2023 was recorded at 5.9 deaths per 1000 people—a notable decline from 6.9 in 2021.[28] Patients with a high SOI often bear a significant disease burden, face critical health challenges and have a poor prognosis.[29] Predictably, our findings revealed that over two-thirds of the sampled patients had a discharge outcome of death, reflecting the high-risk nature of this cohort. However, this mortality rate is comparatively lower than the broader population's rates reported in other studies,[30] emphasising the critical vulnerability of the studied group.

The study identified factors significantly associated with AMR treatment costs (p<0.05), accounting for about 10% of the regression model. The biggest drawback to the study is the overlooked factors not routinely collected in the MalaysianDRG casemix system. AMR affects countries globally, with poverty and inequality exacerbating its drivers and effects. In 2023, WHO reported that AMR pathogens arise primarily from antimicrobial misuse and overuse in humans, animals and plants.[31] Regulatory mechanisms need strengthening to curb over the counter and online antimicrobial sales without prescriptions and eliminate falsified medications. Public awareness campaigns, digital strategies and youth advocacy can help manage expectations and reduce antimicrobial demand. Awareness programmes should promote basic public health measures like clean water, sanitation, hygiene, infection control and surveillance. Furthermore, the use of antimicrobials in food animals is a growing global concern related to food safety and public health, with high antimicrobial exposure in animals serving as reservoirs for AMR transmission to humans and the environment.[32]

AMR's causes and effects transcend human health sectors and national borders, posing severe threats, particularly to developing countries.[22] Prioritising AMR requires strong leadership, political will, multisectoral governance, backed by sufficient financial and human resources investment. Health and other policy-makers must recognise the importance and urgency of combating AMR, given the magnitude of the threat and its impact on overall development. Investing in human capital and resources to mitigate AMR is a high-yield investment for countries. Education and training should target diverse audiences, including primary care staff, laboratory personnel, pharmacists and medical trainees. Established physicians' prescribing habits should be better understood, and methods to encourage antimicrobial stewardship should be explored to ensure antimicrobials are prescribed appropriately, following the WHO Access, Watch and Reserve (Adware) classification system.

A recent study in a major Malaysian hospital identified multidrug resistance as a significant risk factor for hospital-acquired infections.[33] Therefore, a robust laboratory infrastructure and cost-effective diagnostics are crucial for patient management, infection detection and monitor AMR to guide the appropriate use of antimicrobials. Ensuring equitable access to antimicrobials and medical supplies requires focus on research, regulation, manufacturing and distribution. Innovative approaches like artificial intelligence (AI) have potential, as AI-designed molecules effectively killed resistant Acinetobacter baumannii strains in labs. These new compounds also showed activity against other resistant bacteria including *E. coli*, *K. pneumoniae* and MRSA.[34] This showcases the potential of generative AI to create structurally novel, synthesisable in the laboratory and effective small-molecule antimicrobial candidates from vast chemical spaces, with empirical validation. Policy-makers must recognise that resistance costs will be lower than developing new antimicrobials, which could raise drug prices or increase treatment costs for infections without effective therapy.

This study, like others employing cross-sectional designs, is subject to certain limitations beyond those previously mentioned. A primary limitation is the inability to establish causality due to data being collected at a single point in time. Consequently, distinguishing whether relationships between variables are causal or merely associative becomes challenging. Additionally, cross-sectional designs are inherently prone to confounding, where unmeasured variables may influence the relationships being studied. To address this issue and minimise bias, we used multivariate analysis to control for potential confounders and improve the robustness of the findings.

Another critical consideration is the impact of coding errors on the accuracy of cost estimation, which can pose significant challenges in healthcare planning and resource management. Such errors may arise from misinterpretations of requirements, logical flaws in implementation or inaccuracies in data handling. Even minor discrepancies can propagate through the estimation process, leading to substantial inaccuracies that may compromise the quality and accessibility of healthcare services. Furthermore, coding errors often disrupt the integration of cost-related data, especially in complex systems where multiple components interact. Errors in data retrieval or processing can result in outputs that fail to represent true costs, further undermining decision-making accuracy. To mitigate these risks, implementing stringent quality assurance measures—such as code reviews, unit testing and validation using real-world scenarios—is essential. These practices enhance the reliability of cost estimation models and support informed decision-making aligned with organisational objectives.

Studies on AMR frequently focus on hospitals and specialised medical institutions, given their central role in healthcare delivery and access to detailed patient records. While this approach provides valuable insights, it overlooks significant economic impacts of AMR in other healthcare settings, such as primary care clinics, long-term care facilities, outpatient centres and community-based practices. These environments account for a substantial share of patient care and are integral to antimicrobial usage. Excluding them risks underestimating the total financial burden of AMR, including extended treatments, productivity losses and alternative therapies. Moreover, the community-level spread of resistant pathogens, which often originates outside hospitals, is under-represented. Resistance patterns in outpatient clinics and nursing homes can significantly influence infection control strategies and economic dynamics in broader healthcare systems. Broadening the focus of AMR studies to encompass diverse healthcare settings is essential for capturing the full economic impact and devising effective, system-wide interventions. By including data from all care environments, researchers and policy-makers can gain a comprehensive understanding of AMR's challenges and implement strategies that address its far-reaching consequences across the continuum of care.

Nevertheless, determining which costs to measure depends critically on the chosen perspective. This study focused on excess medical costs for treating AMR infections in public hospitals from the perspective of a heavily subsidised health system's viewpoint. Cost data were drawn from Malaysian, maintained by the Malaysian MoH to minimise bias. While these data may not perfectly represent actual resource use, they are often the most reliable available.[35] Collecting precise healthcare cost, factor and resource data is challenging and labour-intensive, with subjective cost attribution varying, potentially leading to overestimated costs.[9] Despite difficulties in distinguishing AMR infection treatment costs from underlying disease treatment, these costs are reasonable estimations of overall economic impact and provide valuable information for future reference. This research marks the first comprehensive nationwide analysis of its kind, unprecedented in its scope. By collecting and analysing detailed data from across the country, it fills a significant gap in the existing literature and guides policy decisions on the national level.

Conclusions

Assessing the true economic impact of AMR is challenging due to the numerous variables and perspectives involved. From Malaysia healthcare provider's point of view, the perpetual cost rise for treating AMR patients requires policy and financial attention comparable to that given to other chronic diseases. Older patients, high SOI and patients with AMR who survived and discharged have higher odds of driving the AMR treatment cost more than the annual national base rate. Hence, investing in current interventions (eg, ASP, public awareness programme and multisectoral involvement) to control and combat AMR will save future healthcare costs and safeguard the workforce and the global economy. Improved methods are needed to evaluate the practical implications for prescribers, patients, healthcare businesses, pharmaceutical companies and the public.

As the Malaysian healthcare system has achieved effective universal health coverage and is moving towards a more sustainable payment mechanism, administrators focused on costs and benefits have become key decision-makers. Therefore, economic arguments are necessary to persuade health system administrators that AMR is a significant issue. Without their attention, securing funding to address the problems will be difficult. A shift in perception and action is required to prioritise the economic impact of AMR appropriately.

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