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*Original Research*

# Antimicrobial Susceptibility of Bacteria Isolated from Diabetic Foot Infections in Dhamar Governorate, Yemen

**Eftekhar A. Al-Ghasani [1*], Abdulrahman H. Amer[2], Mohammed A. Al- Kholane [1], Amna M. Al-Haj[3], Basel AM. Ahmed[3], Bya'an SK. Al-Makhlafi[3], Hussam AM. Obaid[3], Hussam HH. Nasir[3], Lina SA. Dhaba'an[3]**

[1]Department of Microbiology, Faculty of Medicine, Thamar University, Dhamar, Yemen.
[2] Department of Laboratory medicine, Faculty of Medical Sciences, Thamar University, Dhamar, Yemen.
[3] Graduation Research Group, MB ChB program, Faculty of Medicine, Thamar University, Dhamar, Yemen

**For Correspondence:**
Eftekhar A. Al-Ghasani
Thamar University, Faculty of Medicine, Department of Microbiology, Dhamar, Yemen
Email: Eftekhar2020@tu.edu.ye
Tel.: +967777206661

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## Abstract

**Background:** Diabetic foot infections (DFIs) are a major complication of diabetes, particularly in resource-limited settings like Yemen, where antimicrobial resistance (AMR) and fragmented healthcare exacerbate outcomes. Dhamar Governorate faces unique challenges, including limited diagnostics, inappropriate antibiotic use, and sparse local data on DFI etiology and resistance patterns, necessitating context-specific insights.

**Aim:** This study aimed to identify predominant bacterial pathogens in DFIs, characterize their antibiotic susceptibility, and evaluate sociodemographic and clinical risk factors to inform tailored management in Dhamar, Yemen.

**Methods:** A cross-sectional study was conducted at two hospitals in Dhamar (April–November 2021). Thirty hospitalized DFI patients were enrolled. Wound samples were collected via swab/aspiration, cultured, and tested for antibiotic susceptibility using disc diffusion (EUCAST guidelines). Sociodemographic, clinical, and microbiological data were analyzed using SPSS.

**Results:** Bacterial infections were detected in 70% (21/30) of patients, predominantly Gram-positive organisms (85.7%). Key risk factors included illiteracy (infected: 84.2% vs. non-infected: 45.5%, p=0.042), urban residence (100% vs. 59.1% rural, p=0.067), and amputation (100% infected vs. 60.9% non-amputated, p=0.048). Type-II diabetes showed borderline association with infection (83.3% vs. 50.0% Type-I, p=0.051). Alarmingly, 100% resistance to amoxicillin and 90.5% to cefuroxime were observed. Vancomycin (94.4% sensitivity in Gram-positive isolates) and amikacin (100% sensitivity in Gram-negative isolates) were most effective.

**Conclusion:** The high prevalence of DFIs and widespread AMR in Dhamar underscore urgent needs for improved antibiotic stewardship and localized guidelines. Empiric use of vancomycin (Gram-positive coverage) and amikacin (Gram-negative) may be warranted, but susceptibility testing remains critical. Addressing socioeconomic risk factors, such as patient education and glycemic control, is essential to reduce DFI morbidity. This study highlights the imperative for enhanced AMR surveillance in low-resource settings.

**Keywords:** Diabetic foot infections; antimicrobial resistance; Yemen; antibiotic susceptibility; risk factors.

## 1. Introduction

Diabetic foot infections (DFIs) are a devastating complication of diabetes mellitus, contributing significantly to morbidity, mortality, and healthcare costs globally. In low-resource settings like Yemen, where diabetes prevalence is rising and healthcare infrastructure is strained, DFIs pose a critical challenge, often leading to prolonged hospitalizations, amputations, and socioeconomic burdens [1,2]. Effective management of these infections relies on timely antimicrobial therapy, yet the escalating threat of multidrug-resistant (MDR) organisms complicates treatment and worsens outcomes [3,4].

The microbial etiology of DFIs is diverse, often involving polymicrobial communities dominated by Staphylococcus aureus, Pseudomonas aeruginosa, and Enterobacteriaceae [1,2,5]. However, regional variations in bacterial prevalence and resistance patterns necessitate localized data to guide empirical therapy. For instance, studies in India and Sudan reported Gram-negative predominance (e.g., Proteus spp., Escherichia coli) with high resistance to cephalosporins and fluoroquinolones [2,3], while research in Saudi Arabia highlighted S. aureus as the most common isolate, with methicillin-resistant strains (MRSA) showing resistance to β-lactams [6]. In Yemen, limited data from Taiz and Sana'a revealed P. aeruginosa and S. aureus as predominant pathogens, with alarming resistance to first-line antibiotics like ceftriaxone and gentamicin [7,8]. These findings underscore the urgency of region-specific surveillance, particularly in Dhamar, where diagnostic constraints and inappropriate antibiotic use may exacerbate resistance.

The rise of extended-spectrum β-lactamase (ESBL)-producing Gram-negative bacteria and MDR Acinetobacter spp., which exhibit near-total resistance to common antibiotics, further complicates DFI management [1,4]. For example, studies in Cameroon and South India identified Morganella morganii and Klebsiella pneumoniae as emerging MDR threats, susceptible only to carbapenems and amikacin [2,4]. Similarly, Yemeni studies reported high resistance rates among Gram-positive isolates, with S. aureus showing sensitivity only to ciprofloxacin and vancomycin [7,8]. Such trends highlight the inadequacy of empirical regimens in regions lacking local susceptibility data.

In Dhamar Governorate, the absence of comprehensive microbiological studies impedes evidence-based treatment. Existing research from Yemen's neighboring regions emphasizes the need for tailored approaches: for instance, a Taiz-based study found that 26% of DFI patients underwent amputations, with polymicrobial infections linked to poorer outcomes [8]. Furthermore, inadequate antibiotic stewardship and limited access to advanced diagnostics likely contribute to the proliferation of resistant strains [7].

This study aims to characterize the bacterial profile and antimicrobial susceptibility patterns of DFIs in Dhamar. By identifying prevalent pathogens and their resistance trends, the findings will inform region-specific treatment protocols, optimize antibiotic stewardship, and reduce complications such as amputations. In a setting where empirical therapy remains the norm, this research provides a critical foundation for mitigating the burden of MDR infections and improving clinical outcomes.

## 2. Methods

### Study Setting

A cross-sectional study was conducted at two healthcare facilities in Yemen: Thamar University - Al-Wahdah Teaching Hospital (TUWTH), Dhamar governorate, Yemen in Ma'abar City and Dhamar Hospital in Dhamar City, between April and November 2021. Participants were hospitalized patients with infectious complications in the lower limbs, requiring surgical management of lower-extremity wounds. Clinical infection was diagnosed based on the presence of at least two indicators: localized swelling/induration, periwound erythema, tenderness/pain, warmth, or purulent discharge. Non-infected wounds or common skin infections were excluded.

### Study Participants and Data Collection

The study included all patients admitted or requiring admission for diabetic foot complications at the selected hospitals during the study period.

A total of 30 patients with diabetic foot infections from Dhamar Governorate, Yemen, were enrolled.

Trained investigators administered structured questionnaires to participants. Prior to distribution, the study's purpose and anonymity assurances were explained. Verbal informed consent was obtained, and participants completed questionnaires under investigator supervision. Completed forms were manually reviewed for accuracy before data transcription and statistical analysis.

### Microbiological Analysis and Antibiotic Testing

Specimen Collection: Wound preparation involved debridement and cleansing with sterile saline to minimize contamination by skin flora. No antiseptics were applied pre-sampling.

Superficial wounds were sampled using sterile dry swabs pressed for 5 seconds; deep wounds underwent aspiration or sterile saline injection/aspiration

Bacterial Identification: Samples were immediately cultured in nutritive broth (37°C, 24–48 hours), then subcultured on blood and MacConkey agars. *Staphylococcus* isolates underwent coagulase testing using human plasma to differentiate *S. aureus* (coagulase-positive).

*Antibiotic Susceptibility:* Isolates underwent disc diffusion testing with: (concentrations in μg):

- Amoxicillin (25), Amoxicillin/Clavulanic acid (20/10), Gentamicin (10), Ciprofloxacin (5), Levofloxacin (5), Cefuroxime (30), Doxycycline (30), Azithromycin (15), Nitrofurantoin (100), Ceftriaxone (30), Clotrimazole (10), Linezolid (10), Amikacin (30), Norfloxacin (10), Vancomycin (30).
- Interpretation followed 2016 EUCAST guidelines. Multidrug resistance (MDR) was classified per European Centre for Disease Prevention and Control criteria [9].

### Statistical analysis

Data was analysed using IBM SPSS for Windows software (version 22). All the variables were presented as frequencies and percentages. The Chi-square test was used to assess the differences between the Groups. Significant associations were considered at P value $\leqslant 0.05$.

### Ethical Considerations

The approval of the study protocol was obtained from the Thamar University Medical Ethics Committee (TUMEC). Before commencing the study, the survey's objectives were explained to all the participants and their guardians. The participants were informed that their participation was voluntary and that the data was subjected to strict confidentiality as well as the freedom to withdraw at any time during the study period. All the participants provided written informed consent was obtained.

# 3. Results

Table 1 shows the socio- demographic characteristics of studied patients. Out of 30 diabetic foot patients subjected to the present study, 14 (46.7%) were in age group of (41-60) years, 13 (43.3%) in age 61 and above and, only three (10.0%) were in age group of (21-40) years. Most of the patients were married (86.7%; 26/30), rural residents (73.3%; 22/30), and males (70.0%; 21/30).

**Table 1: the general characteristics and medical history of the studied patients (n=30)**

| **Variable** | **n** (%) | **Variable** | **n** (%) |
|---|---|---|---|
| **Socio demographic characteristics** | | **Medical history** | |
| **Age / years** | | **Duration since diabetes diagnosis/ years** | |
| 21 - 40 | 3 (10.0) | ≤ 5 | 12 (40.0) |
| 41 - 60 | 14 (46.7) | 6-10 | 8 (26.7) |
| ≥ 61 | 13 (43.3) | ≥ 11 | 10 (33.3) |
| **Gender** | | **History of comorbid chronic diseases** | |
| Male | 21 (70.0) | Yes | 9 (30.0) |
| Female | 9 (30.0) | No | 21 (70.0) |
| **Residence** | | **Diabetic medication** | |
| Rural | 22 (73.3) | Insulin dependent | 9 (30.0) |
| Urban | 8 (26.7) | Oral hypoglycemic | 19 (63.3) |
| **Marital status** | | No drug | 2 (6.7) |
| Married | 26 (86.7) | **Using of diabetic medication** | |
| Single | 4 (13.3) | Regular | 21 (70.0) |
| **Educational level** | | Irregular | 9 (30.0) |
| Illiterate | 19(63.3) | **DM type** | |
| Primary | 6 (20.0) | Type-I | 12 (40.0) |
| Secondary | 5 (16.7) | Type-II | 18 (60.0) |
| **Financial state** | | **Previous history of DFIs** | |
| Excellent | 3 (10.0) | Yes | 3 (10.0) |
| Very good | 5 (16.7) | No | 27 (90.0) |
| Good | 10 (33.3) | **Current amputation** | |
| Accepted | 7 (23.3) | Yes | 7 (23.3) |
| Not good | 5 (16.7) | No | 23 (76.7) |

Nineteen (63.3%) patients were illiterates whereas who had a primary education and secondary education were 20.0%, and 16.7%, respectively. One-third of patients reported good financial status (33.3%).

Regarding to Medical history of the patients. The median of the DM duration in the 30 patients was 8 years with a range of 19 (1 to 20 years). Discovery duration the DM of most (40.0%) the patients were five years and low. Table 1.

Fourteen (46.7%) patients received antibiotic treatment on admission. Six of the 14 patients stated antibiotic names (Augomentin was reported by one patient and Tazact by one too; Cefotaxime by two patients and Ceftriaxone, by two too) whereas Eight patients answered with " don't know". The treatment of seven diabetic foot patients (23.3%) required amputation (toes for four patients and foot for three patients) more details in Figure 1.

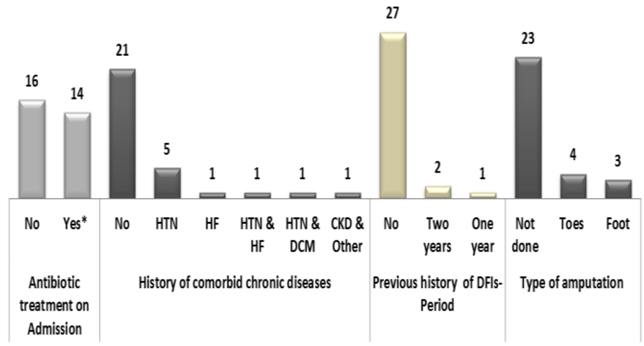


**Figure 1: Frequency of antibiotic treatment on admission, previous history of DFIs and amputation types among the patients (n=30)**

*HTN: Hypertension; HF: Heart frailer; CKD: Chronic kidney disease; DCM.; * Six patients reported Augomentin, Tazact, Cefotaxime, and Ceftriaxone*

As shown in Figure 2, rate of the detected bacterial infection was found to be 70.0% (21/30) among hospitalized diabetic patients with ulcers in foot at surgery departments of Thamar University Al-Wahdah Teaching Hospital (TUWTH), and general Dhamar hospital, Dhamar governorate, Yemen.

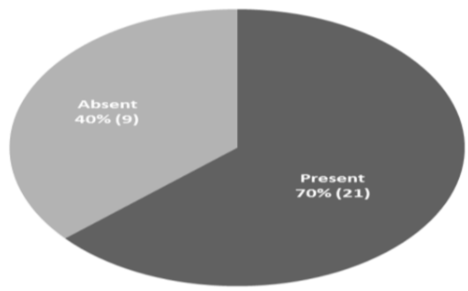


**Figure 2: Rate of the detected bacterial infection among diabetic foot patients in Public Dhamar hospitals, Yemen**

Table 2: This table shows, analyzing associations between infection outcomes and demographic/socioeconomic factors versus diabetes-related clinical factors. Key demographic insights include significantly higher infection rates among uneducated patients (84.2% vs. 45.5%, p=0.042) and borderline elevated risk in urban residents (100% vs. 59.1% rural, p=0.067), while age, gender, and financial status showed no significant associations. Clinically, amputation was strongly linked to infection (100% vs. 60.9% non-amputated, p=0.048), Type-II diabetes approached significance for higher risk (83.3% vs. 50.0% Type-I, p=0.051), and insulin users had the highest infection proportion (88.9%), though medication type and adherence showed no significant differences.

Table 3: This table summarizes antibiotic susceptibility patterns for 21 bacterial isolates (18 Gram-positive, 3 Gram-negative), categorizing results as Sensitive (S), Moderate (M), or Resistant (R). Vancomycin

demonstrated the highest efficacy against Gram-positive bacteria (17/18 sensitive, 94.4%), with no resistance observed, while Amikacin showed full sensitivity in Gram-negative isolates (3/3, though limited by small sample size). Overall, Vancomycin (81% sensitive), Levofloxacin (81%), and Amikacin (81%) were most effective across all isolates, whereas Amoxicillin (100% resistant) and Cefuroxime (90.5% resistant) exhibited universal or near-universal resistance. Gram-positive infections had higher susceptibility to most antibiotics (e.g., Linezolid: 61.9% sensitive, 38.1% moderate), while Gram-negative isolates, though sparse, showed resistance to Ciprofloxacin (1/3 resistant) and partial sensitivity to Levofloxacin (2/3 sensitive). Notable resistance trends included Ceftriaxone (66.7% resistant) and Azithromycin (33.3% resistant), underscoring challenges in treating infections with common antibiotics.

The data highlights Vancomycin as a first-line option for Gram-positive infections, while Gram-negative cases may require cautious use of Amikacin or Levofloxacin, tempered by the limited sample size. High resistance to beta-lactams (e.g., Amoxicillin, Cefuroxime) emphasizes the need for susceptibility testing to guide therapy.

**Table 2: Distribution of bacterial infections on the socio demographic characteristics and medical history of the patients (n=30)**

| | Infected | | | | | | | | Infected | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **n** | **%** | **%[b]** | **N** | **$X^2$** | ***P*** | .. | **Variable** | **n** | **%** | **%[b]** | **N** | **$X^2$** | ***P*** |
| **Age / years** | | | | | | | | **DM Medication** | | | | | | |
| **21 - 40** | 2 | 66.7 | 9.5 | 3 | 2.44 | 0.295 | | **Insulin** | 8 | 88.9 | 38.1 | 9 | 3.712 | 0.156 |
| **41 - 60** | 8 | 57.1 | 38.1 | 14 | | | | **Oral hypoglycemic** | 11 | 57.9 | 52.4 | 19 | | |
| **≥ 61** | 11 | 84.6 | 52.4 | 13 | | | | **No drug** | 2 | 100 | 9.5 | 2 | | |
| **Gender** | | | | | | | | **Using the Medication** | | | | | | |
| **Male** | 13 | 61.9 | 61.9 | 21 | 2.18[a] | 0.21 | | **Regular** | 14 | 66.7 | 66.7 | 21 | 0.37[a] | 0,681 |
| **Female** | 8 | 88.9 | 38.1 | 9 | | | | **Irregular** | 7 | 77.8 | 33.3 | 9 | | |
| **Residence** | | | | | | | | **DM type** | | | | | | |
| **Rural** | 13 | 59.1 | 61.9 | 22 | 4.68 | 0.067 | | **Type-I** | 6 | 50.0 | 28.6 | 12 | 3.81 | 0.051 |
| **Urban** | 8 | 100 | 38.1 | 8 | | | | **Type-II** | 15 | 83.3 | 71.4 | 18 | | |
| **Marital status** | | | | | | | | **Comorbid chronic diseases** | | | | | | |
| **Married** | 18 | 69.2 | 85.7 | 26 | 0.06[a] | 1.000 | | **Yes** | 8 | 88.9 | 38.1 | 9 | 2.184[a] | 0.210 |
| **Single** | 3 | 75 | 14.3 | 4 | | | | **No** | 13 | 61.9 | 61.9 | 21 | | |
| **Educational level** | | | | | | | | **Previous history of DFI** | | | | | | |
| **Uneducated** | 16 | 84.2 | 76.2 | 19 | 4.98 | 0.042 | | **Yes** | 3 | 100 | 14.3 | 3 | 1.429[a] | 0.534 |
| **Educated*** | 5 | 45.5 | 23.8 | 11 | | | | **No** | 18 | 66.7 | 85.7 | 27 | | |
| **Financial state** | | | | | | | | **Amputation** | | | | | | |
| **Insufficient** | 10 | 83.3 | 47.6 | 12 | 1.69[a] | 0.294 | | **Yes** | 7 | 100 | 33.3 | 7 | 3.913 | 0.048 |
| **Sufficient**** | 11 | 61.1 | 52.4 | 18 | | | | **No** | 14 | 60.9 | 66.7 | 23 | | |
| **Total** | 21 | 70.0 | 100 | 30 | | | | **Total** | 21 | 70.0 | 100 | 30 | | |

*** Primary and secondary level; ** the accepted and not good levels ; a extract fisher test; [b] % of total infected patients (n=21); N: Total**

**Table 3: Antibiotic Susceptibility Patterns (n=21 isolates)**

| | Bacteria type | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gram positive (N=18) | | | Gram negative (N=3) | | | Total | | | | | |
| **Antibiotic** | **S** | **M** | **R** | **S** | **M** | **R** | **S** | | **M** | | **R** | |
| | **n** | **n** | **n** | **n** | **n** | **n** | **n** | **%** | **n** | **%** | **n** | **%** |
| **Vancomycin** | 17 | 1 | 0 | 0 | 3 | 0 | 17 | 81.0 | 4 | 19.0 | 0 | 0.0 |
| **Levofloxacin** | 15 | 1 | 2 | 2 | 0 | 1 | 17 | 81.0 | 1 | 4.8 | 3 | 14.3 |
| **Amikacin** | 14 | 0 | 4 | 3 | 0 | 0 | 17 | 81.0 | 0 | 0.0 | 4 | 19.0 |
| **Gentamycin** | 13 | 2 | 3 | 3 | 0 | 0 | 16 | 76.2 | 2 | 9.5 | 3 | 14.3 |
| **Norfloxacin** | 14 | 1 | 3 | 2 | 1 | 0 | 16 | 76.2 | 2 | 9.5 | 3 | 14.3 |
| **Nitrofurantoin** | 14 | 2 | 2 | 2 | 0 | 1 | 16 | 76.2 | 2 | 9.5 | 3 | 14.3 |
| **Ciprofloxacin** | 13 | 3 | 2 | 2 | 0 | 1 | 15 | 71.4 | 3 | 14.3 | 3 | 14.3 |
| **Doxycycline** | 11 | 0 | 7 | 3 | 0 | 0 | 14 | 66.7 | 0 | 0.0 | 7 | 33.3 |
| **Linezolid** | 11 | 7 | 0 | 2 | 1 | 0 | 13 | 61.9 | 8 | 38.1 | 0 | 0.0 |
| **Azithromycin** | 7 | 5 | 6 | 2 | 0 | 1 | 9 | 42.9 | 5 | 23.8 | 7 | 33.3 |
| **Clotrimazole** | 7 | 1 | 10 | 2 | 0 | 1 | 9 | 42.9 | 1 | 4.8 | 11 | 52.4 |
| **Ceftriaxone** | 4 | 2 | 12 | 1 | 0 | 2 | 5 | 23.8 | 2 | 9.5 | 14 | 66.7 |
| **Cefuroxime** | 0 | 2 | 16 | 0 | 0 | 3 | 0 | 0.0 | 2 | 9.5 | 19 | 90.5 |
| **Amoxicillin** | 0 | 0 | 18 | 0 | 0 | 3 | 0 | 0.0 | 0 | 0.0 | 21 | 100.0 |

**S: sensitive; M: Moderate; R: Resistant**

# 4. Discussion

Diabetic foot ulceration is a common complication that occurs due to uncontrolled diabetes.

The findings of this study align with and expand upon existing research on diabetic foot infections (DFIs), particularly in low-resource settings. The high bacterial infection rate (70%) observed in this Yemeni cohort is consistent with studies from similar regions, where delayed presentation, limited healthcare access, and poor glycemic control exacerbate infection risks. For instance, Lipsky BA et al. (2016) reported infection rates of 60–80% in DFIs globally, with higher prevalence in low-income countries due to socioeconomic barriers to care [10].

**Sociodemographic and Clinical Risk Factors**

The association between low education and infection (84.2% vs. 45.5%, p=0.042) mirrors findings by Gadepalli et al. (2006), who identified illiteracy as a predictor of poor foot care practices and delayed treatment-seeking in India [11]. Similarly, the borderline significance of urban residence (100% infection vs. 59.1% rural, p=0.067) contrasts with studies where rural settings often correlate with higher infection risks due to limited healthcare access [12]. This anomaly may reflect urban overcrowding or antibiotic misuse in Yemen's urban centers, as noted by Chan M et al. (2018) [13]. The strong link between amputation and infection (100% vs. 60.9%, p=0.048) aligns with Somasundram et al. (2019), who found that amputations often follow severe, poorly managed infections in resource-limited settings [14].

The near-significant association of type-II diabetes with infection (83.3% vs. 50.0%, p=0.051) parallels global trends where insulin resistance and chronic hyperglycemia in Type-II diabetes impair wound healing [15]. The high infection rate among insulin users (88.9%) may reflect prolonged disease duration or advanced disease severity, consistent with Stepan JG et al. (2018), who linked insulin dependence to higher DFI risks [16]. However, the lack of significance in medication adherence contrasts with studies emphasizing strict glycemic control as critical to infection prevention [17], suggesting contextual factors like irregular monitoring in Yemen.

The dominance of Gram-positive bacteria (85.7%) aligns with global DFI microbiological profiles, though Gram-negative pathogens are increasingly reported in warmer climates [18]. The high efficacy of vancomycin (81% sensitivity) and amikacin (81%) against Gram-positive and Gram-negative isolates, respectively, supports their use as first-line agents in DFIs, as recommended by Lipsky et al. (2016) [10]. However, universal resistance to amoxicillin (100%) and cefuroxime (90.5%) echoes alarming trends of β-lactam resistance in Yemen, likely driven by over-the-counter antibiotic misuse [19]. These findings reinforce the need for local antibiograms to guide empiric therapy, particularly given the high resistance to ceftriaxone (66.7%) and azithromycin (33.3%), which are commonly used in DFI protocols [20].

# 5. Conclusions

The high prevalence of DFIs and widespread AMR in Dhamar underscore urgent needs for improved antibiotic stewardship and localized guidelines. Empiric use of vancomycin (Gram-positive coverage) and amikacin (Gram-negative) may be warranted, but susceptibility testing remains critical. Addressing socioeconomic risk factors, such as patient education and glycemic control, is essential to reduce DFI morbidity. This study highlights the imperative for enhanced AMR surveillance in low-resource settings.

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**Conflicts of interest**
The authors declare that there are no conflicts of interest.

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