

High gastrointestinal carriage rates of extended-spectrum- β -lactamase-producing enterobacterales and associated factors among hospitalized and nonhospitalized children in Kenya

Received: 21 August 2025

Accepted: 3 March 2026

Published online: 10 March 2026

Cite this article as: Githii S., Ndungu C., Maingi J.M. *et al.* High gastrointestinal carriage rates of extended-spectrum- β -lactamase-producing enterobacterales and associated factors among hospitalized and nonhospitalized children in Kenya. *Sci Rep* (2026). <https://doi.org/10.1038/s41598-026-43265-6>

Susan Githii, Cecilia Ndungu, John M. Maingi & Abednego Musyoki

We are providing an unedited version of this manuscript to give early access to its findings. Before final publication, the manuscript will undergo further editing. Please note there may be errors present which affect the content, and all legal disclaimers apply.

If this paper is publishing under a Transparent Peer Review model then Peer Review reports will publish with the final article.

High gastrointestinal carriage rates of extended-spectrum- β -lactamase-producing Enterobacterales and associated factors among hospitalized and nonhospitalized children in Kenya

Susan Githii^{1,4#}, Cecilia Ndungu^{2,4}, John M. Maingi³, Abednego Musyoki^{4#}

1. National Public Health Laboratory, 20750- 00202, Upperhill, Kenyatta National Hospital Grounds, Nairobi, Kenya
2. Department of Medical Laboratory, Murang'a County Referral Hospital, 69-10200, Murang'a, Kenya
3. Department of Biochemistry, Microbiology and Biotechnology, School of Pure and Applied Sciences, Kenyatta University, Nairobi, Kenya, 43844-00100, Nairobi, Kenya.
4. Department of Medical Laboratory Science, School of Health Sciences, Kenyatta University, Nairobi, Kenya, 43844-00100, Nairobi, Kenya.

#corresponding email address: susan.githii@yahoo.com,
musyoki.abednego@ku.ac.ke

Abstract

Background: Gastrointestinal carriage of extended-spectrum β -lactamase-producing Enterobacterales (ESBL-E) presents a critical public health threat globally. However, in resource-constrained countries with poor sanitation, inadequate drinking water, and limited microbiology laboratories like Kenya, epidemiological data of these strains is limited. This study assessed the gastrointestinal carriage of ESBL-E and the risk factors for colonization

among children (≤ 5 years) in the inpatient department (IPD) and outpatient department (OPD).

Method: This was a hospital-based cross-sectional study at Thika Level 5 Hospital, Kenya, from February to June 2023. In total, 540 participants (OPD: 270, IPD: 270) were recruited, using systematic random sampling and consecutive sampling in OPD and IPD, respectively. Children admitted for less than 48 hours in the paediatrics ward and those with a prior history of hospitalization (≤ 3 months) in OPD were excluded. Demographic data were collected using a well-structured questionnaire. Following the standard microbiology methods, stool or rectal swab samples were cultured, with the identity and antimicrobial susceptibility of isolates elucidated by automated platforms.

Results: The overall ESBL-E gastrointestinal carriage rate was 35.4% (191/540), and was highest among outpatients at 40.4% (109/270). Isolates demonstrated co-resistance to aminoglycosides (43-52%), quinolones (52-62%), carbapenems (44-50%), and sulfonamides (92-97%). They were more susceptible to piperacillin/tazobactam (67-95%) and colistin (96-99%). Carbapenemase-producing Enterobacterales (CPE) co-carriage rate was 17.6% (16/91), with similar rates for inpatients (50%, 8/16) and outpatients (50%, 8/16). *Escherichia coli* was the predominant ESBL-E overall (82.2%, 157/191), among outpatients (83.5%, 91/109), and inpatients (80.5%, 66/82), and was also the main CPE (overall: 81.3%, 13/16; OPD: 75%, 6/8; IPD: 87.5%, 7/8). Independent predictors of colonization included child age

(adjusted odds ratio (OR): 1.60, $p = 0.045$) and a history of antimicrobial use from retail pharmacies without a clinician's prescription (adjusted OR: 0.18, $p = 0.047$).

Conclusion: This study demonstrates a substantial burden of gastrointestinal carriage of ESBL-E and CPE co-carriage among children (≤ 5 years), with *E. coli* being the predominant organism. Age less than two years and a history of exposure to non-prescribed antimicrobials were independent factors for colonization. Efforts to limit exposure to contaminated environments and targeted antimicrobial stewardship initiatives are required to mitigate AMR in the current study setting.

Keywords: Gastrointestinal carriage, ESBL-producing Enterobacterales, co-resistance, carbapenemase-producing Enterobacterales, Risk factors

1.0 Background

Extended-spectrum β -lactamase (ESBL)-producing Enterobacterales (ESBL-E) pose a severe global health threat. The World Health Organization (WHO) designated these strains as "critical priority pathogens," highlighting the urgent need for new antimicrobial agents and effective surveillance to prevent their spread in clinical settings (1). ESBLs are potent, plasmid-encoded enzymes that inactivate β -lactam antimicrobials with oxyimino groups, such as oxyimino-cephalosporins and oxyimino-monobactams, but

not by cephamycins and carbapenems (2). Infections caused by Enterobacterales that produce ESBLs are associated with severe clinical outcomes, increased mortality rates, prolonged hospitalization, and higher healthcare costs (3) (4).

The global gastrointestinal carriage of ESBL-E is around 14%, with variation ranging from 2% to 46% among individuals based on geographical regions (5). A high carriage of 59% and 50.4% of ESBL-E in children residing in rural Africa, characterized by high poverty and suboptimal hygienic conditions, is documented (6) (7). The plasmid-borne-ESBL genes are frequently transmitted, facilitating swift spread among bacterial populations in hospital and community settings(8). ESBL genetic determinants are often found in mobile genetic elements, which carry genes that confer resistance to many antimicrobials, such as quinolones, aminoglycosides, tetracyclines, and trimethoprim/sulfamethoxazole. Consequently, ESBL-E frequently exhibit multidrug resistance phenotypes (9).

ESBL-E causes septicemia, intra-abdominal abscesses, urinary tract infections (UTIs), brain abscesses, and pneumonia, especially those acquired within hospital environments (10). Infections caused by bacteria carrying ESBLs are treated using carbapenem antimicrobials; however, the widespread use of this antimicrobial class has expedited the spread of

another significant group of β -lactamases known as carbapenemases. Improper and irrational utilization of antimicrobial drugs, inadequate sanitation, and suboptimal infection control practices, especially in developing countries, create favourable conditions for the emergence and dissemination of resistant microorganisms(11).

Enterobacterales naturally resides in the intestinal tracts of humans and animals; therefore, the gastrointestinal tract is the primary reservoir for ESBLs, allowing horizontal exchange among colonizing bacterial populations(12). The colonized individuals are at significant risk for subsequent infections and disseminating these 'superbugs' through environmental faecal contamination (12). In Kenya, as in many other resource-constrained countries, epidemiological data on ESBL-E faecal carriage is limited. This study investigated the gastrointestinal carriage rates and risk factors for ESBL-E colonization among children under five years seeking treatment in the outpatient department and those hospitalized at Thika Level 5 Hospital in Kenya.

2.0 Materials and Methods

2.1 Study setting, design, and population

This study was conducted at Thika Level 5 Hospital, a 467-bed public health facility with approximately 800 to 1000 daily outpatient workload. The facility

serves a large population catchment area, including Kiambu, Nairobi City, Muranga, Kirinyaga and Machakos counties.

A cross-sectional study design was adopted among children (≤ 5 years) admitted to the hospital's pediatric ward and those seeking healthcare services in the outpatient department (OPD). A total of 540 children, equally drawn from inpatient (hospitalized for at least 48 hours) and outpatient departments were recruited between February and June 2023. A systematic random sampling method was utilized in the OPD, where hospital records indicated that approximately 3,000 children (≤ 5 years) were anticipated during the 5-month study period. Therefore, every 11th child seeking treatment at the OPD was eligible for enrollment. In the inpatient department, consecutive sampling was adopted due to low number of children admitted (≥ 48 hours) in the pediatric ward during the study period.

The study excluded children admitted for less than 48 hours and outpatients with a prior history of hospitalization within three months of sampling to avoid those with healthcare-associated ESBL-E colonization. Informed consent was obtained from the parent or guardian of each participating child. Those who declined to give informed consent were excluded from the study.

2.2 Samples collection

A structured questionnaire was administered during face-to-face interviews to obtain demographic and clinical data from participants. Collected information included the child's age, gender, history, and sources of antimicrobial use, drinking water sources, and clinical presentation at the time of sample collection. Diarrhoea was defined as the passage of three or more loose or liquid stools per day (13). Data regarding antimicrobial use within the previous three months, drinking water sources, sources of antimicrobials, and dose completion behaviors were obtained from parents or guardians.

Stool samples were collected in clean, dry, wide-necked containers. For a child unable to provide a stool sample, a rectal swab was used as an alternative. Stool was prioritized as the preferred sample type due to its higher bacterial yield and reliability in detecting intestinal carriage. Rectal swabs served as a substitute when the selected child was unable to provide a stool sample; thus, maximizing participant inclusion and minimizing data loss. Eleven per cent (58/540) of the study samples were stool, while 89.3% (482/540) were swabs. All samples were placed in Cary-Blair transport medium (Hopebio, Qingdao, China) and transported in a cool box to the hospital's microbiology laboratory for processing within two hours.

2.3 Screening for ESBL-E gastrointestinal carriage

Stool samples and rectal swabs were inoculated onto MacConkey agar (Oxoid Limited, Basingstoke, Hampshire, UK) supplemented with ceftazidime (2 mg/mL) as previously described by Reddy and colleagues (14), and incubated aerobically at 37°C for 18 to 24 hrs. The resultant colonies were screened for ESBL production using the Double Disk Test. A bacterial suspension equivalent to 0.5 McFarland-equivalent standard was prepared and inoculated on Mueller-Hinton Agar (MHA), air-dried for 3 min, added cefotaxime (30 µg), ceftazidime (30 µg), and amoxicillin/clavulanic acid (20 µg/10 µg) discs at a 30 mm radius to radius distance. The plates were incubated overnight in ambient air at 37 °C. *Klebsiella pneumoniae* (American Culture Type Collection (ATCC) 700603 and *Escherichia coli* ATCC 25922 were used as quality control organisms. ESBL-producing isolates showed an inhibition zone surrounding the cefotaxime and/or ceftazidime that increased towards the β-lactam inhibitor (15).

2.3 Confirmation of ESBL production among isolates

The Phenotypic Confirmatory Disk Diffusion Test was used to confirm the ESBL-E following the 2023 Clinical and Laboratory Standards Institute (CLSI) guidelines (16). Bacterial suspensions equivalent to 0.5 McFarland standard were prepared and inoculated on MHA. Ceftazidime (30 µg) disk alone and in combination with clavulanic acid (30/10 µg), as well as cefotaxime (30 µg) disk alone and in combination with clavulanic acid (30/10

µg), were added, and the plates were incubated in ambient air for 16–18 hours at 37°C. Isolates that exhibited an increase of ≥ 5 mm in the zone of inhibition for either antimicrobial agent tested in combination with clavulanic acid compared to the zone diameter of the agent when tested alone were considered and confirmed as ESBL producers. This study used *E. coli* ATCC 25922 and *K. pneumoniae* ATCC 700603 as the negative and positive control organisms.

2.4 Isolates identification and antimicrobial susceptibility testing

The study identified ESBL-E isolates using the matrix-assisted laser desorption ionization-time of flight mass spectrometry ((MALDI-TOF MS) (Bruker Daltonik GmbH, Bremen, Germany)) and tested the isolates for antimicrobial susceptibility using VITEK2 (bioMK2 bi S.A., NS. A, Nu, Germany). CLSI (2023) guidelines informed the choice and interpretation of antimicrobial tested, including cefepime, ceftriaxone, cefuroxime, ceftazidime, cefotaxime, meropenem, ciprofloxacin, gentamicin, ampicillin, colistin, trimethoprim-sulfamethoxazole, piperacillin-tazobactam, and amikacin. *Pseudomonas aeruginosa* (ATCC 27853) and *E. coli* (ATCC 25922) served as the reference organisms for quality control. Multidrug resistance was defined as resistance to at least one antimicrobial in at least three classes(17).

2.5 Colistin susceptibility testing

Colistin susceptibility was tested using broth microdilution testing as recommended by the CLSI 2023 (16). Tubes containing calcium magnesium Muller Hinton Broth for each isolate were labelled 1, 2, 4 $\mu\text{g/ml}$ and 0 $\mu\text{g/ml}$ (control), corresponding to colistin discs added. The tubes were gently vortexed for 30 minutes to allow the colistin to elute from the disc. A 0.5 MacFarland standard suspension for the test organism was prepared, 50 μl added to the control tube (0 $\mu\text{g/ml}$) and the tubes labelled 1, 2 and 4 $\mu\text{g/ml}$. The original inoculum was inoculated on a blood agar plate using a ten (10) μl loop for purity check. The plates and tubes were incubated at 35°C for 16-20 hours. The purity plates were examined to ensure the inoculum was pure with the control tube (0 $\mu\text{g/ml}$) checked for turbidity, demonstrating the test validity. The minimum inhibition concentration (MIC) of ≤ 2 $\mu\text{g/ml}$ was interpreted as intermediate, whereas MIC ≥ 4 $\mu\text{g/ml}$ was resistant as per the CLSI, 2023 (16). The CLSI guideline only provides the “intermediate” and “resistance” but not “susceptible” interpretation for colistin susceptibility testing because the breakpoints are challenging to define due to variability in testing methods and clinical outcomes. Further, the lack of a clear “susceptible” category prevents misleading interpretations and ensures cautious use of colistin. *E. coli* ATCC 25922 and *P. aeruginosa* ATCC 27853 were used as control organisms.

2.5 Screening for carbapenemase production among carbapenem-resistant ESBL-E isolates

Carbapenem-resistant ESBL-E were screened for carbapenemase production using the modified carbapenem inactivation method (mCIM) (18). Each isolate was inoculated in 2 ml of Trypticase Soy Broth (TSB) (HiMedia, India) that contained 10 µg of meropenem, and the cultures were incubated at 30-35°C for 4 hours. After incubation, a suspension of *E. coli* (ATCC 25922) was prepared in sterile saline to achieve a suspension density equivalent to the 0.5 McFarland standard. The suspension was then spread onto Mueller-Hinton agar (MHA) and the meropenem disk was retrieved from the TSB culture containing the test organism and placed on the agar. The plates were incubated for 18-24 hours at 35°C. Results were interpreted based on the inhibition zone diameters as outlined by the Clinical and Laboratory Standards Institute (CLSI) (16). An inhibition zone diameter of 6-15 mm was considered a positive result, while a diameter of ≥ 19 mm was classified as negative. For quality control purposes, *E. coli* (ATCC 25922) served as the negative control, and *K. pneumoniae* (ATCC 1705) served as the positive control.

2.6 Statistical analysis

The Stata version 13 (STATA Corporation, College Station, TX, USA) was used for data analysis. Categorical data is presented in frequencies and percentages, whereas continuous data in means and medians in tables. The spectrum of ESBL isolates is illustrated in the figures, while the antimicrobial susceptibility profiles are presented in tables. Binary logistic regression

(BLR) was used to determine association between asymptomatic faecal carriage of ESBL-E and patient type (inpatient vs. outpatient). Additionally, BLR was conducted to determine the association between the gastrointestinal carriage of ESBL-E and the demographic and clinical characteristics of the participants. Associations with p-values of ≤ 0.2 were further analyzed using multivariate regression to assess the independence of these associations. Statistically significant results were defined as having a p-value of ≤ 0.05 within a 95% confidence interval (95% CI). Carbapenem resistance was defined as resistance to meropenem (≥ 4 $\mu\text{g/ml}$).

3.0 Results

3.1 Demographic and clinical characteristics of study participants

This study sampled 540 children (≤ 5 years), equally drawn from outpatient department (OPD: 50%, 270/540) and inpatient departments (IPD: 50%, 270/540). The majority of the participants were males (51.9%, 280/540) and aged ≤ 24 months (75%, 405/540). Only 25.7% (139/540) of the participants presented with diarrhoea, Table 1. Most of the participants had a history of antimicrobial use with 3 months of this study (62.4%, 338/540) and relied on municipal water for domestic use (91.7%, 495/540).

Table 1: *Demographic and clinical characteristics of inpatient and outpatient children (≤ 5 years) at Thika Level 5 Hospital, February - June 2023*

Variable	Category	All participants N=540 (%)	Inpatient s, n=270 (%)	Outpatient ts, n=270 (%)
----------	----------	-------------------------------	------------------------------	--------------------------------

Age {IQR: 12(6-24)} months				
	<i>≤24 months</i>	405(75.0)	207(76.7)	198(73.3)
	<i>>24 months</i>	135(25.0)	63(23.3)	72(26.7)
Gender				
	<i>Male</i>	280(51.9)	136(50.4)	144(53.3)
	<i>Female</i>	260(48.1)	134(49.6)	126(46.7)
Clinical presentation				
	<i>Vomiting</i>	148(27.4)	49(18.1)	99(36.7)
	<i>Chills</i>	16(3.0)	3(1.1)	13(4.8)
	<i>Diarrhoea</i>	139(25.7)	42(15.6)	97(35.9)
	<i>Headache</i>	5(0.9)	3(1.1)	2(0.7)
	<i>Respiratory illness</i>	220(40.7)	76(28.1)	144(53.3)
	<i>Fever</i>	204(37.8)	68(25.2)	136(50.4)
History of antimicrobials use in the past 3		338(62.4)	146(54.1)	192(71.1)
Participants administered with clinician's prescribed antimicrobials		75(13.9)	38(14.1)	37(13.7)
Source of antimicrobials used				
	<i>Retail pharmacy</i>	72(13.3)	37(25.3)	35(13.0)
	<i>Healthcare facility</i>	266(49.3)	109(40.4)	157(58.1)
Sourced antimicrobials from retail pharmacy with clinician's prescription		72(12.6)	37(13.7)	35 (13.0)
Completed the last antimicrobial dose		304(56.3)	196(72.6)	108(40.0)
Source of domestic water				
	<i>Municipal water</i>	495(91.7)	254(94.1)	241(89.3)
	<i>Borehole water</i>	45(8.3)	16(5.9)	29(10.7)

IQR: interquartile range

3.2 Gastrointestinal carriage of extended-spectrum beta-lactamase-producing Enterobacterales

In this study, the overall gastrointestinal carriage of ESBL-E was 35.4%, 95% CI: 31.3–39.4% (191/540). There was no co-carriage of ESBL-E among the study participants. Among outpatients, the rate was 40.4% (95% CI: 34.5–46.2% (109/270)), 1.55 times higher than 30.4% among the inpatient (95% CI: 24.9–35.9% (82/270)). This difference was statistically significant (odds ratio = 1.55, 95% CI: 1.09–2.21, $p = 0.015$ (Table 2)).

Table 2: *Gastrointestinal carriage of ESBL-E among inpatient and outpatient children (≤ 5 years) at Thika Level 5 Hospital, February - June 2023*

Patient type	ESBL-E carriage		Odds ratio (95%CI)	P- value
	Present n(%)	Absent n(%)		
Outpatients	109 (40.4)	161 (59.6)	1.55(1.09 - 2.21)	0.015
Inpatients	82 (30.4)	188 (69.6%)	Ref	
Overall	191(35.4)	349(64.6)		

A total of four ESBL-E species were recovered from the inpatients, with *E. coli* (66/270, 24.4%) as the predominant isolate (Fig.1). Seven ESBL-E species were recovered, including four species (*Citrobacter freundii*, *Citrobacter farmeri*, *Citrobacter yongae*, and *Enterobacter bugandensis*) that were distinct from those isolated from inpatients. ESBL-producing *Klebsiella variicola* was not found among outpatients. As observed among inpatients, *E. coli* was the most common ESBL-E (91/270, 33.7%), Fig 1.

Figure 1: *Gastrointestinal carriage of ESBL-E among inpatient and outpatient children (≤ 5 years) at Thika Level 5 Hospital, February - June 2023.* **ESBL-E:** extended spectrum beta-lactamase-producing Enterobacterales, **OPD** outpatient department, **IPD** inpatient department, %: percentage

3.3 Antimicrobial susceptibility profiles of ESBL-E isolates

Due to the limited number of isolates, the antimicrobial resistance (AMR) for *C. freundii* (n=4), *C. farmeri* (n=1), *Citrobacter yongae* (n=1), *E.*

bugandensis (n=1), *K. variicola* (n=1), and *Morganella morganii* (n=2) was not determined; however, their antimicrobial susceptibility results are shown in Supplementary Table S1. Co-resistance levels among extended-spectrum β -lactamase-producing *K. pneumoniae* (ESBL-Kp) and extended-spectrum β -lactamase-producing *E. coli* (ESBL-Ec) were high for aminoglycosides (43-52%), carbapenem (44-50%), quinolones (52-62%), and sulfonamides (92-97%), as detailed in Table 3. In contrast, the lowest co-resistance was seen with colistin (1-4%) and the β -lactam/ β -lactamase inhibitor piperacillin/tazobactam (TZP), which had resistance rates of 10-24%. Notably, TZP resistance was highest among ESBL-Kp isolates from inpatients (24%), Table 3.

Table 3: Antimicrobial co-resistance of ESBL- producing *E. coli* and *K. pneumoniae* isolates from inpatient and outpatient children (≤ 5 years) at Thika Level 5 Hospital, February - June 2023

Antimicrobial class	Antimicrobial agent	<i>E. coli</i>			<i>K. pneumoniae</i>		
		All n=157 (%)	OPD n=91 (%)	IPD n=66 (%)	All n=25 (%)	OPD n=15 (%)	IPD n=10 (%)
Penicillin	ampicillin	152(97)	88(56)	64(41)	25(100)	10(40)	15 (60)
	TZP	16(10)	5 (3)	11(7)	6(24)	1(4)	5(20)
2GC	cefuroxime	155(99)	89(57)	66(42)	25(100)	10(40)	15(60)
3GC	cefotaxime	154(98)	88(56)	66(42)	25(100)	10(40)	15(60)
4GC	cefepime	130(83)	78(50)	52(33)	21(84)	8(32)	13(52)
AMI	amikacin	68(43)	50(32)	18(11)	13(52)	6(24)	7(28)
	gentamicin	73(46)	51(32)	22(14)	12(48)	5(20)	7(28)
Quinolones	ciprofloxacin	97(62)	65(41)	32(20)	13(52)	0(0)	13(52)
Sulfonamides	SXT	153(97)	91(58)	62(39)	23(92)	9(36)	14 (56)

Carbapenem	meropenem	79(50)	43(27.4)	36(22.9)	11(44)	4(16)	7(28)
Polymyxins	colistin	1(1)	1(1)	0(0)	1(4)	1(4)	0(0)

OPD outpatient department, **IPD** inpatient department, **2GC** second-generation cephalosporin, **3GC** third-generation cephalosporin, **4GC** fourth-generation cephalosporin, **AMI** aminoglycosides, **TZP** piperacillin/tazobactam, **SXT** Trimethoprim/sulfamethoxazole.

3.4 Co-carriage of ESBL-E and CPE

Overall, 47.6% (91/191) of ESBL-E in this study were carbapenem-resistant (CR). Of these, sixteen isolates were carbapenemase-producing Enterobacterales (CPE), translating into a co-carriage rate of 17.6% (16/91). The CPE/ESBL-E co-carriages were similarly distributed among inpatients (50.0%, 7/16) and outpatients (50.0%, 8/16), Fig. 2. *E. coli* was the most common ESBL-E/CPE co-carrying isolate overall (81.3%, 13/16) among (OPD: 75%, 6/8), and among IPD (87.5%, 7/8), Fig. 2.

Figure 2: Co-carriage of ESBL-E and CPE among inpatient and outpatient children (≤ 5 years) at Thika Level 5 Hospital, February - June 2023. **ESBL-E:** extended spectrum beta-lactamase-producing Enterobacterales, **CPE:** carbapenemase-producing Enterobacterales, **%:** percentage, **OPD:** outpatient department, **IPD:** inpatient department

3.5 Risk factors associated with gastrointestinal carriage of ESBL-E

Children aged 24 months or younger were found to be twice as likely to have gastrointestinal colonization with ESBL-E compared to those older than 24 months, with an adjusted odds ratio (OR) of 1.60 (95% CI: 1.01 - 2.38, $p = 0.045$), Table 4. Additionally, outpatients who purchased antimicrobials from retail pharmacies with a clinician's prescription were 82% less likely to harbor ESBL-E compared to those who bought the antimicrobials from such drug stores without a prescription (adjusted OR of 0.18 (95% CI: 0.03 - 0.97, $p = 0.047$), Supplementary Table S2.

Table 4: *Factors associated with the gastrointestinal carriage of the ESBL-E among children (≤ 5 years) at Thika Level 5 Hospital, February - June 2023*

Characteristic	Total, n(%)	ESBL-E		Crude OR (95%CI)	P-value	Adjusted OR (95%CI)	P-value
		Yes n(%)	No n(%)				
Age							
≤ 24 months	405(75.0)	149(80.1)	256(72.3)	1.54(1.01 - 2.37)	0.048*	1.60(1.01 - 2.38)	0.045*
>24 months	135(25.0)	37(19.9)	98(27.7)	Ref			
Gender							
Male	280(51.7)	93(50.0)	186(52.7)	0.90(0.63 - 1.28)	0.584		
Female	260(48.3)	93(50.0)	168(47.3)	Ref			
Clinical presentation							
Vomiting							
Yes	148(27.4)	49(26.3)	99(28.0)	0.92(0.62 - 1.38)	0.761		
No	392(72.6)	137(73.7)	255(72.0)	Ref			
Chills							
Yes	16(3.0)	5(2.7)	11(3.1)	0.86(0.29 - 2.51)	0.506		
No	524(97.0)	181(97.3)	343(96.9)	Ref			
Diarrhoea							
Yes	139(25.8)	46(24.7)	93(26.3)	0.92(0.61 - 1.38)	0.756		

No	401(74.2)	140(75.3)	261(73.7)	Ref			
Headache							
Yes	5(0.9)	1(0.5)	4(1.1)	0.47(0.05 - 4.24)	0.664		
No	535(99.1)	186(99.5)	349(98.9)	Ref			
Respiratory illness							
Yes	220(40.7)	77(41.4)	143(40.6)	1.03(0.72 - 1.48)	0.927		
No	320(59.3)	110(58.8)	210(59.5)	Ref			
Fever							
Yes	204(38.0)	63(33.9)	141(40.2)	0.76(0.53 - 1.11)	0.162	0.77(0.53 - 1.12)	0.165
No	333(62.0)	123(66.1)	210(59.5)	Ref			
Antibiotics use history in the past 3 months							
Yes	338(62.5)	112(60.2)	226(63.8)	0.86(0.60 - 1.24)	0.454		
No	202(37.5)	74(39.8)	128(36.2)	Ref			
Source of antimicrobials							
Retail pharmacy	72(21.3)	22(19.8)	50(22.0)	0.99(0.58 - 1.71)	0.55		
Healthcare facility pharmacy	266(78.7)	89(80.2)	177(78.0)	Ref			
Participants that administered clinician's prescribed antimicrobials							
Yes	34(45.3)	11(44.0)	23(46.0)	0.92(0.35 - 2.42)	0.534		
No	41(54.7)	14(56.0)	27(54.0)	Ref			
Completed the last antimicrobial dose							
Yes	304(56.3)	109(56.8)	195(56.0)	0.94(0.67 - 1.36)	0.855		
No	236(43.7)	83(43.2)	153(44.0)	Ref			
Source of water							
Municipal water							
Yes	495(91.7)	168(90.3)	327(92.4)	0.77(0.41 - 1.44)	0.417		
No	45(8.3)	18(9.7)	27(7.6)	Ref			
Borehole water							
Yes	45(8.3)	18(9.7)	27(7.6)	1.30(0.70 - 2.42)	0.417		
No	495(91.7)	168(90.3)	327(92.4)	Ref			

OR: Odds ratio, **Ref:** Reference category, *Significant at 0.05.

4.0 Discussion

In this study, the overall gastrointestinal carriage rate of ESBL-E was 35.4% (191/540). This rate is comparable to 34.3% (207/603) reported among children in Dar es Salaam, Tanzania (7) and 37% among children under five years of age from hospitals and community settings in the Gaza Strip, Palestine(19). Our observed ESBL-E carriage rate is lower than the 40.3% faecal carriage observed in rural Tanzania among patients with urinary tract infections (20). Among inpatients in our study, the ESBL-E carriage rate was 30.4%, 95% CI: 24.9-35.9% (82/270), meaning that one in every three hospitalized patients harbored ESBL-producing organisms. Our inpatient carriage rate is notably higher than the 10% (59/569) reported among neonates (0-28 days) at the point of admission in Kilifi, Kenya(21), and the 21.1% rate for inpatients reported in a systematic review and meta-analysis of global prevalence and trends of human intestinal carriage of ESBL-Ec (22). However, our inpatient rate is lower than 39.1% reported in Gaza Strip in Palestine(19) and 50.4% in Dar es Salaam, Tanzania (7) among children (< 2 years). Additionally, it was lower than 44% carriage rate for ESBL-producing *E. coli* among children (1-59 months) in Kisii and Homa Bay hospitals, Kenya, as reported by Tornberg-Belanger et al. (23), and the 62.9% (154/245) rate for *Klebsiella* spp. isolates at discharge in the same Kenyan hospitals (24). Our study indicates a high rate of community transmission of multidrug-resistant bacteria. Additional research is needed to identify the sources of these resistant bacterial strains within the community in order to inform AMR control programs.

Further, the ESBL-E carriage rate observed in our study was lower than reported by Edwards et al. (50%, 9/18) among neonates sampled between 1 and 46 days post admission in Kisumu, Kenya (25), and lower than the post-acquisition levels (55%) reported among neonates (1-59 months) admitted to a neonatal ward in Kilifi, Kenya (21). ESBL-E colonization rates have been associated with longer hospital stays and antimicrobial use (24). The differences in hospital stays in the current study and others in Kenya could have impacted the carriage rate levels. Hospital environments are known reservoirs of MDR organisms, with prolonged hospitalization likely to increase the risk of colonization and infection.

The ESBL-E carriage rate among outpatients was 40.4% (95% CI: 34.5-46.2%; 109/270), which is similar to the 43% (159/366) found in rural children aged 2 and 5 years in the Somali region of Ethiopia(26). This rate in our study is higher than the 10% (59/569) reported among neonates (0-28 days) at admission in Kilifi, Kenya (21), 11.6% among children under 2 years in Dar es Salaam, Tanzania(7), 17.1% (46/269) for ESBL-producing *E. coli* and *K. pneumoniae* among children under five in Addis Ababa, Ethiopia (28), and 35.1% among children under five in Gaza Strip, Palestine(19).

Even though colonization by MDR organisms is expectedly higher in hospital settings(30), outpatients in our study exhibited a higher ESBL-E carriage rate

than inpatients. Notably, a recent systematic review and meta-analysis highlighted a sharper annual increase in intestinal carriage of ESBL-producing *E. coli* within the community (1.5% per year) compared to healthcare settings (1.3% per year) (22). Globally, community carriage rates escalated dramatically, rising from just 2.6% in 2001 to 26.4% in 2016—a tenfold surge. Meanwhile, in healthcare environments, prevalence climbed from 7% to 25.7% during the same period (22). These patterns underscore an accelerating burden of ESBL-E in community settings, which provides important context for the findings of the present study. The high community-level carriage suggests community dissemination of ESBL genes, likely driven by antimicrobial misuse, poor sanitation, and unregulated access to antimicrobials. In general, the observed discrepancies in the ESBL carriage rates in the current study and previous ones suggest differences in the study population, variations in adherence to antimicrobials stewardship and infection prevention and control programs, sanitary conditions, and ESBL detection methods(31) (32). The high ESBL-E faecal carriage in developing countries may be attributable to substandard hygiene conditions and the inappropriate use of antimicrobials, particularly when antimicrobials are sold over the counter without a prescription by clinicians (33).

In the in- and outpatients, *E. coli* (inpatients: 66/83, 79.5%); outpatients: 91/109, 83.5%) was the predominant ESBL-E. These results are comparable with the previous studies in Ethiopia, (34), Tanzania(20), Burkina Faso (35),

Netherlands(36), Uganda(37), and Turkey (38) but contradict other study reports in Ethiopia and Uganda(39), where *K. pneumoniae* was the predominant ESBL producer compared to *E. coli*. *E. coli* is the most abundant facultative anaerobe of the human gastrointestinal tract (GIT) microflora that causes disease in immunocompromised individuals and those with breached GIT integrity, except clones that have acquired specific virulence attributes that allow them to cause a broad spectrum of disease (40). The high faecal carriage of ESBL-producing *E. coli* and *K. pneumoniae* observed in the current study presents a critical public health threat, especially in settings with poor adherence to infection prevention and control measures and inadequate microbiology laboratory capacity and sanitation. GIT colonization with ESBL-producing may precede infections, with the colonized patients serving as silent reservoirs for transmission of AMR traits(41), and infections are frequently associated with increased morbidity, mortality, length of hospitalization, and healthcare costs(4) (3).

ESBL-producing *E. coli* and *K. pneumoniae* isolates showed high co-resistance to ampicillin (97%) and increased susceptibility (90%) to the tested β -lactam/ β -lactamase inhibitor, piperacillin/tazobactam (TZP). Inhibitor resistance was highest among inpatient isolates (7-20%) compared to outpatients (3-4%). As expected, resistance to β -lactam/ β -lactamase inhibitors was lower than to β -lactams alone, as these inhibitors target serine β -lactamase enzymes (42). However, our findings indicate notable

tazobactam resistance in both *E. coli* and *K. pneumoniae*. Like other first-generation inhibitors such as clavulanic acid and sulbactam, tazobactam inhibits Ambler class A enzymes(42). This may explain the observed resistance and suggests possible over-reliance on β -lactam/ β -lactamase inhibitors in this setting.

Nearly half (47.6%, 91/191) of all ESBL-E isolates in this study were carbapenem-resistant (CR). This is higher than the 31.1% prevalence reported among ESBL-E isolates from children (aged <1 year) in the Gaza Strip (19). In our study, 16.5% (15/91) of CR isolates were carbapenemase producers, with a similar distribution among inpatients (16.3%, 7/43) and outpatients (16.7%, 8/48). The co-carriage rate of ESBL-E and carbapenemase-producing Enterobacteriales (CPE) among inpatients was lower than what was observed among neonates at discharge in Kisumu, Kenya (33.3%, 6/18) and Ibadan, Nigeria (79.2%, 18/24) (25). However, the co-carriage in our study was higher than the 2.9% reported among inpatients and outpatients in five hospitals in Burkina Faso, where over 54.9% of the study population were children under 15 years old, including 78% of infants (43). These findings suggest a substantial reservoir of carbapenem-resistant ESBL-E in both hospital and community settings. This poses significant infection control and antimicrobial stewardship challenges, such as an increased risk of hard-to-treat infections and the potential for transmission. Notably, the CR ESBL-E isolates in this study showed low resistance to

colistin, with susceptibility rates between 96% and 99%. Kanwalpreet et al. also reported a similarly low colistin resistance (5.6%) in Gram-negative bacteria (44). These results suggest that colistin retains clinical value for treating CR ESBL-E infections in our setting. Use of newer agents for infections caused by CR bacteria—including cefiderocol, imipenem-cilastatin-sulbactam, ceftazidime-avibactam, meropenem-vaborbactam, ceftolozane-tazobactam, eravacycline, and plazomicin—is limited by high cost, restricted availability, and a lack of comprehensive clinical data (45).

This study found that children aged 24 months or younger had significantly higher odds of gastrointestinal colonization with ESBL-E. This aligns with previous research demonstrating that age is a major risk factor for ESBL-E carriage, with the highest vulnerability observed among infants under one year (7) (46). During this early developmental stage, frequent hand-to-mouth behavior and poor hygiene practices—particularly in crawling children who come into contact with contaminated surfaces—create ideal conditions for acquiring drug-resistant bacteria (47). Other factors such as healthcare exposure within the previous six months further could have increased the likelihood of colonization, consistent with earlier studies showing that repeated contact with healthcare settings facilitates the acquisition and transmission of ESBL-E (21, 45). Additional factors identified in other studies, such as the use of indwelling devices and consumption of untreated water

sources like boreholes, similarly highlight how environmental and clinical exposures compound the risk of colonization (46).

Among outpatients in the present study, a history of non-prescribed antimicrobial use was associated with an 82% higher likelihood of ESBL-E carriage. This finding is consistent with global evidence indicating that inappropriate antimicrobial access and use are major drivers of antimicrobial resistance. A recent scoping review estimated that 62% of antimicrobial use worldwide occurs without a prescription (48). In regions with limited regulatory oversight and weak antimicrobial stewardship—such as many parts of sub-Saharan Africa—non-prescription antimicrobial use is particularly pervasive (49). For example, one review reported that 69% of requests for antimicrobials were dispensed without prescription or consultation (50). Such practices promote selective pressure favouring resistant organisms and accelerate community spread of AMR (51). Taken together, the findings of this study reinforce existing evidence that younger age and inappropriate antimicrobial use all contribute meaningfully to ESBL-E colonization in children.

5.0 Study limitations

This study has several limitations. It was conducted in a single hospital, which may limit the generalizability of the findings to other settings. Molecular

characterization of isolates was not performed due to limited laboratory capacity, preventing identification of specific ESBL genes and clonal relationships. Reliance solely on phenotypic methods may have reduced diagnostic sensitivity compared to molecular techniques. Additionally, variability in sample types-rectal swabs may underestimate colonization compared with stool samples- and the cross-sectional design may have influenced the accuracy of colonization estimates and limited the ability to assess temporal trends. Despite these limitations, the findings provide valuable baseline data on ESBL-E carriage and resistance profiles, contributing to antimicrobial stewardship efforts and highlighting the need for larger, multicentric, and molecular-based studies to better understand the epidemiology of ESBL-producing bacteria.

6.0 Conclusion

This study demonstrates a substantial burden of gastrointestinal carriage of extended-spectrum β -lactamase-producing *Enterobacterales* and co-carriage with carbapenemase-producing *Enterobacterales* among children aged five years and below, with *E. coli* being the predominant organism. Younger children—particularly those aged 24 months or less—and those with a history of exposure to non-prescribed antimicrobials were significantly more likely to be colonized.

To mitigate the spread of multidrug-resistant organisms and protect young children from preventable colonization and subsequent infections, interventions should prioritize strengthening hygiene practices in early childhood settings, households, and hospitals, limiting children's exposure to contaminated environments. At the same time, targeted antimicrobial stewardship initiatives are essential, including community education on the risks of over-the-counter antimicrobial use, improved regulation of antimicrobial access, and enhanced counselling by healthcare providers.

Abbreviations

WHO World Health Organization

AST Antimicrobial Susceptibility Testing

CLSI Clinical and Laboratory Standards Institute

MALDI-TOF MS Matrix assisted laser desorption ionization-time of flight mass spectrometry

MDR Multidrug-drug resistant

ESBL Extended-spectrum beta-lactamases

ESBL-E Extended-spectrum beta-lactamases producing Enterobacterales

OPD Outpatient Department

IPD Inpatient Department

Declarations**Ethics approval and consent to participate.**

The study was approved by Kenyatta University's ethical research committee (Protocol Approval No. PKU/2620/E1745) as well as the National Commission of Science, Technology, and Innovation (NACOSTI). Approval for collection of samples was obtained from Ethical Research Committee, Thika Level 5 hospital. An informed consent was obtained from parent or guardian of each child before participating in this study. The research project was conducted in accordance with the Declaration of Helsinki, prioritizing participants' well-being and ensuring timely communication of critical findings to the doctors responsible for the patients. Each patient was assigned a unique Personal Identification Number (PIN) for anonymity, and all information collected was kept confidential. Participants in the study received no monetary compensation, and there were no penalties for those who chose not to participate.

Consent for Publication

Not applicable.

Availability of data and materials

The datasets utilized in this study can be acquired from the corresponding author upon request.

Competing interests

The authors state that they do not have any conflicts of interest.

Funding

This study did not receive financial support from any funding agencies.

Author contributions

SG, JM and AM conceived and developed the study, interpreted the data, and drafted the manuscript; CN assisted in laboratory work. All authors read and approved the final manuscript.

Authors' details

1. National Public Health Laboratory, 20750- 00202, **Upperhill, Kenyatta National Hospital Grounds**
2. Department of Medical Laboratory, Murang'a County Referral Hospital, 69-10200, Murang'a, Kenya
3. Department of Biochemistry, Microbiology and Biotechnology, School of Pure and Applied Sciences, Kenyatta University, Nairobi, Kenya, 43844-00100, Nairobi, Kenya.
4. Department of Medical Laboratory Science, School of Health Sciences, Kenyatta University, Nairobi, Kenya, 43844-00100, Nairobi, Kenya.

References

1. WHO. WHO bacterial priority pathogens list, 2024: Bacterial pathogens of public health importance to guide research, development and strategies to prevent and control antimicrobial resistance [Internet]. [cited 2025 Apr 22]. Available from: <https://www.who.int/publications/i/item/9789240093461>
2. Sawa T, Kooguchi K, Moriyama K. Molecular diversity of extended-spectrum β -lactamases and carbapenemases, and antimicrobial resistance. *Journal of Intensive Care*. 2020 Jan 28;8(1):13.

3. Rozenkiewicz D, Esteve-Palau E, Arenas-Miras M, Grau S, Duran X, Sorlí L, et al. Clinical and Economic Impact of Community-Onset Urinary Tract Infections Caused by ESBL-Producing *Klebsiella pneumoniae* Requiring Hospitalization in Spain: An Observational Cohort Study. *Antibiotics (Basel)*. 2021 May 15;10(5):585.
4. Ling W, Paterson DL, Harris PNA, Furuya-Kanamori L, Edwards F, Laupland KB. Mortality, hospital length of stay, and recurrent bloodstream infections associated with extended-spectrum beta-lactamase-producing *Escherichia coli* in a low prevalence region: A 20-year population-based large cohort study. *International Journal of Infectious Diseases*. 2024 Jan 1;138:84–90.
5. Karanika S, Karantanos T, Arvanitis M, Grigoras C, Mylonakis E. Fecal Colonization With Extended-spectrum Beta-lactamase-Producing Enterobacteriaceae and Risk Factors Among Healthy Individuals: A Systematic Review and Metaanalysis. *Clinical Infectious Diseases*. 2016 Aug 1;63(3):310–8.
6. Farra A, Frank T, Tondeur L, Bata P, Gody JC, Onambele M, et al. High rate of faecal carriage of extended-spectrum β -lactamase-producing Enterobacteriaceae in healthy children in Bangui, Central African Republic. *Clin Microbiol Infect*. 2016 Oct;22(10):891.e1-891.e4.
7. Tellevik MG, Blomberg B, Kommedal Ø, Maselle SY, Langeland N, Moyo SJ. High Prevalence of Faecal Carriage of ESBL-Producing Enterobacteriaceae among Children in Dar es Salaam, Tanzania. *PLoS One*. 2016;11(12):e0168024.
8. Zhang S, Yang J, Abbas M, Yang Q, Li Q, Liu M, et al. Threats across boundaries: the spread of ESBL-positive Enterobacteriaceae bacteria and its challenge to the “one health” concept. *Front Microbiol [Internet]*. 2025 Feb 21 [cited 2025 Nov 10];16. Available from: <https://www.frontiersin.org/journals/microbiology/articles/10.3389/fmicb.2025.1496716/full>
9. Partridge SR, Kwong SM, Firth N, Jensen SO. Mobile Genetic Elements Associated with Antimicrobial Resistance. *Clin Microbiol Rev*. 2018 Oct;31(4):e00088–17.
10. Denkel LA, Maechler F, Schwab F, Kola A, Weber A, Gastmeier P, et al. Infections caused by extended-spectrum β -lactamase-producing Enterobacterales after rectal colonization with ESBL-producing *Escherichia coli* or *Klebsiella pneumoniae*. *Clinical Microbiology and Infection*. 2020 Aug 1;26(8):1046–51.
11. Moyo P, Moyo E, Mangoya D, Mhango M, Mashe T, Imran M, et al. Prevention of antimicrobial resistance in sub-Saharan Africa: What has worked? What still needs to be done? *Journal of Infection and Public Health*. 2023 Apr 1;16(4):632–9.
12. Ruh E, Zakka J, Hoti K, Fekrat A, Guler E, Gazi U, et al. Extended-spectrum β -lactamase, plasmid-mediated AmpC β -lactamase, fluoroquinolone resistance, and decreased susceptibility to carbapenems in Enterobacteriaceae: fecal carriage rates and associated risk factors in the community of Northern Cyprus. *Antimicrobial Resistance & Infection Control*. 2019 Jun 10;8(1):98.

13. Diarrhoeal disease [Internet]. [cited 2025 Nov 20]. Available from: <https://www.who.int/news-room/fact-sheets/detail/diarrhoeal-disease>
14. Reddy P, Malczynski M, Obias A, Reiner S, Jin N, Huang J, et al. Screening for extended-spectrum beta-lactamase-producing Enterobacteriaceae among high-risk patients and rates of subsequent bacteremia. *Clin Infect Dis*. 2007 Oct 1;45(7):846-52.
15. Mutua JM, Njeru JM, Musyoki AM. Extended-spectrum β -lactamase-producing gram-negative bacterial infections in severely ill COVID-19 patients admitted in a national referral hospital, Kenya. *Annals of Clinical Microbiology and Antimicrobials*. 2023 Oct 14;22(1):91.
16. CLSI M100-Ed33 - Performance Standards for Antimicrobial Susceptibility Testing - 33rd Edition [Internet]. [cited 2024 Aug 30]. Available from: <https://webstore.ansi.org/standards/clsi/clsim100ed33?srsId=AfmBOortXni7qSjZdZMENmqTSIW9mkzEbEc1SjsqoUx6JMzduNZF1TeU>
17. Aklilu A, Manilal A, Ameya G, Woldemariam M, Siraj M. Gastrointestinal Tract Colonization Rate of Extended-Spectrum Beta-Lactamase- and Carbapenemase-Producing Enterobacteriaceae and Associated Factors Among Hospitalized Patients in Arba Minch General Hospital, Arba Minch, Ethiopia. *Infect Drug Resist*. 2020;13:1517-26.
18. Mutuma CK, Maingi J, Maina AK, Njeru J, Musyoki AM. Asymptomatic gastrointestinal carriage of multidrug-resistant carbapenemase-producing Enterobacteriaceae among children under five years in a Kenyan hospital. *IJID Regions*. 2023 Dec 1;9:25-31.
19. El Aila NA, Laham NAA, Ayesh BM, Naas T. Fecal carriage of extended-spectrum β -lactamase-producing enterobacteriales from hospitals and community settings in Gaza Strip, Palestine. *BMC Microbiology*. 2023 Nov 30;23(1):376.
20. Macha ME, Qi W, Seiffert SN, Bösch A, Kohler P, Urassa HM, et al. High prevalence of fecal carriage of extended-spectrum beta-lactamase producing Enterobacteriales among patients with urinary tract infections in rural Tanzania. *Front Microbiol* [Internet]. 2025 Jan 6 [cited 2025 Nov 14];15. Available from: <https://www.frontiersin.org/journals/microbiology/articles/10.3389/fmicb.2024.1517182/full>
21. Kagia N, Kosgei P, Ooko M, Wafula L, Mturi N, Anampiu K, et al. Carriage and Acquisition of Extended-spectrum β -Lactamase-producing Enterobacteriales Among Neonates Admitted to Hospital in Kilifi, Kenya. *Clin Infect Dis*. 2019 Aug 16;69(5):751-9.
22. Bezabih YM, Bezabih A, Dion M, Batard E, Teka S, Obole A, et al. Comparison of the global prevalence and trend of human intestinal carriage of ESBL-producing *Escherichia coli* between healthcare and community settings: a systematic review and meta-analysis. *JAC Antimicrob Resist*. 2022 Jun 2;4(3):dlac048.

23. Tornberg-Belanger SN, Rwigy D, Mugo M, Kitheka L, Onamu N, Ounga D, et al. Antimicrobial resistance including Extended Spectrum Beta Lactamases (ESBL) among *E. coli* isolated from Kenyan children at hospital discharge. *PLOS Neglected Tropical Diseases*. 2022 Mar 31;16(3):e0010283.
24. Rwigy D, Nyerere AK, Diakhate MM, Kariuki K, Tickell KD, Mutuma T, et al. Phenotypic and molecular characterization of β -lactamase-producing *Klebsiella* species among children discharged from hospital in Western Kenya. *BMC Microbiology*. 2024 Apr 23;24(1):135.
25. Edwards T, Williams CT, Olwala M, Andang'o P, Otieno W, Nalwa GN, et al. Molecular surveillance reveals widespread colonisation by carbapenemase and extended spectrum beta-lactamase producing organisms in neonatal units in Kenya and Nigeria. *Antimicrob Resist Infect Control*. 2023 Feb 22;12:14.
26. Muhammed A, Alemu A, Hosch S, Osman Y, Tschopp R, Yersin S, et al. Fecal carriage of ESBL-producing *E. coli* and genetic characterization in rural children and livestock in the Somali region, Ethiopia: a one health approach. *Antimicrobial Resistance & Infection Control*. 2024 Dec 18;13(1):148.
27. Bezabih YM, Bezabih A, Dion M, Batard E, Teka S, Obote A, et al. Comparison of the global prevalence and trend of human intestinal carriage of ESBL-producing *Escherichia coli* between healthcare and community settings: a systematic review and meta-analysis. *JAC Antimicrob Resist*. 2022 Jun 1;4(3):dlac048.
28. Tola MA, Abera NA, Gebeyehu YM, Dinku SF, Tullu KD. High prevalence of extended-spectrum beta-lactamase-producing *Escherichia coli* and *Klebsiella pneumoniae* fecal carriage among children under five years in Addis Ababa, Ethiopia. *PLOS ONE*. 2021 Oct 1;16(10):e0258117.
29. Muleme J, Musoke D, Balugaba BE, Kisaka S, Makumbi FE, Buregyeya E, et al. Epidemiology of extended-spectrum beta-lactamase-producing *Escherichia coli* at the human-animal-environment interface in a farming community of central Uganda. *PLOS Global Public Health*. 2023 Jun 13;3(6):e0001344.
30. Parra G, Lautenbach E, Mosepele M, Mannathoko N, Gross R, Call DR, et al. Colonization with antibiotic resistant bacteria in communities and hospitals across six countries, including Bangladesh, Botswana, Chile, Guatemala, India, and Kenya. *Sci Rep*. 2025 Jul 1;15(1):21275.
31. Villanueva P, Coffin SE, Mekasha A, McMullan B, Cotton MF, Bryant PA. Comparison of Antimicrobial Stewardship and Infection Prevention and Control Activities and Resources Between Low-/Middle- and High-income Countries. *Pediatr Infect Dis J*. 2022 Mar;41(3):S3-9.
32. Cox JA, Vlieghe E, Mendelson M, Wertheim H, Ndegwa L, Villegas MV, et al. Antibiotic stewardship in low- and middle-income countries: the same but different? *Clinical Microbiology and Infection*. 2017 Nov 1;23(11):812-8.

33. Batista AD, A Rodrigues D, Figueiras A, Zapata-Cachafeiro M, Roque F, Herdeiro MT. Antibiotic Dispensation without a Prescription Worldwide: A Systematic Review. *Antibiotics (Basel)*. 2020 Nov 7;9(11):786.
34. Desta K, Woldeamanuel Y, Azazh A, Mohammad H, Desalegn D, Shimelis D, et al. High Gastrointestinal Colonization Rate with Extended-Spectrum β -Lactamase-Producing Enterobacteriaceae in Hospitalized Patients: Emergence of Carbapenemase-Producing *K. pneumoniae* in Ethiopia. *PLoS One*. 2016;11(8):e0161685.
35. Ouedraogo AS, Sanou M, Kissou A, Sanou S, Solaré H, Kaboré F, et al. High prevalence of extended-spectrum β -lactamase producing enterobacteriaceae among clinical isolates in Burkina Faso. *BMC Infect Dis*. 2016 Jul 11;16:326.
36. van den Bunt G, van Pelt W, Hidalgo L, Scharringa J, de Greeff SC, Schürch AC, et al. Prevalence, risk factors and genetic characterisation of extended-spectrum beta-lactamase and carbapenemase-producing Enterobacteriaceae (ESBL-E and CPE): a community-based cross-sectional study, the Netherlands, 2014 to 2016. *Euro Surveill*. 2019 Oct;24(41):1800594.
37. Najjuka CF, Kateete DP, Kajumbula HM, Joloba ML, Essack SY. Antimicrobial susceptibility profiles of *Escherichia coli* and *Klebsiella pneumoniae* isolated from outpatients in urban and rural districts of Uganda. *BMC Res Notes*. 2016 Apr 25;9:235.
38. Hazirolan G, Mumcuoglu I, Altan G, Özmen BB, Aksu N, Karahan ZC. Fecal carriage of extended-spectrum beta-lactamase and ampc beta-lactamase-producing enterobacteriaceae in a turkish community. *Niger J Clin Pract*. 2018 Jan;21(1):81-6.
39. Kateregga JN, Kantume R, Atuhaire C, Lubowa MN, Ndukui JG. Phenotypic expression and prevalence of ESBL-producing Enterobacteriaceae in samples collected from patients in various wards of Mulago Hospital, Uganda. *BMC Pharmacol Toxicol*. 2015 Jun 2;16:14.
40. Kaper JB, Nataro JP, Mobley HLT. Pathogenic *Escherichia coli*. *Nat Rev Microbiol*. 2004 Feb;2(2):123-40.
41. Crits-Christoph A, Hallowell HA, Koutouvalis K, Suez J. Good microbes, bad genes? The dissemination of antimicrobial resistance in the human microbiome. *Gut Microbes*. 2022 Dec 31;14(1):2055944.
42. Khanna NR, Gerriets V. Beta-Lactamase Inhibitors. In: *StatPearls* [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 [cited 2024 Aug 30]. Available from: <http://www.ncbi.nlm.nih.gov/books/NBK557592/>
43. Garba Z, Bonkougou IJO, Somda NS, Natama MH, Somé G, Sangaré L, et al. Fecal carriage of carbapenemase and AmpC- β -lactamase producers among extended spectrum β -Lactamase-producing *E. coli* and *Klebsiella* spp. isolates in patients attending hospitals. *BMC Infectious Diseases*. 2025 Jan 23;25(1):109.

44. Sodhi K, Mittal V, Arya M, Kumar M, Phillips A, Kajla B. Pattern of colistin resistance in *Klebsiella* isolates in an Intensive Care Unit of a tertiary care hospital in India. *J Infect Public Health*. 2020 Jul;13(7):1018–21.
45. Kipsang F, Munyiva J, Menza N, Musyoki A. Carbapenem-resistant *Acinetobacter baumannii* infections: Antimicrobial resistance patterns and risk factors for acquisition in a Kenyan intensive care unit. *IJID Reg*. 2023 Dec;9:111–6.
46. Zankere T, Lechiile K, Mokgwathi K, Tlhako N, Moorad B, Ntereke TD, et al. Admission screening for extended-spectrum cephalosporin-resistant and carbapenem-resistant Enterobacterales colonization at a referral hospital in Botswana: A one-year period-prevalence survey, 2022-2023. *PLOS Glob Public Health*. 2025;5(10):e0005018.
47. Zachariah OH, Lizzy MA, Rose K, Angela MM. Multiple drug resistance of *Campylobacter jejuni* and *Shigella* isolated from diarrhoeic children at Kapsabet County referral hospital, Kenya. *BMC Infect Dis*. 2021 Jan 23;21:109.
48. Edessa D, Assefa N, Dessie Y, Asefa F, Dinsa G, Oljira L. Non-prescribed antibiotic use for children at community levels in low- and middle-income countries: a systematic review and meta-analysis. *Journal of Pharmaceutical Policy and Practice*. 2022 Sep 30;15(1):57.
49. Omulo S, Oluka M, Achieng L, Osoro E, Kinuthia R, Guantai A, et al. Point-prevalence survey of antibiotic use at three public referral hospitals in Kenya. *PLoS One*. 2022;17(6):e0270048.
50. Belachew SA, Hall L, Selvey LA. Non-prescription dispensing of antibiotic agents among community drug retail outlets in Sub-Saharan African countries: a systematic review and meta-analysis. *Antimicrob Resist Infect Control*. 2021 Jan 14;10(1):13.
51. Hamdani SS, Bhat BA, Tariq L, Yaseen SI, Ara I, Rafi B, et al. Antibiotic Resistance: The Future Disaster [Internet]. Rochester, NY; 2020 [cited 2024 Aug 30]. Available from: <https://papers.ssrn.com/abstract=3722888>



