Emerging antimicrobial resistance among uropathogens causing urinary tract infections in pregnant women: a retrospective study from Saudi Arabia

Md Sayeed Akhtar[1], Ahmed Ali Muyidi[2], Reem Alqhtani[2], Faris Al Salem[1], Ghassan Alqahtani[1], Khalid Shaher[1], Khalid Orayj[1], Sultan Mohammed Alshahrani[1], Sirajudeen Shaik Alavudeen[1] and Sadaf Farooqui[3]

[1] Department of Clinical Pharmacy, College of Pharmacy, King Khalid University, Abha, Asir, Saudi Arabia
[2] Main Laboratory and Blood Bank, Abha Maternity and Pediatric Hospital, Abha, Asir, Saudi Arabia
[3] Department of Clinical Pharmacy, College of Pharmacy, Prince Sattam Bin Abdulaziz University, Al-Kharj, Riyadh, Saudi Arabia

ABSTRACT

It is evident that urinary tract infections (UTIs) can lead to poor maternal and perinatal outcomes. We designed this study to assess the susceptibility patterns of urinary pathogens to antimicrobials, along with their applicability for the mother and fetus, to ensure effective UTI treatment during pregnancy. This retrospective study was conducted to assess bacterial UTIs in the inpatient department of a tertiary care teaching hospital in Saudi Arabia. A total of 154 pregnant women with a confirmed case of UTI were included. Urine samples were collected by the midstream urine sampling method as per the standard procedure. We observed that around 52% of participants were in the 26–35 age group. The most common isolate was *Escherichia coli* (58.44%), followed by *Klebsiella pneumoniae* (22.73%) and *Streptococcus* group B (3.90%). Considering the best choices in pregnancy for *Escherichia coli* isolates, nitrofurantoin (100%) showed the highest efficacy among participants, followed by fosfomycin (88.8%), amoxicillin-clavulanic acid (84.28%), and cefotaxime intravenously (90%). In prenatal care, it is of the utmost importance to regularly evaluate the susceptibility and resistance pattern of antimicrobials to UTI-related pathogens during the course of pregnancy in order to provide optimal therapy for both mothers and infants.

Subjects Microbiology, Evidence Based Medicine, Gynecology and Obstetrics, Women's Health
Keywords Urinary tract infection, Antimicrobial resistance, Maternal health, Pregnancy, Antenatal care, Saudi Arabia

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Corresponding author
Md Sayeed Akhtar,
mdhusain@kku.edu.sa

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INTRODUCTION

Urinary tract infection (UTI) is defined by the presence of $\geq 10^5$ CFU/ml in a urine culture with no more than two species of organisms identified, at least one of which is a bacterium (*Centers for Disease Control and Prevention , 2025*). Worldwide, UTIs are the most common bacterial infection during pregnancy, affecting approximately 23.9% globally (*Salari et al., 2023*) and around 10% in Saudi Arabia (*Barnawi et al., 2024*). However, recent data suggest that this value may be higher, posing a considerable economic burden to the

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country (*Broughton et al., 2025*). These infections typically begin within the first 6 weeks of conception, peaking between the 22nd and 24th weeks of pregnancy. Contributing factors include urethral dilatation, increased bladder volume, and decreased bladder tone, all of which increase urinary stasis and ureterovesical reflux. Meanwhile, about 70% of pregnant women develop glycosuria, which encourages bacterial growth in the urine (*Ansaldi & Martinez de Tejada Weber, 2023*; *FitzGerald & Graziano, 2007*). It is evident that early screening and treatment of UTIs during pregnancy results in a reduction in the incidence of low birth weight and preterm birth (*US Preventive Services Task et al., 2019*). Antibiotic resistance is a globally acknowledged health threat that complicates the search for effective treatment, even for commonly encountered bacterial infections caused by strains of *Escherichia coli* (*Antimicrobial Resistance Collaborators, 2022*; *Uddin et al., 2021*; *Alavudeen et al., 2021*). Antibiotic resistance is projected to continue to increase in the next decades with higher morbidity and mortality rates, along with rising healthcare expenses, as indicated by Centers for Disease Control and Prevention (*Centers for Disease Control and Prevention, 2019*). Therefore, it is essential to create policies that govern the appropriate use of antimicrobials. Such policies should be incorporated into urological practice to ensure the effective utilization of antibiotics and safeguard public health (*World Health Organization, 2025*). Antibiotic susceptibility patterns are crucial for clinicians in choosing the right antibiotics for patients with UTIs to maximize compliance (*Altamimi et al., 2023*). In addition, the prevalence of resistance to antibiotics commonly prescribed to maternity care patients for UTIs due to *Escherichia coli* has been found to be on the rise, particularly in countries outside the Organization for Economic Co-operation and Development, where antibiotics are available over the counter (*Altamimi et al., 2023*; *Bryce et al., 2016*). Global data show an increasing resistance to conventional antibiotics among uropathogens, with emerging resistance to newer and more potent antimicrobial agents. In Saudi Arabia and worldwide, up to 33% of the uropathogens responsible for UTIs are resistant to amoxicillin, as well as to other antibiotics; this pattern has become even more worrying over time (*Almutawif & Eid, 2023*; *Ku et al., 2024*). Given these concerns, we designed this study to assess the changing patterns of susceptibility to commonly used antimicrobials among urinary pathogens responsible for UTIs. Moreover, this study contributes to the establishment of proper antibiotic utilization guidelines and promotes evidence-based antibiotic prescribing practices in healthcare.

MATERIALS AND METHODS

Study type, setting, and period

This observational, retrospective study was conducted using routinely collected laboratory and clinical records of pregnant women on consecutive based sampling method to assess bacterial UTIs in the obstetrics and gynecology department of a tertiary care maternity hospital in Abha, Saudi Arabia. Data were extracted from hospital laboratory databases using a standardized data collection approach. In study setting, institutional antimicrobial stewardship guidelines and national standards guide empirical antibiotic therapy for UTIs in pregnant women, with changes depending on culture and antimicrobial susceptibility

results. Standard laboratory protocols were used to assess and evaluate antimicrobial susceptibility for evidence-based antibiotic selection. All laboratory data was collected between January 2024 and December 2024 based on received written informed consent from the participants.

Specimen collection

Sample collection and microscopic examination

Midstream clean-catch urine samples were collected in sterile containers following standard instructions. Samples were transported to the laboratory within one hour of collection or refrigerated at 4 °C if delayed. Each sample was examined microscopically; pyuria was defined as ≥10 leukocytes per high-power field, and the presence of casts was recorded when observed.

Urine culture

Using a calibrated loop, 0.001 mL of well-mixed, uncentrifuged urine was inoculated onto 5% sheep blood agar and MacConkey agar. Plates were incubated aerobically at 37 °C for 24 h; plates showing no growth were re-incubated for an additional 24–48 h before being reported as negative. Significant bacteriuria was defined as a single uropathogen at ≥105 CFU/mL, in accordance with Clinical and Laboratory Standards Institute (CLSI, 2024) criteria (*Mathers et al., 2026*). Both asymptomatic and symptomatic pregnant women meeting this threshold were included. Cultures yielding three or more distinct colony morphotypes were considered contaminated and excluded.

Organism identification

Bacterial isolates were presumptively identified by colony morphology and Gram staining. Definitive species-level identification was performed using the Autof MS1000 matrix-assisted laser desorption/ionization time-of-flight (MALDI-TOF) mass spectrometry system (Autobio Diagnostics, Zhengzhou, China) according to the manufacturer's protocol. Each isolate was spotted onto a disposable 96-spot target plate, overlaid with α-cyano-4-hydroxycinnamic acid (CHCA) matrix, and analyzed using the Autof Acquirer software with the onboard reference database. Identification scores were interpreted as follows: ≥9.000 was accepted as reliable species-level identification, 6.000–8.999 as genus-level identification, and <6.000 as no reliable identification, with repeat testing performed using formic acid extraction. Method verification followed Clinical and Laboratory Standards Institute (CLSI) M58 (Methods for Identification of Cultured Microorganisms Using MALDI-TOF MS) guidelines (*Clinical and Laboratory Standard Institute, 2017*). Daily quality control was performed using *Staphylococcus aureus* ATCC 25923, *Escherichia coli* ATCC 25922, and *Candida albicans*, and all results remained within acceptable ranges throughout the study period.

Antimicrobial susceptibility testing

Antimicrobial susceptibility testing was performed using the VITEK 2 (VITEK 2 XL; bioMérieux, Marcy-l'Étoile, France) and MicroScan WalkAway-96 Plus (Siemens Healthineers, Deerfield, IL, USA) automated systems, following the manufacturers'

protocols. The antimicrobial panel tested against urinary isolates was selected in accordance with Clinical and Laboratory Standards Institute (CLSI) recommendations for urinary tract pathogens, with agents chosen on the basis of organism group (Gram-negative or Gram-positive), clinical relevance to urinary tract infection therapy, and the urine-only agents specified in CLSI M100 (*e.g.*, nitrofurantoin and fosfomycin for *Escherichia coli* and *Enterococcus spp.*). Minimum inhibitory concentrations (MICs) were interpreted according to CLSI recommendations (*Mathers et al., 2026*). Susceptibility data were retrieved from the hospital laboratory information system. Quality control for susceptibility testing was performed using *Escherichia coli* ATCC 25922, *Staphylococcus aureus* ATCC 25923, *Pseudomonas aeruginosa* ATCC 27853, and *Enterococcus faecalis* ATCC 29212, with results consistently within CLSI-defined acceptable ranges. Isolates classified as "intermediate" were grouped with non-susceptible for the purpose of multidrug resistance analysis.

Detection of Extended-Spectrum β-Lactamase (ESBL) production

Screening for extended-spectrum β-lactamase (ESBL) production was performed on all *Enterobacterales* isolates, particularly *Escherichia coli, Klebsiella pneumoniae, Klebsiella oxytoca,* and *Proteus mirabilis*, showing reduced susceptibility to one or more of the indicators cephalosporins (cefotaxime, ceftriaxone, ceftazidime) or aztreonam, in accordance with *Mathers et al. (2024)* screening criteria. The VITEK 2 AST cards include an advanced expert system (AES) that automatically detects ESBL phenotypes based on MIC patterns of ceftazidime, cefotaxime, and cefepime alone and in combination with clavulanic acid. Confirmation of ESBL production was performed using the combination disk method, in which the inhibition zone diameter around ceftazidime (30 μg) and cefotaxime (30 μg) disks were compared with that around ceftazidime/clavulanic acid (30/10 μg) and cefotaxime/clavulanic acid (30/10 μg) disks. Phenotypic confirmation of ESBL production was considered as an increase in zone diameter of $\geq$5 mm for either antibiotic in the presence of clavulanic acid compared with the zone diameter when tested alone as recommended by *Mathers et al. (2024)*. *Escherichia coli* ATCC 25922 (ESBL-negative) and *Klebsiella pneumoniae* ATCC 700603 (ESBL-positive) were used as quality control strains for the confirmatory test.

Sample size calculation

For a prevalence/proportion study, the sample size was calculated using the single population proportion formula assuming a UTI prevalence of 5%, a 95% confidence level, and a margin of error of 2.7%, resulting in a required sample size of 250 participants. However, only 154 samples were selected based on inclusion and exclusion criteria for final analysis.

Inclusion criteria

This study included relevant sensitivity/resistance data related to microbiological isolates in pregnant women. Participants age $\geq$18 years, pregnant women with confirmed diagnosis of UTI, complete demographic and availability of laboratory data on antimicrobial susceptibility were included for study.

Exclusion criteria

Cultures with colonies $<10^5$ CFU/mL and those already on antibiotic drugs were excluded. Data on isolated organisms other than bacteria such as candida, incomplete medical records, catheter-associated UTIs, contaminated samples, and major comorbidities (such as liver disease, renal insufficiency, malignant tumors, and AIDS) were also excluded from this study.

Data curation

All patients were identified retrospectively and consecutively incorporated from the hospital microbiology laboratory database according to established inclusion and exclusion criteria. This systematic retrieval method was employed to reduce selection bias and guarantee the thorough inclusion of eligible cases. Then, the selected patient data were collected from the microbiology laboratory data and recorded in a Microsoft Excel 2021 Worksheet, designated as the microbiological sensitivity documentation form. All data were protected with double-layer password security, and confidentiality was maintained per the ethical guidelines.

Ethical approval

The study protocol was reviewed and approved by the Regional Committee for Research Ethics, Ministry of Health, Aseer Region, Kingdom of Saudi Arabia (approval number: REC -7-2-2024).

Statistical analysis

Statistical analysis was performed using SPSS software, version 21 (SPSS, Chicago, IL, USA). Depending on the type of data, Chi-square test was used to assess associations between categorical variables. Descriptive analysis was applied to analyze demographic characteristics, bacterial isolate distribution, and antimicrobial susceptibility patterns One-Way analysis of variance (ANOVA) is applied to measure the significant differences between the age groups. Wilson method is used to calculate 95% confidence intervals for proportions. Fisher's exact test is applied to compare the prevalence of *Escherichia coli* and *Klebsiella pneumoniae* with other isolates individually. The results are presented in the manuscript using means, standard deviations (SDs), frequencies (N), and percentages (%). All reported *p*-values less than 0.05 correspond to null and alternative hypothesis tests evaluating group-wise differences in demographic and clinical variables.

RESULTS

A total of 154 patients with confirmed UTIs during pregnancy were included in this study. The distribution of bacteria was predominantly Gram-negative (92.85%), whereas Gram-positive bacteria comprised a smaller portion (7.14%). Throughout the study period, *Escherichia coli* and *Klebsiella pneumoniae* were primarily recorded, along with other sixteen different bacterial species.

Table 1 indicated that the mean age of the total 154 study participants was 32.35 ± 6.67 years (95% CI [31.29–33.41]). The majority of the individuals were in the 31–35-year

Table 1 Frequency distribution and mean age of UTI patients in different age groups.

Age group (years)	N (%)	Mean age ± SD	95% CI	
20–25	25 (16.2)	22.12 ± 1.53	21.48–22.75	
26–30	33 (21.4)	27.81 ± 1.46	27.29–28.33	One way ANOVA value (F) = 656.73
31–35	48 (31.2)	33.22 ± 1.30	32.84–33.60	
36–40	30 (19.5)	37.83 ± 1.39	37.31–38.35	
41–45	14 (9.1)	42.14 ± 1.16	41.46–42.81	Degree of freedom = 5,148
46–51	4 (2.6)	47.75 ± 2.36	43.99–51.50	
Total	154 (100)	32.35 ± 6.67	31.29–33.41	$P = 0.001$

Notes.

Data are presented as mean, SD, number (N) and percentage (%) in all six groups. Descriptive was applied to measure the mean, SD and One-Way analysis of variance (ANOVA) is applied to measure the significant differences between the age groups. *P*-value <0.05 is considered significant difference between the age groups.

UTI, Urinary tract infection; SD, Standard deviation; CI, Confidence interval.

age group (31.16%), followed by the 26–30-year (21.42%) and 36–40-year (19.48%) age groups. Minimum proportions were reported in older age groups particularly in the age range of 46–50 years (2.59%). One-way ANOVA demonstrated statistical difference in mean age between the age groups ($P = 0.001$).

As depicted in Table 2, *Escherichia coli* was identified as the most common uropathogen, accounting for 58.44% of the cases, followed by *Klebsiella pneumoniae* (22.73%), Group B Streptococcus (3.90%), and *Enterobacter aerogenes* (3.90%). Other microbiological isolates such as *Citrobacter freundii, Klebsiella oxytoca,* and *Pseudomonas putida* were also reported.

Escherichia coli and *Klebsiella pneumoniae* were confirmed to be the most common uropathogen ($P < 0.001$) since its prevalence was significantly higher than that of all other isolated bacteria.

We also analyzed the distribution of different microbiological isolates in UTIs during pregnancy based on participant age group (Table 3). *Escherichia coli* was the predominant organism in every age category, accounting for 64% in the 20–25 age group, 72.73% in 26–30, 52.08% in 31–35, 53.33% in 36–40, 50% in 41–45, and 50% in 46–51 years. The next most common isolate was *Klebsiella pneumoniae*, showing the highest frequency in the 36–40 age group (30%), followed by 31–35 (29.17%) and 41–45 (28.57%). Other bacterial isolates occur at lower rates. Statistical analysis indicated that the distribution of most bacterial isolates did not significantly differ across age groups ($P > 0.05$). However, the prevalence of *Pseudomonas aeruginosa* and *Staphylococcus sciuri* was significantly related to age group ($\chi^2 = 37.745$, $p < 0.001$), with a Cramér's V of 0.495, signifying a moderate association. For other isolates, Cramér's V values ranged from 0.113 to 0.256, indicating weak correlations with age groups. However, the overall trend remained consistent across age groups.

Table 4 depicts the resistance and susceptibility patterns of the different isolates found in UTI patients in terms of the most effective antimicrobial agents. We found that *Escherichia coli* was highly susceptible to amoxicillin–clavulanic acid (84.25%), amikacin (97.61%), ceftolozane–azobactam (100%), cefotaxime (90%), gentamycin (92.42%), tobramycin (96.77%), nitrofurantoin (100%), piperacillin–tazobactam (95.45%), and tigecycline

Table 2 Distribution of different microbial isolates in urinary tract infections during pregnancy.

Type of isolates	N	%	95% CI (%)
Escherichia coli[*]	90	58.44	50.55–65.93
Klebsiella pneumoniae[*]	35	22.73	16.82–29.96
Group B Streptococcus[#]	6	3.90	1.80–8.24
Enterobacter aerogenes/Klebsiella aerogenes	6	3.90	1.80–8.24
Citrobacter freundii	2	1.30	0.36–4.61
Klebsiella oxytoca	2	1.30	0.36–4.61
Pseudomonas putida	2	1.30	0.36–4.61
Acinebacter baumannii	1	0.65	0.11–3.59
Enterobacter cloacae	1	0.65	0.11–3.59
Klebsiella ozaenae	1	0.65	0.11–3.59
Listeria monocytogenes[#]	1	0.65	0.11–3.59
MRSA[**#]	1	0.65	0.11–3.59
Pseudomonas aeruginosa	1	0.65	0.11–3.59
Pseudomonas fluorescens	1	0.65	0.11–3.59
Serratia marcescens	1	0.65	0.11–3.59
Staphylococcus sciuri[#]	1	0.65	0.11–3.59
Staphylococcus warneri[#]	1	0.65	0.11–3.59
Streptococcus agalactiae[#]	1	0.65	0.11–3.59
Total	154	100	–

Notes.

Data are presented as number (N), percentage (%), and 95% confidence interval (CI). Wilson method is used to calculate 95% confidence intervals for proportions. Fisher's exact test is applied to compare the prevalence of *Escherichia coli and Klebsiella pneumoniae* with other isolates individually.

[*]*P*-value <0.001 is considered significant difference between the groups.

[**]MRSA, Methicillin resistance *Staphylococcus aureus*.

[#]Gram-positive bacteria.

(100%). Similarly, *Klebsiella pneumoniae* showed high susceptibility to amoxicillin–clavulanic acid (83.33%), amikacin (92.85%), ceftolozane–tazobactam (87.5%), ceftriaxone (80%), cefotaxime (100%), tobramycin (88.88%), gentamycin (95.45%), nitrofurantoin (75%), piperacillin–tazobactam (92.85%), and tigecycline (100%). Particularly, Table 4 further indicated that carbapenems such as ertapenem, imipenem, and meropenem showed 100% effectiveness against most of the isolates. In terms of resistance, *Escherichia coli* exhibited resistance to ceftriaxone (38.09%), norfloxacin (23.8%), ciprofloxacin (31.38%), levofloxacin (27.27%), and co-trimoxazole (26.72%). Moreover, all isolates (100%) showed intermediate sensitivity to amoxicillin. *Klebsiella pneumoniae* was resistant to ceftazidime (33.33%), ceftriaxone (20%), norfloxacin (33.33%), ciprofloxacin (31.25%), levofloxacin (28.57%), nitrofurantoin (25%), co-trimoxazole (28.57%), and others. *Enterobacter aerogenes (Klebsiella aerogenes)* exhibited resistance to amikacin (50%), amoxicillin–clavulanic acid (100%), ceftazidime (50%), cefotaxime (50%), cefoxitin (100%), nitrofurantoin (33.33%), and piperacillin (50%). Importantly, the data revealed 100% resistance to amoxicillin–clavulanic acid in *Pseudomonas putida, Serratia marcescens, and Staphylococcus sciuri* (Data File S1).

Table 3 Distribution of different microbial isolates based on age group in urinary tract infections during pregnancy.

Bacterial isolates	Age group (Years)						χ^2 value	Degree of freedom	*P*-value	Cramér's *V*
	20–25	26–30	31–35	36–40	41–45	46–51				
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)				
Escherichia coli	16 (64)	24 (72.73)	25 (52.08)	16 (53.33)	7 (50)	2 (50)	4.740	5	0.448	0.175
Klebsiella pneumoniae	5 (20)	3 (9.09)	14 (29.17)	9 (30)	4 (28.57)	0 (0)	7.086	5	0.214	0.215
Group B Streptococcus	2 (8)	1 (3.03)	2 (4.17)	1 (3.33)	0 (0)	0 (0)	1.955	5	0.855	0.113
Enterobacter aerogenes/ Klebsiella aerogenes	0 (0)	1 (3.03)	3 (6.25)	1 (3.33)	1 (7.14)	0 (0)	2.372	5	0.796	0.124
Citrobacter freundii	0 (0)	2 (6.06)	0 (0)	0 (0)	0 (0)	0 (0)	7.430	5	0.191	0.220
Klebsiella oxytoca	0 (0)	1 (3.03)	0 (0)	1 (3.33)	0 (0)	0 (0)	2.938	5	0.710	0.138
Pseudomonas putida	0 (0)	0 (0)	1 (2.08)	1 (3.33)	1 (7.14)	0 (0)	3.516	5	0.621	0.151
Acinebacter baumannii	1 (4)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	5.194	5	0.393	0.184
Enterobacter cloacae	0 (0)	0 (0)	1 (2.08)	0 (0)	0 (0)	0 (0)	2.223	5	0.818	0.120
Klebsiella ozaenae	0 (0)	0 (0)	0 (0)	0 (0)	1 (7.14)	0 (0)	10.065	5	0.073	0.256
Listeria monocytogenes	0 (0)	0 (0)	0 (0)	1 (3.33)	0 (0)	0 (0)	4.160	5	0.527	0.164
MRSA	0 (0)	0 (0)	1 (2.08)	0 (0)	0 (0)	0 (0)	2.223	5	0.818	0.120
Pseudomonas aeruginosa	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (25)	37.745	5	<0.001	0.495
Pseudomonas fluorescens	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.000	5	1.00	0.000
Serratia marcescens	0 (0)	1 (3.03)	0 (0)	0 (0)	0 (0)	0 (0)	3.691	5	0.595	0.155
Staphylococcus sciuri	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (25)	37.745	5	<0.001	0.495
Staphylococcus warneri	1 (4)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	5.194	5	0.393	0.184
Streptococcus agalactiae	0 (0)	0 (0)	1 (2.08)	0 (0)	0 (0)	0 (0)	2.223	5	0.818	0.120
Total	25 (100)	33 (100)	48 (100)	30 (100)	14 (100)	4 (100)				

Notes.

Data are presented as number (N) and percentage (%) in all six groups. Cramér's V is applied to measure the effect size along with the Chi-square test to determine the strength of association between two categorical variables, bacterial isolates and different age groups.*P*-value <0.05 is considered significant difference between the groups. MRSA, Methicillin resistance *Staphylococcus aureus*.

Table 4 Resistance and sensitivity pattern of the different isolates in urinary tract infections during pregnancy.

Antibiotics	Amikacin		Amox-Clav		Ceftazidime		Ceftolozane/tazobactam	
Isolates	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**
Enterobacter aerogenes/ Klebsiella aerogenes	0 (0)	3 (100)	3 (100)	0 (0)	1 (50)	1 (50)	0 (0)	0 (0)
Escherichia coli	1 (2.38)	41 (97.61)	11 (15.71)	59 (84.28)	12 (24)	38 (76)	0 (0)	12 (100)
Klebsiella pneumoniae	1 (7.17)	13 (92.85)	5 (16.66)	25 (83.33)	6 (33.33)	12 (66.67)	1 (12.5)	7 (87.5)
Group B Streptococcus	0 (0)	6 (100)	0 (0)	6 (100)	0 (0)	6 (100)	0 (0)	6 (100)
***P*-value**	0.001		0.001		0.001		0.001	
Antibiotics	**Ciprofloxacin**		**Ertapenem**		**Gentamicin**		**Imipenem**	
Isolates	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**
Enterobacter aerogenes/ Klebsiella aerogenes	0 (0)	4 (100)	0 (0)	0 (0)	0 (0)	5 (100)	1 (100)	0 (0)
Escherichia coli	17 (31.38)	37 (68.51)	0 (0)	14 (100)	5 (7.57)	61 (92.42)	0 (0)	38 (100)
Klebsiella pneumoniae	5 (31.25)	11 (68.75)	0 (0)	8 (100)	1 (4.54)	21 (95.45)	0 (0)	14 (100)
Pseudomonas putida	0 (0)	2 (100)	2 (100)	0 (0)	0 (0)	2 (100)	0 (0)	2 (100)
Group B Streptococcus	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
***P*-value**	0.001		0.001		0.001		0.001	
Antibiotics	**Cefotaxime**		**Cefotaxime-Clav-K**		**Cefoxitin**		**Norfloxacin**	
Isolates	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**
Enterobacter aerogenes/ Klebsiella aerogenes	1 (50)	1 (50)	0 (0)	0 (0)	2 (100)	0 (0)	0 (0)	1(100)
Escherichia coli	3 (10)	27 (90)	0 (0)	0 (0)	3 (14.28)	18 (85.71)	5 (23.8)	16 (76.19)
Klebsiella pneumoniae	0 (0)	5 (100)	0 (0)	0 (0)	0 (0)	4 (100)	1 (33.33)	2 (66.66)
Group B Streptococcus	0 (0)	6 (100)	0 (0)	6 (100)	0 (0)	6 (100)	0 (0)	0 (0)
***P*-value**	0.001		0.001		0.001		0.001	
Antibiotics	**Meropenem**		**Nitrofurantoin**		**Piperacillin-Tazobactam**		**Tigecycline**	
Isolates	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**
Enterobacter aerogenes/ Klebsiella aerogenes	0 (0)	4 (100)	1 (33.33)	2 (66.67)	1 (50)	1 (50)	0 (0)	3 (100)
Escherichia coli	0 (0)	47 (100)	0 (0)	76 (100)	3 (4.54))	63 (95.45)	0 (0)	26 (100)
Klebsiella pneumoniae	0 (0)	18 (100)	4 (25)	12 (75)	2 (7.14)	26 (92.85)	0 (0)	7 (100)
Pseudomonas putida	0 (0)	2 (100)	2 (100)	0 (0)	0 (0)	2 (100)	0 (0)	0 (0)
Group B Streptococcus	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	6 (100)	0 (0)	0 (0)
***P*-value**	0.001		0.001		0.001		0.001	

(*continued on next page*)

Table 4 (*continued*)

Antibiotics	Co-trimoxazole		Fosfomycin		Oxacillin		Amoxycillin	
Isolates	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**
Enterobacter aerogenes/ Klebsiella aerogenes	1 (16.66)	5 (83.33)	1 (50)	1 (50)	0 (0)	0 (0)	0 (0)	0 (0)
Escherichia coli	23 (26.72)	63 (73.25)	1 (11.11)	8 (88.88)	0 (0)	0 (0)	0 (0)	7 (100)
Klebsiella pneumoniae	10 (28.57)	25 (71.42)	0 (0)	1 (100)	0 (0)	0 (0)	0 (0)	1 (100)
Group B Streptococcus	6 (100)	0 (0)	0 (0)	0 (0)	0 (0)	6 (100)	0 (0)	1 (100)
***P*-value**	0.001		0.001		0.001		0.001	
Antibiotics	**Ceftriaxone**		**Levofloxacin**		**Tobramycin**		**Aztreonam**	
Isolates	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**	**R - N (%)**	**S - N (%)**
Enterobacter aerogenes/ Klebsiella aerogenes	0 (0)	1 (100)	0 (0)	2 (100)	0 (0)	2 (100)	0 (0)	0 (0)
Escherichia coli	8 (38.09)	13 (61.9)	9 (27.27)	24 (72.73)	1 (3.22)	30 (96.77)	2 (25)	6 (75)
Klebsiella pneumoniae	2 (20)	8 (80)	2 (28.57)	5 (71.42)	1 (11.11)	8 (88.88)	0 (0)	1 (100)
Pseudomonas putida	–	–	0 (0)	2 (100)	–	–	0 (0)	0 (0)
Group B Streptococcus	0 (0)	6 (100)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	6 (100)
***P*-value**	0.001		0.001		0.001		0.001	

Notes.

Data are presented as number (N) and percentage (%) in all groups. Chi-square analysis was performed to evaluate the association between bacterial isolates and antibiotic resistance patterns. R, Resistance; S, Sensitivity; MRSA, Methicillin resistance *Staphylococcus aureus*; *P*-value, <0.05 is considered significant difference between the groups.

We also evaluated the overall distribution of susceptibility patterns between the different antibiotics used in UTIs during pregnancy (Table 5). The data indicated that, overall, the isolates were highly sensitive to amikacin (96.05%), ceftolozane–tazobactam (96.77%), ertapenem (93.10%), gentamycin (93.52%), imipenem (95.45%), meropenem (100%), nitrofurantoin (80.33%), piperacillin–tazobactam (89.08%), tigecycline (97.56%), cefotaxime (82.98%), cefotaxime–clavulanate (100%), ceftazidime–clavulanate (100%), tobramycin (95.65%), fosfomycin (85.71%), and linezolid (100%). On the contrary, various isolates identified in pregnancy-associated UTIs exhibited either resistance against or intermediate susceptibility to antimicrobials like cefazolin (60.34%), ciprofloxacin (27.06%), ampicillin (71.76%), ampicillin–sulbactam (45%), co-trimoxazole (28.57%), tetracycline (100%), amoxicillin (100%), piperacillin (100%), and cefixime (100%). Nitrofurantoin exhibited the highest sensitivity among commonly prescribed antibiotics at 80.33% (95% CI [72.40–86.41]), followed by levofloxacin at 78.85% (95% CI [65.97–87.76]), cefoxitin at 77.78% (95% CI [61.92–88.28]), co-trimoxazole at 71.43% (95% CI [63.65–78.11]), ciprofloxacin at 72.94% (95% CI [62.66–81.24]), ceftriaxone at 71.74% (95% CI [57.45–82.68]), and amoxicillin–clavulanate at 72.31% (95% CI [64.06–79.28]). In contrast, elevated resistance rates were seen for ampicillin (69.47%; 95% CI [61.12–76.70]), cefazolin (55.17%; 95% CI [42.45–67.25]), cefuroxime (37.18%; 95% CI [27.29–48.27]), cefepime (34.48%; 95% CI [25.34–44.94]), and co-trimoxazole (28.57%; 95% CI [21.89–36.35]). Intermediate resistance was noted for amoxicillin and vancomycin (100% intermediate response), while tetracycline and nalidixic acid exhibited no susceptible isolates. We also observed multi drug resistance (MDR) isolates in our study in different age groups (Data File S2).

Table 6 demonstrated binary logistic regression analyses data to evaluate the association between microorganism type and antibiotic resistance. Data indicated that resistance to ampicillin was significantly higher among *Klebsiella pneumoniae* isolates compared with the reference microorganism *Escherichia coli* (OR = 17.71, 95% CI [2.29–136.88], $P = 0.006$). In contrast, no statistically significant associations were observed for resistance other antimicrobials.

DISCUSSION

The goal of this study was to assess the demographic characteristics, microbiological profile and antibiotic sensitivity patterns of microbiological isolates from pregnant women diagnosed with UTIs to provide guidance for antibiotic recommendations in the gynecology and obstetrics ward of a tertiary care hospital in Abha, Saudi Arabia. Antimicrobial susceptibility testing of individual isolates is important to confirm bacterial susceptibility to the empirical antimicrobial agents chosen (*Alavudeen et al., 2021*; *Lee et al., 2019*). This study provides important local antimicrobial resistance data from Abha, Saudi Arabia, which may impact empirical antibiotic selection and support antimicrobial stewardship initiatives.

The findings demonstrated that women in the reproductive age, particularly those aged 31–35 years, constituted the majority of UTIs cases. This is consistent with the typical

Table 5 Comprehensive distribution of susceptibility pattern between different antibiotics in urinary tract infections during pregnancy.

Antibiotic	Sensitive N (%)	95% CI (Sensitive)	Intermediate N (%)	95% CI (Intermediate)	Resistant N (%)	95% CI (Resistant)
Co-trimoxazole	105 (71.43)	63.65–78.11	0 (0.00)	0.00–2.55	42 (28.57)	21.89–36.35
Ampicillin	37 (28.24)	21.24–36.49	3 (2.29)	0.78–6.52	91 (69.47)	61.12–76.70
Amoxicillin-Clavulanate	94 (72.31)	64.06–79.28	10 (7.69)	4.23–13.58	26 (20.00)	14.03–27.69
Nitrofurantoin	98 (80.33)	72.40–86.41	16 (13.11)	8.24–20.25	8 (6.56)	3.36–12.41
Piperacillin-Tazobactam	106 (89.08)	82.20–93.50	6 (5.04)	2.33–10.56	7 (5.88)	2.88–11.65
Gentamicin	101 (93.52)	87.22–96.83	0 (0.00)	0.00–3.43	7 (6.48)	3.17–12.78
Ceftazidime	65 (69.89)	59.93–78.27	7 (7.53)	3.69–14.73	21 (22.58)	15.27–32.07
Cefepime	55 (63.22)	52.73–72.59	2 (2.30)	0.63–8.00	30 (34.48)	25.34–44.94
Ciprofloxacin	62 (72.94)	62.66–81.24	1 (1.18)	0.21–6.37	22 (25.88)	17.76–36.09
Meropenem	81 (100.00)	95.47–100	0 (0.00)	0.00–4.53	0 (0.00)	0.00–4.53
Cefuroxime	44 (56.41)	45.36–66.86	5 (6.41)	2.77–14.14	29 (37.18)	27.29–48.27
Amikacin	73 (96.05)	89.03–98.65	1 (1.32)	0.23–7.08	2 (2.63)	0.72–9.10
Imipenem	63 (95.45)	87.47–98.44	1 (1.52)	0.27–8.10	2 (3.03)	0.83–10.39
Cefazolin	23 (39.66)	28.09–52.51	3 (5.17)	1.77–14.14	32 (55.17)	42.45–67.25
Levofloxacin	41 (78.85)	65.97–87.76	0 (0.00)	0.00–6.88	11 (21.15)	12.24–34.03
Cefotaxime	39 (82.98)	69.86–91.11	2 (4.26)	1.17–14.25	6 (12.77)	5.98–25.17
Ceftriaxone	33 (71.74)	57.45–82.68	2 (4.35)	1.20–14.53	11 (23.91)	13.91–37.94
Tobramycin	44 (95.65)	85.47–98.80	0 (0.00)	0.00–7.71	2 (4.35)	1.20–14.53
Tigecycline	40 (97.56)	87.40–99.57	0 (0.00)	0.00–8.57	1 (2.44)	0.43–12.60
Ampicillin-Sulbactam	22 (55.00)	39.83–69.29	9 (22.50)	12.32–37.50	9 (22.50)	12.32–37.50
Cefoxitin	28 (77.78)	61.92–88.28	3 (8.33)	2.87–21.83	5 (13.89)	6.08–28.66
Ceftolozane-Tazobactam	30 (96.77)	83.81–99.43	0 (0.00)	0.00–11.03	1 (3.23)	0.57–16.19
Ertapenem	27 (93.10)	78.04–98.09	0 (0.00)	0.00–11.70	2 (6.90)	1.91–21.96
Norfloxacin	21 (77.78)	59.24–89.39	0 (0.00)	0.00–12.46	6 (22.22)	10.61–40.76
Aztreonam	13 (72.22)	49.13–87.50	2 (11.11)	3.10–32.80	3 (16.67)	5.84–39.22
Tetracycline	0 (0.00)	0.00–20.39	11 (73.33)	48.05–89.10	4 (26.67)	10.90–51.95
Fosfomycin	12 (85.71)	60.06–95.99	0 (0.00)	0.00–21.53	2 (14.29)	4.01–39.94
Piperacillin	2 (16.67)	4.70–44.80	7 (58.33)	31.95–80.67	3 (25.00)	8.89–53.23
Nalidixic acid	0 (0.00)	0.00–25.88	7 (63.64)	35.38–84.83	4 (36.36)	15.17–64.62
Oxacillin	7 (77.78)	45.26–93.68	0 (0.00)	0.00–29.91	2 (22.22)	6.32–54.74
Amoxicillin	0 (0.00)	0.00–29.91	9 (100.00)	70.09–100	0 (0.00)	0.00–29.91
Penicillin	7 (87.50)	52.91–97.76	0 (0.00)	0.00–32.44	1 (12.50)	2.24–47.09
Cefotaxime-Clavulanate	6 (100.00)	60.97–100	0 (0.00)	0.00–39.03	0 (0.00)	0.00–39.03
Ceftazidime-Clavulanate	6 (100.00)	60.97–100	0 (0.00)	0.00–39.03	0 (0.00)	0.00–39.03
Vancomycin	0 (0.00)	0.00–48.99	4 (100.00)	51.01–100	0 (0.00)	0.00–48.99
Cefixime	0 (0.00)	0.00–56.15	3 (100.00)	43.85–100	0 (0.00)	0.00–56.15
Linezolid	2 (100.00)	34.24–100	0 (0.00)	0.00–65.76	0 (0.00)	0.00–65.76

Notes.

Data are presented as frequency (N), percentage (%), and 95% confidence intervals (CI) for susceptibility, intermediate response, and resistance proportions using the Wilson method.

Table 6 Logistic regression analysis of antibiotic resistance across microorganisms *Klebsiella pneumoniae vs. Escherichia coli*.

Antibiotic	Odds Ratio (OR)	95% CI	*P*-value
Amoxicillin–Clavulanate	1.073	0.338–3.408	0.9053
Ampicillin	17.714	2.292–136.881	0.0059
Ampicillin–Sulbactam	0.917	0.128–6.556	0.9309
Aztreonam	3.600	0.280–46.359	0.3259
Cefazolin	0.306	0.081–1.158	0.0813
Cefotaxime	2.160	0.481–9.697	0.3148
Ceftazidime	1.667	0.611–4.548	0.3185
Ceftriaxone	0.406	0.068–2.415	0.3219
Ciprofloxacin	1.842	0.643–5.276	0.2561
Ertapenem	1.000	0.061–16.391	1.0000
Fosfomycin	0.714	0.078–6.534	0.7632
Gentamicin	1.556	0.546–4.435	0.4094
Imipenem	0.889	0.052–15.241	0.9351
Levofloxacin	1.429	0.463–4.411	0.5355
Meropenem	1.125	0.067–18.985	0.9342
Nitrofurantoin	0.692	0.212–2.260	0.5428
Piperacillin–Tazobactam	1.286	0.079–20.894	0.8608
Tobramycin	1.444	0.455–4.580	0.5340
Trimethoprim–Sulfamethoxazole	2.000	0.704–5.682	0.1930

Notes.

Binary logistic regression analysis is used to assess the relationship between antibiotic resistance and microorganism type. For every antibiotic, *P*-values, odds ratios (ORs), and 95% confidence intervals (CIs) are shown. The *Escherichia coli* is considered as reference in this regression model.

childbearing age reported in the obstetric population worldwide (*Foxman et al., 2023*). The prevalence of UTIs in pregnant women was significantly influenced by age. Our study demonstrated a higher incidence (78.06%) of bacteriuria in younger participants (26–40 years), which is consistent with previous studies (*Laari et al., 2022*; *Johnson et al., 2021*). The predominance of women in the 31–35-year age group may also reflect increased parity and prolonged reproductive exposure, which have been identified as important risk factors for bacteriuria during pregnancy. Additionally, the UTIs in active reproductive age has been reported as due to hormonal, anatomical, and physiological alterations during pregnancy that predispose to urinary stasis and ascending bacterial colonization (*Laari et al., 2022*; *Johnson et al., 2021*). According to the US Preventive Services Task Force recommendation, screening for asymptomatic bacteriuria is recommended in all pregnant women (*US Preventive Services Task et al., 2019*). The treatment of UTIs can vary depending upon the microbiological susceptibility to antimicrobial agents. *Escherichia coli* and *Klebsiella pneumoniae* were the most prevalent causative organisms, reported in 75–90% of UTI isolates (*Barnawi et al., 2024*; *Alhazmi et al., 2023*). Consistently, a high prevalence of *Escherichia coli* (58.44%), followed by *Klebsiella pneumoniae* (22.73%), was observed in our study and remains the principal etiological agent of pregnancy-associated UTIs. Other microorganisms such as Group B *Streptococcus* (3.9%) or *Enterobacter aerogenes* (3.25%)

were also identified, indicating the prevalence of a diverse range of microbes in pregnant UTI patients, as reported previously (*Laari et al., 2022*; *Johnson et al., 2021*). The data also showed a trend of a higher prevalence of *Escherichia coli* in younger patients compared to *Klebsiella pneumoniae* and *Enterobacter aerogenes*. This indicates a stable dominance of *Escherichia coli* as the primary uropathogen responsible for urinary tract infections in the study population, regardless of age category (*Laari et al., 2022*; *Johnson et al., 2021*). The presence of this microorganism indicates fecal contamination and poor personal hygiene during pregnancy (*Thakre et al., 2015*; *Platte, Reynolds & Kim, 2024*). Thus, promoting hygiene maintenance from the beginning of pregnancy should be a part of prenatal care. Uropathogenic *Escherichia coli* has many virulence features, such as the ability to produce biofilms, adhesins, fimbriae, and hemolysins (*Govindarajan & Kandaswamy, 2022*). This finding is in line with that of (*Aljohani et al., 2023*), reported from Saudi Arabia who found that *Escherichia coli* prevalence rates among pregnant women with UTIs ranged from 50 to 70%. *Escherichia coli* and *Klebsiella pneumoniae* are confirmed to be prominent uropathogens during pregnancy due to their significantly increased prevalence compared to other isolates.

Klebsiella pneumoniae was the second most common pathogen found in this research. *Klebsiella* species are becoming increasingly known as nosocomial and community-acquired infections that are MDR, making these findings clinically important. In their *2019* study, *Russo & Marr* highlighted how the acquisition of extended-spectrum β-lactamase (ESBL) genes and carbapenem resistance determinants has led to *Klebsiella pneumoniae* emergence as a leading cause of complex UTIs. Although less common, other isolates like *Citrobacter freundii*, *Pseudomonas putida*, *Enterobacter cloacae*, and *Serratia marcescens* could suggest opportunistic infections linked to compromised immune systems in pregnancy and changes in their urinary tracts. *Escherichia coli* remained the most common isolate across all age groups. In contrast, *Staphylococcus sciuri* and *Pseudomonas aeruginosa* were significantly associated with age group, with a modest effect size (Cramér's $V = 0.495$), while the majority of isolates did not demonstrate any statistically significant change with respect to age. Colonization patterns or histories of antimicrobial exposure may be affected by an increasing maternal age, according to these results. Recurrent infections and exposure to resistant microbes are more common in older pregnant women compared to younger women, according to *Dube et al. (2022)*, who also found age-associated microbial differences. Although maternal age is a factor in uropathogen distribution, the poor Cramér's V values seen in most isolates suggest that it is not the only determinant. To promote appropriate antibiotic use, antimicrobial stewardship committee members should evaluate susceptibility patterns regularly, as new resistant strains may emerge and empirical therapy should change accordingly to prevent the misuse of antimicrobial agents (*Ha, Haste & Gluckstein, 2019*; *Barlam et al., 2016*). Our study showed that *Escherichia coli* exhibited susceptibility to amoxicillin–clavulanic acid in 84.24% of cases, amikacin in 97.61%, ceftolozane–tazobactam/nitrofurantoin/tigecycline in 100%, cefotaxime in 90%, gentamycin in 92.42%, tobramycin in 96.77%, and piperacillin–tazobactam in 95.45%. However, *Escherichia coli* isolates showed high resistance to ampicillin and amoxicillin (100%), consistent with previous studies (*Barnawi et al., 2024*;

Simon-Oke, Odeyemi & Afolabi, 2019). Therefore, the rational use of antibiotics must be implemented based on susceptibility data. Carbapenems were effective in 100% of the isolates reported in our study (Barnawi et al., 2024; Ali, Reda & Ormago, 2022; Chen et al., 2023). However, they should be reserved for infections caused by organisms resistant to narrow-spectrum antimicrobials (Ansaldi & Martinez de Tejada Weber, 2023). In clinical practice, nitrofurantoin and cephalexin are recommended as the safest alternatives by The American College of Obstetricians and Gynecologists, as well as by the American Academy of Family Physicians (Committee on Clinical Consensus–Obstetrics , 2023; Colgan, Jaffe & Nicolle, 2020). The results of our study support the use of nitrofurantoin in treating UTIs among pregnant women due to its 100% efficacy in *Escherichia coli* and other isolates. We observed that 73.25% of cases of *Escherichia coli*, 71.42% of cases of *Klebsiella pneumoniae,* and 80% of cases of *Enterobacter aerogenes* showed a susceptibility to co-trimoxazole. Other isolates exhibited antimicrobial sensitivity values consistent with previous studies (Barnawi et al., 2024; Simon-Oke, Odeyemi & Afolabi, 2019; Ali, Reda & Ormago, 2022). Ampicillin, ceftriaxone, ciprofloxacin, levofloxacin, norfloxacin, and co-trimoxazole were among the widely prescribed antibiotics that *Escherichia coli* and *Klebsiella pneumoniae* showed significant resistance to in this study. Resistance to ampicillin was over 69%, and there was also high resistance to cefazolin, cefuroxime, and cefepime. According to WHO monitoring data (World Health Organization, 2025) and a study by Nedbal et al. (2024), there is a growing trend of Gram-negative uropathogens developing resistance to β-lactams and fluoroquinolones. Community members' lack of sensitivity to antibiotics, their tendency to self-medicate, and their lack of commitment to their treatment may all contribute to the rise of fluoroquinolone resistance. Saudi Arabia is one of several Middle Eastern nations where empirical antibiotic prescribing is frequent, and there has been consistent documentation of significant resistance to co-trimoxazole and ampicillin (Almogbel et al., 2024). Based on our sensitivity data and reported safety profiles, our recommendations about safe antimicrobials for UTI treatment during pregnancy include nitrofurantoin, amoxicillin–clavulanic acid, fosfomycin, and intravenous ceftriaxone (Corrales, Corrales-Acosta & Corrales-Riveros, 2022).

The logistic regression analysis also showed that *Klebsiella pneumoniae* isolates were substantially more resistant to ampicillin than *Escherichia coli* (OR = 17.71, 95% CI [2.29–136.88], $P = 0.006$). This study confirms prior publications indicating inherent and acquired β-lactam resistance pathways in *Klebsiella* species. Navon-Venezia, Kondratyeva & Carattoli (2017) found that plasmid-mediated β-lactamases, altered porin channels, and efflux pump overexpression significantly contribute to ampicillin resistance in *Klebsiella pneumoniae*. In contrast, no statistically significant relationships were detected for resistance against most other antibiotics, which may be due to insufficient isolate numbers and broad confidence ranges.

Our study highlights the importance of antimicrobial stewardship in pregnancy-associated UTIs and strongly recommends antibiotic sensitivity testing prior to making treatment decisions to ensure effective disease management and to prevent MDR (US Preventive Services Task et al., 2019; World Health Organization, 2019). Furthermore,

this study may help guide evidence-based prescribing practices, empirical use of antibiotics and contribute to reducing antimicrobial resistance in the local population.

The limitations of this study include its small sample size, which may have reduced the statistical power of the study, particularly for isolates other than *Escherichia coli* and *Klebsiella pneumoniae*, and the focus on a single-center population. Additionally, the findings may not be fully generalizable to the pregnant population of Abha, Saudi Arabia, particularly for pathogens with a very small number of isolates, restricts reliable interpretation of the results.''

A pooled data analysis is recommended to support policies regarding antibiotic recommendations for pregnant UTI patients in Saudi Arabia.

CONCLUSIONS

The patterns of local antibiotic susceptibility among the bacteria that cause urinary tract infections in pregnant women in Abha, Saudi Arabia are provided by the study. The predominant isolates identified in this study were *Escherichia coli* and *Klebsiella pneumoniae*. They exhibited significant resistance to various antimicrobial agents, particularly ampicillin, amoxicillin, and co-trimoxazole. Therefore, culture and antibiotic susceptibility testing are recommended to rationalize antibiotic use and prevent the emergence of drug-resistant cases. For some isolated pathogens, the number of isolate was very small and thus the reported resistance or susceptibility patterns for these organisms should be interpreted with caution and may not be representative of the broader population. Based on real-life data, antimicrobial stewardship programs should be implemented, and formularies should be regularly updated to maximize therapeutic benefits and contain the development of resistant strains.

ADDITIONAL INFORMATION AND DECLARATIONS

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Competing Interests

The authors declare there are no competing interests.

Author Contributions

- Md Sayeed Akhtar conceived and designed the experiments, authored or reviewed drafts of the article, and approved the final draft.

- Ahmed Ali Muyidi analyzed the data, authored or reviewed drafts of the article, and approved the final draft.
- Reem Alqhtani analyzed the data, authored or reviewed drafts of the article, and approved the final draft.
- Faris Al Salem performed the experiments, prepared figures and/or tables, and approved the final draft.
- Ghassan Alqahtani performed the experiments, prepared figures and/or tables, and approved the final draft.
- Khalid Shaher performed the experiments, prepared figures and/or tables, and approved the final draft.
- Khalid Orayj conceived and designed the experiments, prepared figures and/or tables, and approved the final draft.
- Sultan Mohammed Alshahrani analyzed the data, prepared figures and/or tables, and approved the final draft.
- Sirajudeen Shaik Alavudeen conceived and designed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- Sadaf Farooqui analyzed the data, authored or reviewed drafts of the article, and approved the final draft.

Human Ethics

The following information was supplied relating to ethical approvals (i.e., approving body and any reference numbers):

The study protocol was reviewed and approved by the Regional Committee for Research Ethics, Ministry of Health, Aseer Region, Kingdom of Saudi Arabia (approval number: REC -7-2-2024).

Data Availability

The following information was supplied regarding data availability:

The raw measurements are available in the Supplemental Files.

Supplemental Information

Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.21928#supplemental-information.

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