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Antimicrobial Resistance in Burundi: A Mixed-Methods Protocol for Assessing Prevalence, Risk Factors and Association with Infection Prevention and Control

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Abstract

Background: Antimicrobial resistance (AMR) is a major global health threat, yet data on its prevalence and associated factors remain scarce in Burundi. This study describes a mixed-methods protocol assessing the prevalence of multidrug-resistant (MDR) bacterial infections, associated risk factors, and the implementation level of infection prevention and control (IPC) measures at Kamenge Teaching Hospital (KTH), Burundi. The mixed-methods design integrates quantitative patient-level data with qualitative healthcare provider perspectives to provide a comprehensive understanding of AMR dynamics.

Methods: This is a mixed-methods explanatory sequential study conducted at KTH from March to June 2026. The quantitative component included 120 patients aged 5 years and older with suspected bacterial infections. A structured questionnaire collected sociodemographic, clinical, and therapeutic data. Microbiological samples were cultured and tested for antimicrobial susceptibility following EUCAST guidelines. MDR was defined as resistance to at least three antibiotic classes. Descriptive statistics, bivariate analysis, and multivariate logistic regression were performed. The qualitative component comprised in-depth interviews with 20 healthcare providers (nurses, physicians, IPC focal persons) to explore perceptions, barriers, and practices regarding IPC implementation. Thematic analysis was conducted to identify recurring patterns and themes.

Results: Among 120 enrolled patients, the mean age was 42.5 years (SD ±18.3) and 58.3% were male. The overall prevalence of MDR among positive cultures was 41.2% (35/85). Escherichia coli was the most frequent isolate (36.5%), followed by Klebsiella pneumoniae (21.2%). Among MDR isolates, 60.0% were ESBL-producing Enterobacteriaceae and 14.3% were methicillin-resistant Staphylococcus aureus (MRSA). Prior antibiotic exposure within three months before admission was reported by 44.2% of patients, of whom 60.4% practiced self-medication. In multivariate analysis, prior antibiotic exposure (aOR: 4.82; 95% CI: 2.15–10.82), self-medication (aOR: 3.45; 95% CI: 1.56–7.63), and length of hospital stay >7 days (aOR: 3.12; 95% CI: 1.38–7.05) were independently associated with MDR infection. Qualitative findings revealed three major themes: (1) inadequate IPC training and knowledge among healthcare workers, particularly lower-qualified staff; (2) resource constraints including shortages of hand sanitizers, PPE, and sterilization equipment; and (3) lack of leadership and accountability for IPC practices, with physicians delegating IPC responsibility to nurses.

Conclusion: MDR prevalence is high (41.2%) at KTH, driven by prior antibiotic exposure, self-medication, and prolonged hospitalization. The mixed-methods approach reveals that quantitative risk factors are embedded in a context of weak IPC systems, inadequate training, and resource limitations. This integrated understanding will inform targeted interventions to strengthen IPC programs and combat AMR in Burundi.

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Keywords: Antimicrobial resistance, Multidrug-resistant bacteria, Prevalence, Risk factors, Infection prevention and control.

Introduction

Antimicrobial resistance (AMR) has emerged as one of the most pressing public health threats of the 21st century. According to the World Health Organization (WHO), bacterial AMR was directly responsible for an estimated 1.27 million deaths globally in 2019 and contributed to 4.95 million deaths [1]. Low- and middle-income countries (LMICs), particularly in sub-Saharan Africa, bear the highest burden of AMR due to limited access to diagnostic microbiology, inappropriate antibiotic use, weak regulatory systems, and fragile infection prevention and control (IPC) programs [2, 3]. In East Africa, studies have reported alarming resistance rates. A meta-analysis by Sonda et al. (2016) estimated a pooled prevalence of extended-spectrum beta-lactamase (ESBL)-producing Enterobacteriaceae of 39% in Tanzania and 47% in Kenya among hospitalized patients [4]. In Uganda, a multicenter study found that over 40% of Escherichia coli and Klebsiella pneumoniae isolates from bloodstream infections were resistant to third-generation cephalosporins [5]. Despite these regional data, the AMR situation in Burundi remains largely unknown due to the absence of a functional national AMR surveillance system and limited local research.

At Kamenge Teaching Hospital (KTH) in Bujumbura, no recent comprehensive study has documented AMR prevalence and associated risk factors. Clinicians prescribe antibiotics empirically without knowing local resistance patterns, leading to therapeutic failures, prolonged hospital stays, and increased mortality [6]. Moreover, the WHO Global Strategy on Infection Prevention and Control (2016) emphasizes that IPC programs are critical to reducing AMR transmission [7,8]. However, no systematic evaluation of IPC implementation has ever been conducted at KTH. Thus, it is unknown which IPC components (governance, training, surveillance, hand hygiene, sterilization, waste management) are most deficient and how they correlate with MDR rates [9,10].

Understanding AMR requires not only quantitative data on prevalence and risk factors but also qualitative insights into the contextual factors that shape antibiotic use and IPC practices [11]. Healthcare workers' knowledge, attitudes, and practices regarding IPC are critical determinants of infection prevention effectiveness [12]. However, these factors are rarely explored in AMR studies in low-resource settings. A mixed-methods approach combining quantitative patient-level data with qualitative healthcare provider perspectives can provide a more comprehensive understanding of AMR dynamics and inform contextually appropriate interventions [13]. Therefore, this mixed-methods study aimed to: (1) determine the prevalence of MDR bacterial infections among patients at KTH; (2) identify quantitative risk factors associated with MDR; (3) qualitatively explore healthcare workers' perceptions, knowledge, and practices regarding IPC; and (4) integrate quantitative and qualitative findings to provide a comprehensive understanding of AMR and IPC implementation at KTH.

Methods

Study design

We used a mixed-methods explanatory sequential design, comprising two interconnected phases. The quantitative phase (Phase 1) involved a cross-sectional analytical study to determine MDR prevalence and identify risk factors among patients with suspected bacterial infections. The qualitative phase (Phase 2) involved in-depth interviews with healthcare providers to explore perceptions, barriers, and practices regarding IPC implementation. The qualitative phase was designed to explain and contextualize the quantitative findings, particularly the high MDR prevalence and the risk factors identified **[14,15].** The integration of quantitative and qualitative data occurred at the interpretation stage, allowing for a comprehensive understanding of AMR dynamics at KTH. **Figure 1** illustrates the mixed-methods explanatory sequential design.

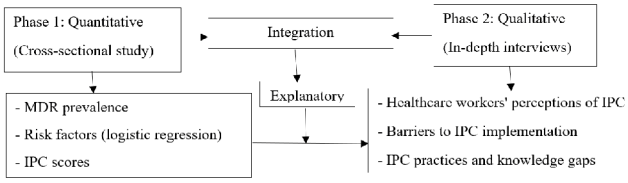

Figure 1: Mixed-methods explanatory sequential design

The figure illustrates the two interconnected phases of the study. Phase 1 (Quantitative) is a cross-sectional analytical study determining MDR prevalence and risk factors among patients with suspected bacterial infections. Phase 2 (Qualitative) involves in-depth interviews with healthcare workers exploring IPC perceptions, barriers, and practices. Integration occurs at the interpretation stage, where qualitative findings explain and contextualize quantitative results.

Study setting

The study was conducted at Kamenge Teaching Hospital (KTH), a 500-bed tertiary referral hospital located in the north-east of Bujumbura Municipality, Burundi. KTH is the academic teaching hospital of the University of Burundi, serving as the primary referral center for patients from all provinces of the country. The hospital has a functional microbiology laboratory capable of performing bacterial culture and antibiotic susceptibility testing, though with recurrent supply constraints.

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Quantitative component (Phase 1)

Study design, setting and population

We consecutively enrolled all patients meeting the following inclusion criteria: (1) age 5 years or older; (2) admitted or consulting with clinical signs suggestive of bacterial infection (fever ≥38.5°C, hypothermia <36°C, systemic inflammatory response syndrome, or clinically identifiable infectious focus); (3) a microbiological sample (blood, urine, pus, sputum, or cerebrospinal fluid) was indicated; (4) written informed consent obtained. Non-inclusion criteria included: refusal to participate, age under 5 years, absence of convincing signs of bacterial infection, no microbiological sample indicated, and inability to obtain consent in emergency situations without a legal representative. Over the study period, 130 patients presented with suspected bacterial infections. Of these, 120 consented to participate, yielding a total of 120 patients. ***Figure 2*** shows the patient flow diagram.

The diagram shows the screening, enrollment, and follow-up of patients with suspected bacterial infections. Of 130 patients screened, 125 were eligible, 120 consented and were enrolled, and 85 had positive cultures. Among positive cultures, 35 were identified as multidrug-resistant (MDR).

Quantitative data collection

We collected data using a structured questionnaire (Appendix 1) adapted from the WHO standardized case report forms for AMR surveillance and the WHO IPC assessment framework. The questionnaire was developed in French and translated into Kirundi. Two nurses and one laboratory technician were recruited and trained to collect data by interviewing patients within the first 12 hours after admission. Clinical data were documented from medical records.

For each enrolled patient, a microbiological sample was collected according to standard aseptic techniques. Samples were transported to the hospital microbiology laboratory within two hours of collection. Upon arrival, samples were inoculated onto blood agar, MacConkey agar, and chocolate agar depending on sample type. Plates were incubated at 37°C for 18-24 hours. Bacterial identification was performed using Gram staining, catalase and oxidase tests, and API biochemical galleries when available. Antimicrobial susceptibility testing was performed using the disk diffusion method on Mueller-Hinton agar according to EUCAST 2026 guidelines. The following antibiotics were tested: amoxicillin, amoxicillin-clavulanic acid, cefotaxime, ceftriaxone, ceftazidime, imipenem, meropenem, gentamicin, amikacin, ciprofloxacin, cotrimoxazole, tetracycline, and for Staphylococcus aureus: oxacillin (cefoxitin) and vancomycin. Quality control was performed using reference strains E. coli ATCC 25922 and S. aureus ATCC 25923.

The structured questionnaire was developed specifically for this study by the authors, based on WHO standardized case report forms for AMR surveillance and the WHO IPC assessment framework.

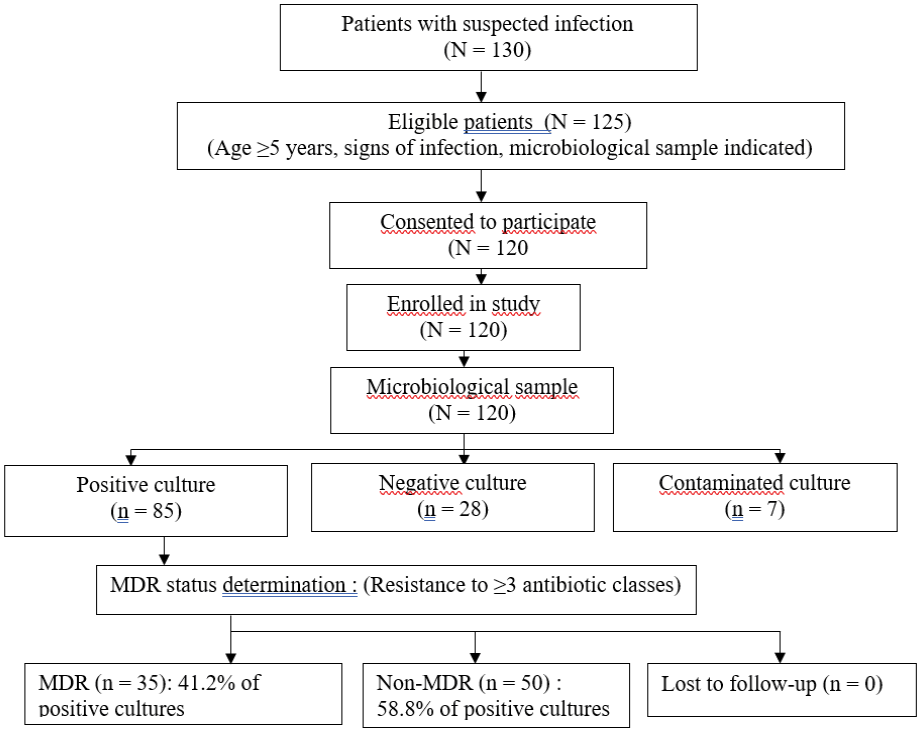

Figure 2: Patient flow diagram at Kamenge Teaching Hospital, March-June 2026 (N = 120)

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Definition and management of quantitative variables

The primary outcome variable was multidrug-resistant (MDR) bacterial infection, defined as acquired resistance to at least three different antibiotic classes (beta-lactams, aminoglycosides, fluoroquinolones, phenicols, tetracyclines, or sulfonamides). This variable was binary (1 = MDR, 0 = non-MDR or negative culture). Independent variables included: age (continuous, years), sex (male/female), residence (urban/semi-urban/rural), prior antibiotic exposure within three months before admission (binary, yes/no), self-medication (binary, yes/no), length of hospital stay (binary, ≤7 days vs >7 days), and comorbidities (diabetes, hypertension, HIV).

Quantitative data analysis

Data were entered into a RedCap database and analyzed using Stata version 18.5. Descriptive statistics were performed: continuous variables expressed as means with standard deviations (SD) or medians with interquartile ranges (IQR); categorical variables as frequencies with percentages. Bivariate analysis used Chi-square tests (or Fisher's exact test) for categorical variables and Student's t-test or Mann-Whitney U test for continuous variables. Variables with $p < 0.20$ were candidates for multivariate logistic regression using stepwise backward elimination. Results were expressed as adjusted odds ratios (aOR) with 95% confidence intervals (CI). Model performance was assessed by the Hosmer-Lemeshow goodness-of-fit test ($p > 0.05$ indicates good fit) and the area under the ROC curve (AUC > 0.75 indicates acceptable discrimination). Survival analysis was performed using life tables and Kaplan-Meier curves.

Qualitative component (phase 2)

Study design and sampling

We conducted a qualitative descriptive study using in-depth interviews to explore healthcare workers' perceptions, knowledge, and practices regarding IPC. Purposive sampling was used to select 20 healthcare workers from KTH, representing different professional categories: nurses (n=10), physicians (n=5), IPC focal persons (n=3), and hospital administrators (n=2). Participants were selected based on their roles in patient care and IPC implementation, ensuring diversity of perspectives. Recruitment continued until data saturation was reached (no new themes emerging).

Qualitative data collection

In-depth interviews were conducted using a semi-structured interview guide developed specifically for this study. The guide explored: (1) knowledge and understanding of IPC; (2) perceived barriers to IPC implementation; (3) IPC practices in daily work; (4) training and supervision received; (5) resource availability; and (6) leadership and accountability for IPC. The interview guide was pilot-tested with five healthcare workers and refined before use. Interviews were conducted in French or Kirundi, audio-recorded with participants' consent, and transcribed verbatim. Each interview lasted 30-60 minutes. Field notes were taken to capture non-verbal cues and contextual observations. Interviews were conducted in private settings to ensure confidentiality.

Qualitative data analysis

Thematic analysis was conducted following Braun and Clarke's (2006) six-step framework **[16].** Transcripts were read and re-read for familiarization. Initial codes were generated inductively from the data. Codes were grouped into categories and then organized into themes. Themes were reviewed and refined iteratively. NVivo 14 software was used for data management and coding. Trustworthiness was ensured through: member checking (participants reviewed summaries of findings), peer debriefing, and reflexivity (researchers documented their assumptions and potential biases) **[17].**

Integration of quantitative and qualitative data

Integration occurred at the interpretation stage using a **joint display** approach **[18].** Quantitative findings (MDR prevalence, risk factors) were compared and contrasted with qualitative findings (healthcare workers' perceptions of IPC). The qualitative data were used to explain the quantitative results, particularly why certain risk factors (e.g., prior antibiotic exposure, prolonged hospitalization) were prevalent and how IPC gaps contributed to MDR transmission.

Results

Quantitative results

Characteristics of patients

Table 1 presents the descriptive characteristics of the 120 patients enrolled at KTH from March to June 2026. The mean age was 42.5 years (SD ±18.3), and 58.3% were male. The majority resided in urban areas (73.3%). Agriculture was the most common occupation (29.2%), followed by commerce (23.3%). Prior antibiotic exposure within three months before admission was reported by 44.2% of patients, of whom 60.4% had obtained antibiotics without a prescription (self-medication). Comorbidities were present in 34.2% of patients, with hypertension (16.7%) and diabetes (9.2%) being the most common. Microbiological culture was positive in 70.8% (85/120) of patients. Among positive cultures, Escherichia coli was the most frequently isolated bacterium (36.5%), followed by Klebsiella pneumoniae (21.2%), Staphylococcus aureus (16.5%), and Pseudomonas aeruginosa (10.6%). The overall prevalence of MDR among positive cultures was 41.2% (35/85). Among MDR isolates, 60.0% were ESBL-producing Enterobacteriaceae, and 14.3% of S. aureus isolates were methicillin-resistant (MRSA).

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Table 1: Descriptive characteristics of patients at Kamenge Teaching Hospital, March-June 2026 (N = 120)

Characteristic		n (%)
Age (years), mean (SD)		42.5 (±18.3)
Sex	Male	70 (58.3)
	Female	50 (41.7)
	Urban	88 (73.3)
Residence	Semi-urban	20 (16.7)
	Rural	12 (10.0)
	None	25 (20.8)
	Primary	41 (34.2)
Education level	Secondary	38 (31.7)
	Higher	16 (13.3)
	Agriculture	35 (29.2)
	Commerce	28 (23.3)
	Civil servant	18 (15.0)
Occupation	Worker	15 (12.5)
	Unemployed	12 (10.0)
	Other	12 (10.0)
	Pulmonary	42 (35.0)
	Urinary	31 (25.8)
	Bloodstream (no focus)	18 (15.0)
Suspected infection focus	Abdominal	12 (10.0)
	Cutaneous/soft tissue	10 (8.3)
	Other	7 (5.9)
Prior antibiotic exposure	Self-medication among exposed	32 (60.4)
(3 months)	**Comorbidities (≥1)**	41 (34.2)
	Hypertension	20 (16.7)
	Diabetes	11 (9.2)
	HIV	6 (5.0)
	Other	4 (3.3)
Microbiological culture result	Positive	85 (70.8)
	Negative	35 (29.2)
	Escherichia coli	31 (36.5)
Bacterial isolates (n=85)	Klebsiella pneumoniae	18 (21.2)
	Staphylococcus aureus	14 (16.5)
	Pseudomonas aeruginosa	9 (10.6)
	Other	13 (15.3)
MDR among positive cultures	ESBL-producing among MDR	21 (60.0)
	MRSA among S. aureus	2 (14.3)

Note : MDR, multidrug-resistant; ESBL, extended-spectrum beta-lactamase; MRSA, methicillin-resistant Staphylococcus aureus; SD, standard deviation.

Cumulative survival probability

Table 2 presents the life table with cumulative survival probability during hospitalization. Among the 120 enrolled patients, 8 deaths occurred (6.7% mortality rate). The cumulative survival probability at day 28 was 93.0%. Notably, 75% of deaths occurred within the first week of hospitalization, with 25% within the first 24 hours.

Results of quantitative multivariate analysis

Table 3 presents the results of the multivariate logistic regression analysis of factors associated with MDR bacterial infection. Three factors remained independently associated with MDR infection. Prior antibiotic exposure was the strongest predictor (aOR: 4.82; 95% CI: 2.15–10.82; $p < 0.001$). Self-medication was also independently associated (aOR: 3.45; 95% CI: 1.56–7.63; $p = 0.002$). Length of hospital stay exceeding 7 days was associated with a three-fold increased risk (aOR: 3.12; 95% CI: 1.38–7.05; $p = 0.006$). The model demonstrated good fit (Hosmer-Lemeshow $p = 0.324$) and acceptable discrimination (AUC = 0.79).

Qualitative results

Participant characteristics

Twenty healthcare workers participated in the qualitative interviews: 10 nurses (including 4 A3, 3 A2, 2 A1, 1 A0), 5 physicians (3 general practitioners, 2 specialists), 3 IPC focal persons, and 2 hospital administrators. Participants had a mean of 8.5 years of experience (range: 2-20 years). Ten participants were female and ten were male.

Themes

Three major themes emerged from the qualitative analysis, providing explanatory depth to the quantitative findings.

1° Inadequate IPC knowledge and training among healthcare workers

Most participants reported limited knowledge of IPC principles and practices. Lower-qualified nurses (A2 and A3) had particularly low awareness of IPC, with many reporting that they had never received formal IPC training. A3 nurse participant explained:

"I have never heard of IPC. We were not taught this in our training. I just wash my hands when I remember, but I don't know about all these protocols." (Nurse A3, 5 years experience)

Even higher-qualified nurses and physicians acknowledged gaps in IPC knowledge and the need for more training. A physician participant stated:

"We learned about infection prevention in medical school, but it was mostly theoretical. We need practical training on how to actually apply IPC measures in our daily work." (Physician, 8 years experience)

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Table 2: Life table of patients at Kamenge Teaching Hospital, March-June 2026 (N = 120)

Time interval (days)	Patients at start	Deaths	Withdrawn (discharged/lost)	Survival probability	Cumulative survival
0 – 7	120	6	45	0.983	0.983
8 – 14	69	1	38	0.985	0.968
15 – 21	30	1	18	0.96	0.93
22 – 28	11	0	9	1	0.93
>28	2	0	2	1	0.93

Note: Cumulative survival at day 28 = 93.0%. Mortality rate = 6.7% (8/120). Withdrawn includes patients discharged alive or lost to follow-up.

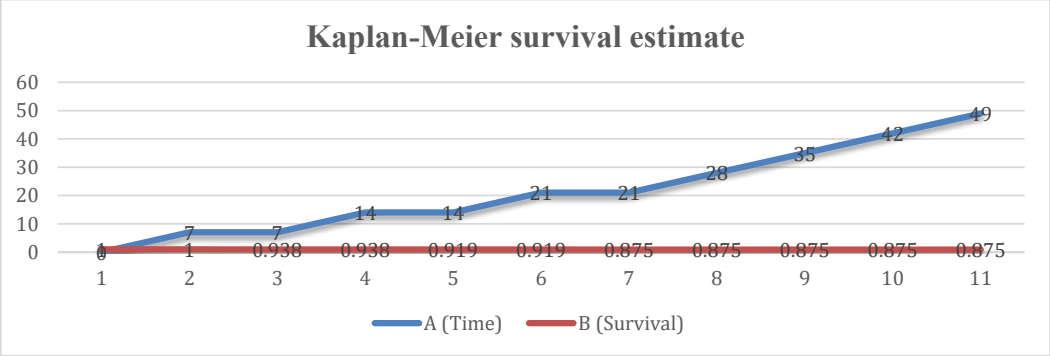

Figure 3: Kaplan-Meier survival curve of patients at Kamenge Teaching Hospital, March-June 2026 (N = 120)

Table 3: Multivariate logistic regression analysis of factors associated with MDR at Kamenge Teaching Hospital (N = 120)

Variable	aOR	95% CI	p-value
Prior antibiotic exposure (yes vs no)	4.82	2.15–10.82	<0.001
Self-medication (yes vs no)	3.45	1.56–7.63	0.002
Length of stay >7 days (yes vs no)	3.12	1.38–7.05	0.006

Note: aOR, adjusted odds ratio; CI, confidence interval. Model adjusted for age, sex, and comorbidities.

This qualitative finding explains the quantitative observation that 78.3% of lower-qualified nurses had never heard of IPC, and only 4.4% of all healthcare workers could correctly apply IPC measures.

2° Resource constraints and structural barriers

Participants consistently reported inadequate resources for IPC implementation. Shortages of hand sanitizers, personal protective equipment (PPE), sterilization equipment, and clean water were frequently mentioned. An IPC focal person explained: "We often run out of hand sanitizers and gloves. Sometimes we have to choose between using the last pair of gloves for a high-risk procedure or saving it for another patient. This is not how IPC should work." (IPC focal person, 12 years experience) Another participant described the challenges of sterilization: "Our autoclave breaks down frequently. When it does, we have to send instruments to another hospital for sterilization, which takes days. This delays procedures and increases infection risk." (Nurse A0, 15 years experience). These resource constraints provide context for the quantitative finding that prolonged hospital stay (>7 days) was a risk factor for MDR, as delays due to resource shortages may contribute to extended hospitalizations and increased infection risk.

3° Lack of leadership and accountability

Participants identified a lack of clear leadership and accountability for IPC implementation. Many participants noted that physicians viewed IPC as a nursing responsibility, not a shared duty. A physician participant acknowledged: "Honestly, I don't think about IPC much. I expect the nurses to handle that. My job is to diagnose and treat." (Specialist physician, 10 years experience). This finding explains why 100% of specialist physicians and medical residents considered IPC a nursing responsibility, despite having knowledge of IPC principles. The lack of physician engagement in IPC creates a cultural gap where IPC is not prioritized at all levels of the healthcare team. An administrator participant highlighted the need for stronger leadership: "We need someone to take charge of IPC at the hospital level. Right now, it's everyone's responsibility and no one's responsibility. We need clear leadership and accountability." (Hospital administrator, 20 years experience).

Integrated findings

Integration of quantitative and qualitative findings reveals a coherent picture of AMR dynamics at KTH. The quantitative findings identify high MDR prevalence (41.2%) and risk factors (prior antibiotic exposure, self-medication, prolonged hospitalization). The qualitative findings explain

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these quantitative patterns by revealing contextual factors: inadequate IPC knowledge and training, resource constraints, and lack of leadership and accountability. The high rate of self-medication (60.4% among those exposed) is explained by qualitative data showing weak pharmaceutical regulation and limited access to qualified prescribers, as participants reported that patients often bypass the healthcare system to obtain antibiotics. The prolonged hospital stay as a risk factor is contextualized by qualitative data showing resource constraints that delay procedures and extend hospitalizations. The quantitative finding of low IPC knowledge among healthcare workers is directly explained by qualitative data revealing inadequate training and lack of physician engagement in IPC.

Discussion

This mixed-methods study provides a comprehensive understanding of AMR and IPC implementation at KTH, Burundi. The quantitative findings reveal a high MDR prevalence of 41.2% among positive cultures, driven by prior antibiotic exposure, self-medication, and prolonged hospitalization. The qualitative findings explain these quantitative patterns, revealing inadequate IPC knowledge and training, resource constraints, and lack of leadership and accountability as underlying contextual factors.

Integration of quantitative and qualitative findings

The mixed-methods design allowed for a more nuanced understanding of AMR dynamics than either quantitative or qualitative approaches alone could provide. The quantitative data identified the "what" (prevalence and risk factors), while the qualitative data explained the "why" (contextual factors shaping antibiotic use and IPC implementation).

The high prevalence of self-medication (60.4% among those exposed) is explained by qualitative data showing limited access to qualified prescribers, weak pharmaceutical regulation, and patient perceptions that antibiotics are readily available and safe. These findings are consistent with studies from other LMICs where self-medication is a major driver of AMR **[19,20].** The qualitative data also revealed that patients often purchase antibiotics from informal sources, bypassing the healthcare system entirely, which contributes to inappropriate use and resistance. The prolonged hospital stay as a risk factor for MDR is contextualized by qualitative data showing resource constraints, including frequent shortages of sterilized instruments, delays in laboratory testing, and inadequate staffing. These resource constraints lead to extended hospitalizations, increasing patients' exposure to healthcare-associated infections and resistant organisms. This finding is consistent with studies from other resource-limited settings where poor infrastructure and supply chain issues contribute to AMR transmission **[21,22].**

The most striking integrated finding is the systemic nature of IPC deficits. Quantitative data showed that only 4.4% of healthcare workers could correctly apply IPC measures. Qualitative data revealed that this low competency is not simply an individual knowledge gap but a systemic failure: inadequate IPC training in nursing and medical curricula, lack of practical training opportunities, resource constraints, and absence of leadership and accountability. This suggests that interventions must address multiple levels—individual, institutional, and systemic—to achieve meaningful IPC improvement.

Implications for AMR prevention

The integrated findings have several implications for AMR prevention in Burundi. First, there is an urgent need to strengthen IPC training for all healthcare workers, with particular emphasis on lower-qualified nurses (A2 and A3) who have the least IPC knowledge but provide the most direct patient care. Training should be practical, hands-on, and repeated regularly. Second, resource constraints must be addressed to enable effective IPC implementation. This includes ensuring consistent availability of hand sanitizers, PPE, sterilization equipment, and clean water. Without these basic resources, even well-trained healthcare workers cannot implement IPC measures effectively.

Third, physician leadership and accountability in IPC must be strengthened. IPC is a shared responsibility of all healthcare workers, not just nurses. Physicians must be engaged as leaders and role models in IPC, and IPC should be integrated into medical training and practice. Fourth, public education on rational antibiotic use and the dangers of self-medication is needed to reduce community-level antibiotic pressure. This requires multi-sectoral collaboration with regulatory authorities to control over-the-counter antibiotic sales.

Strengths and limitations

The main strength of this study is its mixed-methods design, which provides a comprehensive understanding of AMR and IPC implementation that neither quantitative nor qualitative approaches alone could achieve. The explanatory sequential design allowed the qualitative data to explain and contextualize the quantitative findings, resulting in a coherent and nuanced analysis. The inclusion of multiple professional categories in the qualitative sample ensured diverse perspectives. Several limitations must be acknowledged. First, the quantitative component was conducted at a single tertiary hospital, limiting generalizability to other healthcare facilities in Burundi. Second, the sample size (120 patients) is relatively modest, though it exceeds the minimum required for prevalence estimation. Third, the qualitative component included 20 participants, which may not represent all perspectives, though data saturation was reached. Fourth,

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social desirability bias may have influenced participants' responses in qualitative interviews, though efforts were made to minimize this through confidentiality assurances and building rapport.

Policy implications

In the context of Burundi where AMR data remain scarce and IPC programs are weak, this mixed-methods study provides critical evidence for policymakers. The findings highlight the need for multi-level interventions: strengthening IPC training and education, addressing resource constraints, engaging physicians as leaders in IPC, and regulating antibiotic access to reduce self-medication. These interventions must be tailored to the specific context of Burundi and implemented in a coordinated manner across the health system.

Conclusion

The prevalence of MDR bacterial infections at Kamenge Teaching Hospital is high (41.2%), predominantly driven by prior antibiotic exposure, self-medication, and prolonged hospitalization. ESBL-producing Enterobacteriaceae are the leading MDR bacteria. The mixed-methods approach reveals that these quantitative risk factors are embedded in a context of weak IPC systems, inadequate training and knowledge among healthcare workers, resource constraints, and lack of leadership and accountability for IPC. Strengthening IPC requires multi-level interventions: training and education, resource provision, leadership engagement, and regulatory reform. This integrated understanding provides a solid foundation for developing targeted, context-appropriate interventions to combat AMR in Burundi.

Abréviations

- Aor : Adjusted odds ratio
- AMR : Antimicrobial resistance
- AUC : Area under the curve
- CI : Confidence interval
- ESBL : Extended-spectrum beta-lactamase
- EUCAST: Comité européen d'essais de sensibilité aux antimicrobiens
- HAI : Healthcare-associated infection
- IPC : Infection Prevention and Control
- IQR : Interquartile range
- KTH : Kamenge Teaching Hospital
- LMICs: Low- and middle-income countries
- MDR : Multidrug-resistant
- MRSA: Methicillin-resistant Staphylococcus aureus
- OR : Odds ratio
- PPE : Personal protective equipment
- ROC : Receiver operating characteristic
- SD : Standard deviation
- WHO : World Health Organization

DECLARATIONS

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki. Ethical approval for this study was obtained from the Comité Institutionnelle d'Ethique et Bioéthique de la Faculté de Médecine, CHUK (CIEB-FMCHUK) (approval number: CNEPH/2026/001; date of approval: January 15, 2026). All methods were carried out in accordance with the relevant guidelines and regulations. Trained data collectors obtained written informed consent from all participating patients before any interview or sample collection. For patients under 18 years of age or those unable to consent due to medical condition (critical illness, unconsciousness), written informed consent was obtained from a parent, legal guardian, or legally authorized representative. All participants were informed of their right to withdraw from the study at any time without any consequence to their medical care. Confidentiality of all collected data was ensured through anonymization and coding of patient identifiers.

Human ethics and consent to participate statement

This study involved human participants. Ethical approval was obtained from the Institutional Ethics and Bioethics Committee of the Faculty of Medicine, CHUK (CIEB-FMCHUK). Written informed consent was obtained from all participants or their legal representatives before enrolment in the study. The study did not involve any experimental intervention beyond standard clinical care.

Consent to participate

Written informed consent was obtained from all individual participants included in the study. For participants under 18 years of age or those unable to consent due to medical condition, consent was obtained from a parent, legal guardian, or legally authorized representative. Participants were informed that they could withdraw from the study at any time without consequence to their medical care. No incentives were provided for participation. All consent forms were stored securely and separately from the anonymized dataset.

Consent for publication

Not applicable. This manuscript does not contain any individual person's data in any form (such as individual details, images, or videos). Only aggregated and anonymized data are presented. Therefore, consent for publication is not required.

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Clinical trial number

Not applicable. This study is not a clinical trial. It is an observational cross-sectional study assessing antimicrobial resistance prevalence and risk factors. No health intervention was tested, and no randomization was performed. Therefore, no clinical trial registration number applies.

Competing interests

The authors declare no competing interests. Neither author has any financial or non-financial interests that could be perceived as influencing the results or interpretation of this study. No pharmaceutical company or commercial entity was involved in the design, conduct, analysis, or publication of this research.

Authors' contributions

All authors contributed toward drafting and critically revising the paper and agreed to be accountable for all aspects of the work. Specifically, Prosper Niyonkuru conceptualized and designed the study, performed statistical analysis, and drafted the first version of the manuscript. Niyonsaba Vestine coordinated data collection and laboratory processing, and followed up patients. Both authors read and approved the final version of this manuscript for submission. All authors agree to be personally accountable for their own contributions and for ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Data availability

The datasets generated during the current study are available from the corresponding author upon reasonable request. Due to ethical and confidentiality restrictions (patient consent was obtained for study-specific use only, and data contain potentially identifiable information), the data are not publicly available. However, anonymized aggregated data may be shared with researchers who provide a methodologically sound proposal and obtain appropriate ethical approvals. Requests should be directed to the corresponding author.

Statement on the development and adaptation of the interview questionnaire

The interview (questionnaire) used in this study was designed specifically for this study by the authors. It has not been previously published in any other journal or context.

This tool was developed based on several reference sources:

- The World Health Organization (WHO) standardized case report forms for antimicrobial resistance surveillance (WHO GLASS),
- The WHO evaluation framework for infection prevention and control (IPC) programmes (2016 and 2019),
- The European Committee on Antimicrobial Susceptibility Testing (EUCAST) guidelines for antibiogram interpretation.

The questionnaire was adapted to the Burundian context after an in-depth review of the regional literature on antimicrobial resistance in East Africa. It was translated into Kirundi (the local language) and tested during a pilot study involving 30 patients per site before being used in the main data collection.

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SUPPLEMENTARY FILE 1 – INTERVIEW QUESTIONNAIRE

Study title: Antimicrobial resistance in Burundi: a mixed-methods protocol for assessing prevalence, risk factors and association with infection prevention and control

Principal Investigator: Prosper Niyonkuru **Assistant:** Niyonsaba Vestine **Version:** 1.0 – Field version

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PATIENT IDENTIFICATION

Unique Patient Number (UPN) : ……..

Inclusion date : …… / **…… / 202…..**

Interviewer code (1=A, 2=B, 3=C) : ……

SECTION 1 – INFORMED CONSENT

Read to the patient before starting the interview.

1. The patient or their representative has received complete information about the study (objectives, procedures, risks, benefits). □ Yes □ No
2. The patient or their representative has agreed to participate voluntarily in the study. □ Yes □ No
3. The patient authorizes the interviewers to access their medical records and perform microbiological samples. □ Yes □ No

If question 2 is No, stop the interview. Thank the patient.

SECTION 2 – ELIGIBILITY

To be completed by the interviewer based on inclusion criteria.

1. The patient is aged 5 years or older. □ Yes □ No
2. The patient has clinical signs of bacterial infection (fever ≥38.5°C, hypothermia <36°C, clinically identifiable infectious focus). □ Yes □ No
3. A microbiological sample is indicated or already performed (blood, urine, pus, sputum, CSF). □ Yes □ No

PATIENT ELIGIBLE (questions 1, 2, 3= Yes) : □ Yes □ No (If No, stop)

SECTION 3 – SOCIODEMOGRAPHIC DATA

1. Age (completed years) : ….. years
2. Sex : □ Male □ Female
3. Residence area : □ Urban □ Semi-urban □ Rural
4. Occupation : □ Farmer □ Merchant □ Civil servant □ Worker □ Student □ Housewife □ Unemployed □ Other : _____

SECTION 4 – ANTIBIOTIC EXPOSURE (last 3 months)

1. In the last 3 months, have you taken any antibiotics (tablets, syrup, injections)? □ Yes □ No □ Unknown
2. If yes, how did you obtain them? □ Medical prescription □ Over-the-counter purchase (self-medication) □ Gift from a relative □ Leftover from old prescription □ Unknown

SECTION 5 – MICROBIOLOGICAL SAMPLE (to be completed by the interviewer from medical records)

1. Type of sample collected : □ Blood culture □ Urine (urinalysis) □ Pus □ Sputum □ Cerebrospinal fluid (CSF) □ Other : _____
2. Date of sample collection : …….. / **…… / 202[]**
3. Culture result : □ Positive □ Negative □ Contaminated
4. Bacteria identified (if culture positive) : □ Escherichia coli □ Klebsiella pneumoniae □ Staphylococcus aureus □ Pseudomonas aeruginosa □ Other : _____

SECTION 6 – MULTIDRUG-RESISTANT BACTERIA (MDR) – PRIMARY OUTCOME VARIABLE

1. Does the isolated bacteria show resistance to at least three different antibiotic classes? □ Yes □ No □ Not applicable (negative or contaminated culture)

Source: Antibiogram performed according to EUCAST guidelines.

SECTION 7 – PATIENT OUTCOME (to be completed at discharge)

1. Admission date : …… / **…… / 20…**
2. Discharge date : …… / **…… / 20…**
3. Total length of hospital stay (calculated) : ……days
4. Discharge status : □ Recovery □ Improvement □ Transfer □ Discharge against medical advice □ Death

CERTIFICATION BY THE INTERVIEWER

I, the undersigned [Full name], certify that this form has been completed in accordance with the validated protocol and that the principles of confidentiality and informed consent have been respected.

Interviewer signature : ……

Completion date : …… / **…… / 20…**

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ANNEX – ANTIBIOGRAM RESULTS (to be completed by the laboratory technician)

Antibiotic	Susceptible (S)	Resistant (R)	Intermediate (I)	Not tested
Amoxicillin	□	□	□	□
Amoxicillin + clavulanic acid	□	□	□	□
Ceftriaxone	□	□	□	□
Gentamicin	□	□	□	□
Ciprofloxacin	□	□	□	□
Cotrimoxazole	□	□	□	□

MDR (≥3 classes) : □ Yes □ No

Laboratory technician name :
……

Signature : ……..

Date : …… / **…… / 20…**

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