STUDY PROTOCOL

Antimicrobial Resistance in Gram-negative bacteria from Urinary Specimens: a study of prevalence, risk factors and molecular mechanisms of resistance (ARGUS) in Zimbabwe – a study protocol [version 1; peer review: 2 approved]

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Abstract
Antimicrobial resistance (AMR) is compromising our ability to successfully treat infections. There are few data on gram-negative AMR prevalence in sub-Saharan Africa especially from the outpatient setting. This study aims to investigate the prevalence of and underlying molecular mechanisms for AMR in gram-negative bacilli causing urinary tract infections (UTIs) in Zimbabwe. Risk factors for AMR and how AMR impacts on clinical outcomes will also be investigated. Adults presenting with UTI symptoms at primary health clinics in Harare will be included. A questionnaire will be administered, and urine samples will be collected for culture. Participants with positive urine cultures will be followed up at 7-14 days post-enrolment. All participants will also be followed by telephone at 28 days to determine clinical outcomes. Bacterial identification and antibiotic susceptibility testing will be performed on positive cultures. The results from this study will be used to inform policy and development of treatment recommendations. Whole genome sequencing results will provide a better understanding of the prevalent resistance genes in Zimbabwe, of the spread of successful clones, and potentially will contribute to developing strategies to tackle AMR.

Keywords
AMR, antibiotic resistance, Escherichia coli
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Introduction
Antimicrobials have revolutionized modern medicine leading to important reductions in mortality, morbidity and disability. Their discovery and use in medical practice was, however, accompanied by the rapid development of resistance. Antimicrobial resistance (AMR) can reverse the benefits brought by these drugs, leading to increased patient deaths and healthcare costs. Considering the current trends of increasing AMR, it is estimated that by 2050, 10 million deaths per year globally will be caused by antimicrobial resistant infections, exceeding the number of deaths due to cancer.

The increase in AMR is mainly driven by inappropriate antimicrobial use in humans and animals and insufficient infection control systems. Exposure to antimicrobials selects for spontaneous mutations or the acquisition and propagation of bacterial clones harbouring resistance genes. Resistance genes are then mobilized and can disseminate to other commensal and pathogenic organisms. This in turn may lead to increased carriage of resistant organisms in the population and an increase in use of second-line antimicrobial drugs. At an individual level, other risk factors for infections due to resistant organisms are underlying co-morbid conditions and healthcare contact.

AMR is a global problem affecting all countries irrespective of income and geographical location. However, countries differ widely with regards to their detection and reporting capabilities. Surveillance plays a key role in understanding the epidemiology of AMR and informs interventions and control measures. Global surveillance networks, such as the Global AMR Surveillance System (GLASS), were established to ensure standardized data collection and analysis and facilitate data sharing regionally and globally. However, thus far few African countries contribute data to these networks, and the WHO Africa region has limited AMR prevalence data. GLASS focuses on a number of priority pathogens including Escherichia coli and Klebsiella pneumoniae isolated from priority specimens such as blood and urine. Figure 1 and Table 1 illustrate the lack of data from sub-Saharan Africa on AMR in key pathogens, as well as the high prevalence of resistance where such data are available.

Due to limited availability of diagnostics, insufficient laboratory capacity and suboptimal funding of health care systems, in sub-Saharan Africa infections are often treated using a “syndromic” approach. Samples for microbiological investigations are rarely collected outside of national tuberculosis, malaria

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**Figure 1.** Studies from sub-Saharan Africa and prevalence of third-generation cephalosporin resistance in *E. coli* and *K. pneumoniae.* Only studies describing antimicrobial resistance prevalence in isolates from blood or urine cultures are included. The numbers in the small boxes represent the number of isolates with a reported third-generation cephalosporin test result. The orange bars in the graphs represent the proportion of isolates with third-generation cephalosporin resistance for *E. coli* (left) and *K. pneumoniae* (right). The white bars represent the proportion of susceptible isolates. The shaded boxes at the bottom of the picture represent the number of studies according to country. EC: Escherichia coli; KP: Klebsiella pneumoniae. One study presented data from multiple countries and was not included on the map. This figure was compiled using the studies listed in Table 1.

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| Author (year) | Country          | Study period                  | Setting                                                                 | Patient population                                                                                                                                  | Laborator y type                                      | AST method                                                                                          | Sample type | Number of isolates tested (%) | Quality assurance |
|---------------|------------------|-------------------------------|------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|----------------------------------------------------------------------------------------------------|--------------|-----------------------------|--------------------|
| Apondi et al. [2016] | Kenya            | 2002-2013, retrospective      | One teaching/ referral public hospital                                | Inpatients, all blood culture isolates with K. pneumoniae from neonatal unit                                                                         | Hospital laboratory                                  | CLSI, automated blood culture, disc diffusion                                                   | blood         | 281 K. pneumonia             | ISO accredited laboratory |
| Ayoyi et al. [2017] | Kenya            | NA, prospective               | Antenatal clinics from informal settlements in Nairobi                 | Booking appointment for antenatal clinics, asymptomatic                                                                                       | Not specified                                       | Automated (Vitek) for identification and AST                                                      | urine         | 74 E. coli                  | Not specified           |
| Barry et al. [2017] | Senegal          | 08/2012-03/2013, prospective  | Hospital, private clinics                                              | Outpatients and primary clinics                                                                                                                  | Not specified                                       | CLSI, biochemical tests for identification, disc diffusion                                     | urine         | 72 E. coli                  | Not specified           |
| Dotse et al. [2017] | Ghana            | 06/2007-07/2009, retrospective | Regional hospital (rural)                                              | Inpatients of all ages presenting with fever, pre-empted specific symptoms in neonates                                                             | Not specified                                       | EUCAST, Automated blood culture, biochemical identification, disc diffusion                    | blood         | 50 E. coli                  | Not specified           |
| Dibach et al. [2016] | Tanzania         | 03/2017-05/2017, prospective  | Regional referral hospital                                             | Pregnant women with and without pre-eclampsia attending antenatal clinics or admitted to the hospital due to symptoms of UTI                        | Not specified                                       | CLSI, AST by disc diffusion                                                                      | urine         | 50 E. coli                  | Not specified           |
| Kadima et al. [2019] | Tanzania         | 01/2005-12/2012, retrospective | Major urban tertiary referral hospital for children                    | Children admitted to the hospital, 47% CA, 28% HAI, 24% HCA                                                                                  | Not specified                                       | CLSI, automated blood culture, biochemical identification and AST using Vitek2                 | urine         | 583 E. coli                 | Not specified           |
| Manyadi et al. [2017] | Tanzania         | 06/2004-01/2005, retrospective | Hospital laboratory                                                   | Inpatients and outpatients presenting to the hospital due to CA, 49%                                | Not specified                                       | CLSI, identification using biochemical tests and Vitek2                                          | urine         | 110 E. coli                 | Not specified           |

Table 1. Prevalence of resistance in E. coli and Klebsiella spp. in Sub-Saharan Africa in studies published since 2013. AST antimicrobial susceptibility testing; BSAC British Society for Antimicrobial Chemotherapy; CA community-acquired; CLSI Clinical and Laboratory Standards Institute; EUCAST European Committee on Antimicrobial Susceptibility Testing; HA hospital-acquired; HCA healthcare-associated; ISO International Organization for Standardization; LIMS laboratory information management system; QC quality control; UTI urinary tract infection.
| Author et al. (year) | Country | Study period | Setting | Patient population | Laboratory type | AST method | Sample type | Number of isolates tested | Quality assurance |
|---------------------|---------|--------------|---------|--------------------|-----------------|------------|-------------|---------------------------|-----------------|
| Nyasulu et al. [2017] | South Africa | 07/2005-12/2009, retrospective | 7 tertiary public hospitals with laboratories linked to the National Health Laboratory Service | Samples from hospitals | Hospital laboratories reporting to a central laboratory | CLSI, automated blood cultures, identification with Vitek2, or Microscan or conventional biochemical methods, AST manual (disc diffusion or Etest) or automatic (Vitek2 or microscan) | blood | 4466 K. pneumoniae | The individual hospital laboratories had good QA practices, and computerised LIMS |
| Obeng-Nkrumah et al. [2016] | Ghana | 01/2010-12/2013, retrospective | Tertiary-care teaching hospital | Inpatients who had a blood culture collected and were aged ≥28 days; either presenting to the hospital directly or referred for investigations | Hospital laboratory | CLSI, automated blood cultures, identification using biochemical tests, AST by disc diffusion | blood | 118 E. coli 63 K. pneumoniae | Not specified |
| Oli et al. [2017] | Nigeria | 05-07/2016, prospective | Regional teaching hospital | Women with symptoms of UTI presenting to various outpatient clinics | Laboratory within university | CLSI, biochemical tests for identification, AST by disc diffusion | urine | 61 E. coli | Not specified |
| Perovic et al. [2018] | South Africa | 01-12/2016, retrospective | Not specified | Not specified | Four private laboratories | CLSI | blood | 2781 E. coli 2466 K. pneumoniae | Not clearly specified, accredited laboratories |
| Sani et al. [2019] | Tanzania | 07/2016-10/2017, prospective | 4 referral hospitals urban and rural | Children presenting to the hospitals with suspected bloodstream infections | Hospital laboratory and university laboratory | CLSI; manual blood cultures, AST by disc diffusion | blood | 55 K. pneumoniae | Use of reference strains |
| Sani et al. [2019] | Tanzania | 03/2016-05/2017, prospective | 7 healthcare facilities: tertiary hospital, regional referral hospital, district hospital, health centers | Pregnant women, inpatients and outpatients | Not specified | CLSI, biochemical identification, AST by disc diffusion | urine | 164 E. coli 55 K. pneumoniae | Use of reference strains for culture, biochemical tests and AST |
| Author (year) | Country | Study period | Setting | Patient population | Laboratory type | Sample type | Number of isolates tested | AST method | Quality assurance |
|----------------|----------|--------------|---------|-------------------|----------------|------------|------------------------|------------|-----------------|
| Toy et al. [2019] | Burkina Faso, Ghana, Guinea, Kenya, Madagascar, Senegal, Tanzania | 01/2010-08/2013, prospective | Laboratories at each site | Patients of all ages presenting with fever as in- or outpatients, CA-infections | CLSI; Mostly blood cultures, one study, use of reference strains, central coordinator working towards establishing QA/QC, sent to reference laboratories for confirmation | Blood | 120 | CLSI, AST by disc diffusion | Not specified |
| Elikwu et al. [2017] | Nigeria | 12/2015-04/2016, prospective | University teaching hospital | Patients attending the microbiology laboratory | CLSI, AST by disc diffusion | Urine | 96 | E. coli | Not specified |
| Onoh et al. [2013] | Nigeria | 04/2010-03/2011, prospective | Tertiary hospitals | Patients attending hospital with suspected UTIs, all ages | CLSI, AST by disc diffusion | Urine | Not specified | E. coli | Not specified |
| Omoregie et al. (2013) | Nigeria | 02/2010-01/2011, prospective | University, referral hospital | Neocentral sepsis | BSAC, manual (disc diffusion) | Blood | 74 | K. pneumoniae | Not specified |
| Abejew et al. (2014) | Ethiopia | 09/2002-09/2011, retrospective | Public and private hospitals, primary care centers | Patients attending the laboratory with suspected UTIs, mostly outpatients, likely most were CA-infections | National standards, manual (disc diffusion) | Urine | 410 | E. coli | Not specified |
| Abejew et al. (2014) | Nigeria | 09/2002-09/2011, retrospective | Tertiary hospitals | Patients attending hospital with suspected UTIs, mostly outpatients | National standards, manual (disc diffusion) | Urine | 202 | K. pneumoniae | Not specified |
| Iregbu et al. (2013) | Nigeria | 12/2010-11/2011, prospective | Antenatal clinic at traditional birth center | Pregnant women, presenting for antenatal care, mostly outpatients | National standards, manual (disc diffusion) | Urine | 202 | K. pneumoniae | Not specified |
| Oladeinde et al. (2015) | Nigeria | 06/2011-11/2011, prospective | Antenatal clinics at traditional birth center | Pregnant women, presenting for antenatal care, mostly outpatients | National standards, manual (disc diffusion) | Urine | 51 | E. coli | Not specified |
| Onoh et al. (2013) | Nigeria | 01/2010-12/2010, prospective | Public and private hospitals, primary care centers | Pregnant women, presenting for antenatal care, mostly outpatients | National standards, manual (disc diffusion) | Urine | 202 | K. pneumoniae | Not specified |
| Tuem et al. [2019] | Ethiopia | 01/2012-12/2017, retrospective | Tertiary hospitals | Patients attending hospital with suspected UTIs, all ages | National standards, manual (disc diffusion) | Urine | 148 | E. coli | Not specified |
| Osigwe et al. [2013] | Nigeria | 01/2010-12/2012, prospective | Antenatal clinics at traditional birth center | Pregnant women, presenting for antenatal care, mostly outpatients | National standards, manual (disc diffusion) | Urine | Not specified | E. coli | Not specified |
| Omoregie et al. (2013) | Nigeria | 02/2010-01/2011, prospective | University, referral hospital | Neocentral sepsis | BSAC, manual (disc diffusion) | Blood | 74 | K. pneumoniae | Not specified |
| Iregbu et al. (2013) | Nigeria | 01/2010-03/2011, prospective | Tertiary hospitals | Patients attending hospital with suspected UTIs, mostly outpatients | National standards, manual (disc diffusion) | Urine | 202 | K. pneumoniae | Not specified |
| Abejew et al. (2014) | Ethiopia | 09/2002-09/2011, retrospective | Public and private hospitals, primary care centers | Patients attending the laboratory with suspected UTIs, mostly outpatients | National standards, manual (disc diffusion) | Urine | 410 | E. coli | Not specified |
| Author               | Year    | Country          | Study period                          | Setting                                | Patient population                                      | Laboratory type                                                                 | AST method                                                                 | Sample type | Number of isolates tested | Quality assurance |
|---------------------|---------|------------------|---------------------------------------|----------------------------------------|---------------------------------------------------------|--------------------------------------------------------------------------------|------------------------------------------------|-----------------|--------------------------|------------------|
| Akingbade et al.    | 2014    | Nigeria          | 2000-2011, retrospective              | Not specified, unclear                 | Inpatients and outpatients                              | Not specified                                                                     | National standards, manual (disc diffusion) | urine          | 120 E. coli             | Use of reference strains for AST |
| Moroh et al.        | 2014    | Ivory Coast      | 2000-2011, retrospective              | Not clearly specified                  | Inpatients and outpatients                              | Central laboratory of a teaching hospital                                      | Not specified, manual (disc diffusion) | urine          | 879 E. coli (345 from inpatients, 534 from outpatients) | QC use of reference strain for AST |
| Eshetie et al.      | 2015    | Ethiopia         | 02/2014-12/2015, retrospective        | 1 teaching referral hospital           | Inpatients and outpatients with symptomatic UTI         | Not specified                                                                     | National standards, manual (disc diffusion) | urine          | 112 E. coli             | Use of reference strains for AST |
| Oserumolu et al.    | 2015    | Nigeria          | 05/2003-12/2005, retrospective        | 2 tertiary care hospitals              | Inpatients and outpatients with suspected UTI          | Not specified                                                                     | National standards, manual (disc diffusion) | urine          | 137 E. coli             | Not specified, QC use of reference strain for media |
| Buys et al.         | 2016    | South Africa     | 01/2006-12/2011, retrospective        | 1 public teaching and referral hospital for children | Inpatients, Children, UA 35%, HCAP-3% and hospital-onset infections | Not specified                                                                     | National standards, manual (disc diffusion) | urine          | 409 K. pneumoniae        | Has a LIMS |
| Kabwe et al.        | 2016    | Zambia           | 10/2013-05/2014, prospective          | NICU of a teaching hospital            | Inpatients, neonates with suspected sepsis             | Not specified                                                                     | National standards, manual (disc diffusion and Etests) | urine          | Blood                    | ISO accredited, data extracted from LIMS |
| Mana et al.         | 2015-16 | Kenya            | 09/2010-01/2014, retrospective        | 1 teaching hospital, internationally funded | Inpatients and outpatients attending a private hospital (middle- and high-income) | Not specified                                                                     | National standards, automated culture, manual ID and AST (disc diffusion) | Blood          | 139 E. coli, 83 K. pneumoniae (blood) | Automated culture and AST (Vitek), E-tests |
| Mamuye et al.       | 2016    | Ethiopia         | 08/2013-01/2014, prospective          | 1 teaching private laboratory          | Inpatients and outpatients                              | Not specified                                                                     | National standards, manual (disc diffusion) | urine          | 53 E. coli              | Reference strains for AST |
| Bliva et al.        | 2017    | Ethiopia         | 05/2015-05/2016, prospective          | Private laboratory                     | Suspected UTI                                          | Not specified                                                                     | National standards, manual (disc diffusion) | urine          | 139 E. coli             | Not specified, automated (Vitek) |
| Author (year) | Country | Study period | Setting | Patient population | Laboratory type | Sample type | Number of isolates tested | AST method | Quality assurance |
|--------------|---------|--------------|---------|--------------------|----------------|-------------|-------------------------|------------|------------------|
| Henson et al (2017) | Kenya | Since 1994, retrospective | District hospital with international funding | Inpatients adults with CA (49%), HA (51%) infections | In-hospital laboratory, international funding | Blood | 198 | CLSI, automated culture; semi-automated (broth microdilution with automated reading) | Not specified, collected within ongoing surveillance for invasive infections | Reference strain |
| Kengne et al (2017) | Chad | 07-11/2014, prospective | 1 general hospital | Inpatients and outpatients | Not specified | Urine | 128 | E. coli | Not specified, automated (Vitek) |
| Lochan et al (2017) | South Africa | 01/2011-12/2012, retrospective | 1 tertiary care pediatric hospital | Inpatients with CA (56%), HA (64%) infections | National health laboratory | Blood | 92 | E. coli, K. pneumoniae | CLSI, automated culture; automated identification and AST (Vitek) |
| Rakotovao-Ravahatra et al (2017) | Madagascar | 01/2014-02/2016, retrospective | 1 teaching hospital | Not specified | Laboratory of the teaching hospital | Urine | 102 | E. coli | French standards, manual (disc diffusion) |
| Forson et al (2018) | Ghana | 02/08/2016, prospective | 1 hospital | Asymptomatic pregnant women | Not specified | Urine | 82 | E. coli | CLSI manual (disc diffusion) |
| Iroh Tam et al (2019) | Malawi | 1998–2017, retrospective | 1 large central hospital with international funding | Inpatients, reported data on children under 5 years with suspected sepsis | Hospital laboratory with international funding | Blood | Not specified | E. coli, K. pneumoniae | Not specified, part of an institutional blood culture surveillance program |
| Iroh Tam et al (2019) | Malawi | 2008-2012, retrospective | Hospital laboratory with international funding | Inpatients, reported data on children under 5 years with suspected sepsis | Hospital laboratory with international funding | Blood | Not specified | E. coli, K. pneumoniae | Not specified, part of an institutional blood culture surveillance program |
| Iroh Tam et al (2019) | Malawi | 2013-2017, retrospective | Hospital laboratory with international funding | Inpatients, reported data on children under 5 years with suspected sepsis | Hospital laboratory with international funding | Blood | Not specified | E. coli, K. pneumoniae | Not specified, part of an institutional blood culture surveillance program |
| Iroh Tam et al (2019) | Malawi | 2018-2017, retrospective | Hospital laboratory with international funding | Inpatients, reported data on children under 5 years with suspected sepsis | Hospital laboratory with international funding | Blood | Not specified | E. coli, K. pneumoniae | Not specified, part of an institutional blood culture surveillance program |
HIV programmes and a few academic centers. Consequently, there is an overuse of antimicrobials resulting from a “just-in-case” approach to treating infections and a lack of resistance data on which to base prescribing. This is the case of ceftriaxone, which is commonly prescribed to patients admitted to hospitals with suspected infections. The AWaRe classification is a framework developed by the WHO for categorizing essential antimicrobials as ‘watch’, ‘access’ or ‘reserve’ and for guiding their prescription and usage. According to this classification ceftriaxone, the most widely available third-generation cephalosporin, is in the “watch” group and should be used judiciously for restricted indications.

Third-generation cephalosporins are essential drugs for the treatment of severe bacterial infections. Resistance usually develops through the acquisition of extended-spectrum beta-lactamases (ESBL), which hydrolyze the beta-lactam ring rendering third-generation cephalosporins ineffective. ESBL genes are transferrable between different species of Enterobacteriaceae and also are often associated with other mechanisms that cause fluoroquinolone, aminoglycoside and sulphonamide resistance, thus leading to resistance to the main classes of antimicrobials used to treat Gram-negative infections. In sub-Saharan Africa, access to amikacin or to carbapenems for treatment of third-generation cephalosporin resistant infections is extremely limited and cost-prohibitive.

Over two thirds of the 37.9 million people living with HIV (PLWH) in sub-Saharan Africa are in Southern Africa. Southern Africa is particularly severely affected with most countries having an adult HIV prevalence exceeding 10%. PLWH attend health care facilities frequently for scheduled and unscheduled visits, receive more antimicrobial prescriptions and experience more hospital admissions than people without HIV, and therefore may be at increased risk for infections with antimicrobial-resistant organisms.

Co-trimoxazole prophylaxis has been shown to reduce mortality and hospital admissions in PLWH, and is currently recommended for all children and adults with advanced HIV who are at risk for malaria and severe bacterial infections. However, co-trimoxazole has been reported to increase carriage of resistant organisms in PLWH. The increase in colonization with resistant organisms is not limited to an increase in co-trimoxazole resistance but also extends to other drug classes including cephalosporins and fluoroquinolones. For Gram-negative bacilli (GNB), this may be due to the co-localization of resistance genes on the same mobile genetic elements which are transferrable between bacterial species.

Urinary tract infections (UTIs) are the most common infections caused by GNB, with an estimated incidence of 10 per 100 person years among women. Resistance patterns of GNB causing UTIs reflect the community burden of resistance with the added advantage that samples are easy to obtain, and processing easy to standardise. E. coli is the most common cause of UTIs especially in the community setting and K. pneumoniae the second most common.

**Protocol**

**Study hypotheses**

This study hypothesizes that among patients presenting with symptoms of UTI, PLWH have a higher risk of infections with resistant organisms than individuals without HIV. Additionally, because of the AMR prevalence in this setting, the current first-line treatment recommendations of amoxicillin or norfloxacin for UTI treatment will be suboptimal in terms of bacterial antimicrobial susceptibility and resolution of infection.

**Study aims and objectives**

The aims of this study are i) to determine if infections in PLWH are more commonly due to antimicrobial resistant organisms, compared with infections in individuals without HIV infection; ii) to explore the prevalence of and underlying molecular mechanisms for AMR in GNB causing UTIs; iii) to investigate risk factors for AMR, and iv) to examine how AMR impacts on clinical outcome.

**Primary objective:**

1. To determine if there is an association between HIV status and infections with ESBL-producing E. coli in adults (aged 18 years or older) who present with symptoms of UTI to primary healthcare services in Harare, Zimbabwe.

**Secondary objectives:**

2. To estimate the prevalence of third-generation cephalosporin resistance due to ESBL production in E. coli isolated from individuals who present with symptoms of UTI to primary healthcare services in Harare;

3. To determine the prevalence of resistance to amoxicillin and quinolones (first-line drugs for UTIs according to Zimbabwean National guidelines) in bacteria causing UTIs;

4. To identify the risk factors associated with UTIs with bacteria resistant to amoxicillin and quinolones, and with ESBL-producing and multidrug-resistant bacterial strains;

5. To determine the impact of resistance to first-line antimicrobials (amoxicillin and ciprofloxacin) on clinical outcomes (defined as complete resolution of symptoms at follow-up);

6. To evaluate the causes of negative urine cultures in this setting;

7. To determine the molecular mechanisms leading to AMR, virulence factors and population diversity of E. coli.

**Methods**

**Study setting**

The study is conducted in primary healthcare clinics (PHCs) in Harare, Zimbabwe. PHCs provide acute primary care, including treatment for common infections. In addition, all PHCs have 1) maternity services to record and follow pregnancies in their catchment area and perform uncomplicated deliveries, 2) family planning and well-child services for growth monitoring and vaccinations, and 3) HIV services for regular follow-ups and provision of antiretroviral therapy.
The study sites are selected based on the number of clinic presentations, their catchment population and their location within Harare. The catchment population of the clinics, of over 800,000 people, belong mostly to the low-income strata and live in densely populated communities. The clinics selected serve the populations of the following suburbs: Budiriro, Glen View, Glen Norah, Mufakose, Highfields, Kuwadzana, Warren Park, Dzivarasekwa, Kambuzuma and Mbare.

The PHCs are primarily nurse-led and prescriptions are issued in accordance with national guidelines. UTIs are usually diagnosed clinically and first-line treatment is with a fluoroquinolone or amoxicillin. Patients purchase antimicrobials according to prescription either at the PHC pharmacy or at other pharmacies in the community. Study-specific procedures are performed by the study staff who are trained on the protocol and relevant study procedures.

Study design
This is a prospective cohort study enrolling adults (aged ≥18 years) who present with symptoms of UTI at PHCs in southwest Harare, Zimbabwe. Recruitment into the study will be over an 18-month period. All participants are followed up by telephone at 28 days post-enrolment. In addition, participants with a positive urine culture at enrolment are followed up between 7 and 14 days post-enrolment to provide a urine sample to assess for clearance of infection (Figure 2).

Participant recruitment
Study staff screen and enrol participants according to the eligibility criteria. Recruitment is conducted five days per week during regular PHC opening hours. A total of 1500 participants with suspected UTIs will be enrolled. The reason for exclusion of screened participants is recorded.

Eligibility
Patients are enrolled into the study if they fulfil all the inclusion criteria and do not have any of the exclusion criteria. Individuals with catheters are excluded because they are likely to represent a different population with more healthcare exposure, and are more likely to have previously been prescribed antimicrobials and to have infections with resistant organisms. These infections are more likely to be healthcare associated infections rather than community acquired infections, which is the focus of this study. Recruiting individuals with urinary catheters would therefore likely lead to an over-estimation of community-level resistance.

Inclusion criteria:
- age ≥18 years
- presenting with symptoms of UTI (≥2 of the following: dysuria, urgency, frequency, suprapubic pain and/or flank pain). The presence of at least two symptoms is required in order to exclude those who are more likely to have other conditions (e.g. sexually transmitted infections)
- onset of symptoms within two weeks prior to presentation
- presence of symptoms within the last 24 hours
- provision of written informed consent

Exclusion criteria:
- discharge from hospital within the previous 72 hours
- having a urinary catheter in-situ

Procedures at enrolment
Clinical and demographic data collection. Data on age, sex, socio-economic status (measured using standardised asset ownership tool, education and employment of the head of the household), clinical history, prior health care seeking (traditional healer, private practitioner, pharmacy), and risk factors for AMR (prior antimicrobial use or hospitalization during the previous six months, comorbidities including HIV status, antiretroviral treatment, co-trimoxazole prophylaxis, chronic kidney disease and diabetes, current or recent pregnancy, recurrent UTIs) are

**Figure 2. Outline of procedures at enrolment and follow-up. UTI: urinary tract infection, Abx: antibiotics.**
collected using an interviewer-administered questionnaire, confirmed by patient-held records. Drug treatment (if any) and duration of treatment prescribed by the health care worker is recorded. Results of HIV tests, which are routinely carried out at the PHCs, are documented.

Sample collection and laboratory processing
A midstream urine sample for microscopy, culture and antimicrobial susceptibility testing (AST) is collected in a sterile container. The samples are transported to the laboratory as soon as possible and if a prolonged time to delivery is anticipated (>4 hours), the samples are cooled to prevent overgrowth of contaminants.

Urine samples undergo dipstick and microscopy for leucocytes, and culture. A standardised sample volume (1 µl) is inoculated on chromogenic agar (Brilliance UTI agar, Oxoid, UK). Presumptive bacterial identification is performed according to the manufacturers’ instructions. A urine culture is considered positive if ≥10³ colony forming units (CFU)/mL are present with either pure culture or predominance of one organism. If cultures grow a non-uropathogen or if ≥2 organisms are isolated in the absence of a clear predominance of one organism, the culture is considered contaminated. When GNBs cannot be identified by colony appearance on chromogenic agar, biochemical testing with APIs (Analytical Profile Index, bioMérieux, France) is used. AST is performed using the Kirby-Bauer disc diffusion method and interpreted using EUCAST standards. Screening for ESBL production is performed according to EUCAST recommendations. Briefly, if resistance to cefpodoxime alone or ceftriaxone and ceftazidime is detected, double-disc synergy testing between a cephalosporin and clavulanic acid is performed. Similarly, for AmpC detection in isolates with cefoxitin and ceftazidime resistance, synergy testing between cefoxitin and cloxacillin is carried out. In addition, for isolates resistant to third-generation cephalosporins, the minimum inhibitory concentration for ceftriaxone is determined using E-tests (bioMérieux, France).

All bacterial isolates are stored on storage beads at -80°C. Stored E. coli isolates will be used to re-establish cultures on agar plates from which DNA will be extracted using the DNA QiAmp Mini Kit (Qiagen, Hilden, Germany). E. coli isolates will undergo whole genome sequencing to ascertain molecular determinants of AMR, virulence factors and population diversity. For whole genome sequencing, DNA libraries will be prepared using the Nextera XT DNA Sample Preparation Kit (Illumina, San Diego, USA) as per the manufacturer’s instructions. The libraries will be sequenced using the Illumina HiSeq platform (Illumina, San Diego, USA). Trimmed reads will be assembled into contigs using SPAdes and using a publicly available E. coli reference genome. Antimicrobial genotype and virulence gene prediction will be performed using ABRicate. Phylogeny will be determined using FastTree and viewed in FigTree.

Evaluation of negative urine cultures
Pilot data and data from other studies from sub-Saharan Africa have shown that a large proportion of urine cultures from patients with symptoms suggestive of UTI are negative (60–75%) as compared to 25% in Europe. This may be due to various causes such as antimicrobial use prior to sample collection, low bacterial load, delayed sample inoculation leading to overgrowth of contaminants or depletion of pathogen, or symptoms due to sexually transmitted infections rather than UTIs. These alternative causes will also be investigated in a subset of participants from this study (Figure 3).

To determine recent antimicrobial use, information on antimicrobials prior to clinic presentation and on co-trimoxazole use for HIV-positive individuals will be collected. In addition, urine samples will be evaluated for antimicrobial residues using a disc-diffusion adapted from Driscoll et al. Low bacterial loads will

![Figure 3. Evaluation of causes for negative urine cultures. STI: sexually transmitted infections; CT: Chlamydia trachomatis; NG: Neisseria gonorrhoeae; TV: Trichomonas vaginalis.](Image)
be investigated using a highly sensitive culture system that is employed for testing coliform contamination of water and food (CompactDry EC, Nissui, Japan). Point of care inoculation of urine samples using InTrays (BioMed Diagnostics) will be used to determine if sample transportation delays may contribute to contamination and pathogen loss. The prevalence of sexually transmitted infections in Zimbabwe can be as high as 15–20% (unpublished data from Ferrand R.A. et al.). A subset of urine samples will be tested for gonorrhoea and chlamydia using Xpert CT/NG (Cepheid, Sunnyvale, CA, USA) and for trichomonas vaginalis using Xpert TV (for women only).

Provision of routine care for study participants

Clinical care for study participants remains the responsibility of routine health care providers. Urine dipstick, microscopy and culture results are provided to the clinic health care workers, with advice from the study physician on management for complicated cases (such as prior treatment failure, isolation of multidrug resistant bacteria, pregnancy, or severe kidney or liver disease requiring dose-adjustment).

Procedures at follow-up

Participants who have a positive urine culture at enrolment have a follow-up visit between 7 and 14 days after enrolment. Participants are asked to provide information on their symptoms, antimicrobial use and healthcare seeking since their enrolment. If a participant has not taken a prescribed antimicrobial, the reasons are also recorded. A second urine culture is collected to assess for clearance. If UTI symptoms have not resolved, a second course of antimicrobials based on results of the AST is considered, as clinically appropriate.

All participants, irrespective of enrolment culture results, are followed up by telephone 28 days after enrolment to assess clinical outcomes (i.e. symptom resolution, hospital admission, UTI symptom recurrence).

Participants due to come to the clinic for a follow-up visit will be notified in advance of their appointment. If participants are unable to come to the clinic, a home visit will be performed. For the telephone follow-up visit at 28 days, participants will be called on at least three separate occasions on two different days. If they cannot be reached by telephone, a home visit will be attempted. Loss to follow-up will only impact on the outcome analysis and was accounted for in the sample size calculation.

Outcome measures

A UTI is classified as confirmed if the urine culture is positive with a recognised urinary pathogen or possible if the culture is negative or shows contamination. Bacteriological cure is defined as a negative urine culture following an initial positive urine culture. Clinical cure represents resolution of symptoms at the 7- to 14-day follow-up. Relapse is defined as the absence of a positive culture and symptoms after seven days but reappearance or re-presentation with symptoms within 28 days of the initial presentation. AMR to specific drugs and ESBL are defined using the EUCAST standards and guidelines for detection of resistance mechanisms. Multidrug resistance is defined as resistance to one agent from at least three different antimicrobial classes.

Data management

All processes related to data collection, management and storage are governed by standard operating procedures (SOPs) and follow the principles of Good Clinical Practice.

All participants are identified throughout the study by a unique identifying number that is assigned at recruitment using uniquely numbered and barcoded consent forms. Apart from age and sex no personal data are collected on the clinical report forms.

All data are collected and entered on handheld tablets into pre-designed forms using the Open Data Kit (ODK, www.opendatakit.org) software. Electronic data quality is ensured by real-time error capture, internal validation, consistency checks and stringent formatting constraints. For the instances when the data cannot be entered directly into the electronic form (e.g. laboratory results that are only available after 24–49h), data are recorded onto paper forms. Upon completion of the laboratory tests, the data from the paper forms are entered electronically. Paper forms are available in case of failure of electronic data entry in the field.

Data analysis

Categorical variables will be analysed using counts and percentages and continuous variables using means/medians and standard deviations/interquartile ranges. The proportions of study participants with a positive, contaminated and negative urine culture will be determined. Prevalence and 95% confidence intervals will be presented for each causative organism and for resistance to antimicrobials. Univariate associations between risk factors and the presence of first-line and first- and second-line resistance and clinical and bacteriological outcome will be assessed using the \( \chi^2 \) test for categorical variables. STATA (version 14, Stata-Corp, TX, USA) will be used for data analysis.

For the primary objective (association between HIV infection and ESBL presence in E. coli), a logistic regression model will be built, which will include age and sex as the pre-specified confounders and which will be controlled for the other variables which show an association in the univariate analysis (e.g. recent hospitalization, recent antimicrobial use, pregnancy). The molecular mechanisms of resistance and virulence factors will be reported in a descriptive analysis.

Sample size estimates

The sample size calculations used the following assumptions from published studies and a pilot study: 30% of urine cultures are positive, 90% of the positive cultures yield E. coli, ESBL prevalence in E. coli is 15% in HIV-negative and 30% in HIV-positive individuals, 25% of participants are HIV-positive and 90% of study participants know their HIV status. In order to determine if there is a difference in proportions of ESBL-producing E. coli between HIV-positive and HIV-negative individuals, 1404 participants presenting with symptoms of UTI...
would need to be recruited into the study, of which 405 would be included in the primary outcome analysis.

For the clinical outcome analysis, UTI with a bacterial strain showing AMR (defined as resistance to ciprofloxacin or amoxicillin according to Zimbabwean guidelines)\(^1\) will be considered as the exposure, and complete resolution of symptoms (clinical cure) at the day 7 follow-up visit the outcome. Preliminary data from this study have shown that the prevalence of AMR in UTI isolates is 83%. The assumptions used will be: 500 cultures are positive, loss to follow up is 10%, 80% of isolates are resistant to amoxicillin or ciprofloxacin, 30% of participants with symptoms have a positive culture, and 20% of patients did not take antimicrobials. Estimating a positive impact of treatment on clinical cure in participants without AMR of 80–90% and 40–50% in participants with AMR, the study will have >80% power to detect a difference between the groups.

**Study status**

The study began recruiting participants in June 2019 and recruitment is ongoing.

**Discussion**

Although there are indications that PLWH are at increased risk for infections with resistant organisms as compared to the general population, most studies have focused on gram-positive pathogens such as *Streptococcus pneumoniae*\(^2\) and *Staphylococcus aureus*\(^3\). The ARGUS study will investigate if there is an association between HIV infection and AMR in GNB causing UTIs in Harare. The study will also investigate other risk factors for AMR in this setting. Results may contribute to the development of specific treatment recommendations based on the risk of AMR. Furthermore, the study will provide important data on the prevalence of AMR in community-acquired infections caused by GNB in this setting which will inform antibiotic prescribing guidelines, as well as the development of strategies to prevent further dissemination of resistance. The findings of this study are especially important since data on priority organisms for AMR surveillance from a large number of clinics across Harare will be collected. The information on outcomes of infections will guide the design of future management algorithms including identification of patients at risk for persistent infections and for complications.

The study is limited by its recruitment from a single city in Zimbabwe and therefore results might not be generalizable to the whole country which has a predominantly rural population. However, participants are recruited from ten PHCs across Harare and are therefore representative of the urban population. Individuals accessing healthcare at the clinics are required to pay a consultation fee. Due to the economic challenges in Zimbabwe, there has been an increase in consultation fees alongside rapid inflation. Therefore, individuals with mild symptoms may not access the clinic and will therefore not be included.

**Ethics and dissemination**

The study was approved by the ethics committees of the Medical Research Council of Zimbabwe (MRCZ/A/2406), the London School of Hygiene and Tropical Medicine (Ref. 16424), and the Biomedical Research and Training Institute. The study was granted permission from the City of Harare Department of Health. All study participants have provided/must provide written informed consent prior to enrolment into the study.

The study results will be disseminated to healthcare workers at the clinics through leaflets and dissemination meetings with the aim to enhance understanding, discuss the findings and ultimately improve future patient management. Significant microbiological results from individual patients will be reported to the attending healthcare worker as soon as they are available, in order to optimise treatment for individual patients. A report of the study results will be provided to the PHC healthcare workers, the Ministry of Health and Child Care, Harare City Health and other relevant stakeholders and policy makers. Data from this study may be used to inform treatment guidelines in order to improve patient management. The results of this study will be presented at national and international conferences to a wider audience and will be published in peer-reviewed journals.

**Data availability**

No data are associated with this article.

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Nabil Karah
Department of Molecular Biology, and Umeå Centre for Microbial Research, Umeå University, Umeå, Sweden

The manuscript describes a study protocol on the prevalence, risk factors, and molecular mechanisms of AMR in Zimbabwe. Both the study design and the manuscript were very well done.

Comment 1
- What equation have the authors used to calculate the sample size? The equation reference should be cited.

Comment 2
- The high rate of negative cases (60–75%) could also be due to inappropriate ordering and acquisition of urine cultures (Redwood et al., 2018). The fact that this service is free-of-charge could be an appealing factor.

Minor comments:
- “to treat infections successfully.” instead of “to successfully treat infections.”
- “Gram-negative” instead of “gram-negative” (correct throughout the manuscript).
- to investigate the prevalence and determine the molecular mechanisms of AMR in.
- “and its impact on clinical outcomes” instead of “how AMR impacts on clinical outcomes”.
- “to guide treatment recommendations” instead of “to inform policy and development of treatment recommendations”.
- Maybe “understanding of the molecular epidemiology of successful pathogens and the prevalence of clinically significant AMR genes in Zimbabwe”.
- has, however, been accompanied.
Delete “At an individual level”.

“The risk factors ...” instead of “Other risk factors ...”

Maybe re-write as: Underlying co-morbid conditions and ... are major risk factors for infections due to resistant organisms.

What do you mean by “healthcare contact”? Be more specific.

However, few African countries have so far contributed data to these networks.

health care systems in sub-Saharan Africa, infections are

“antimicrobials as ‘access’, ‘watch’ or ‘reserve’ and for” instead of “antimicrobials as ‘watch’, ‘access’ or ‘reserve’ and for”

According to this classification, ...

“access to amikacin or carbapenems” instead of “access to amikacin or to carbapenems”

severely affected, with most countries

Re-write a correctly structured sentence instead of “However, co-trimoxazole has been reported to increase carriage of resistant organisms in PLWH”

Delete “which are transferrable between bacterial species.”

Delete “i) to determine if infections in PLWH are more commonly due to antimicrobial resistant organisms, compared with infections in individuals without HIV infection;”

Re-write a clear sentence instead of “ii) to explore the prevalence of and underlying molecular mechanisms for AMR in GNB causing UTIs,”

Change the order of sentences as following: Primary healthcare clinics (PHCs) in Zimbabwe provide acute primary care, including treatment for common infections. In addition, all PHCs have 1) maternity services to record and follow pregnancies in their catchment area and perform uncomplicated deliveries, 2) family planning and well-child services for growth monitoring and vaccinations, and 3) HIV services for regular follow-ups and provision of antiretroviral therapy. The study is conducted in “add the exact number” selected PHCs in Harare, Zimbabwe. The study sites are selected based on the number of clinic presentations, their catchment population and their location within Harare. The catchment population of the clinics, of over 800,000 people, belong mostly to the low-income strata and live in densely populated communities. The selected “PHCs” serve the populations of the following suburbs: Budiriro, Glen View, Glen Norah, Mufakose, Highfields, Kuwadzana, Warren Park, Dzivarasekwa, Kambuzuma and Mbare.

Delete “for microscopy, culture and antimicrobial susceptibility testing (AST)”
A UTI is classified as “confirmed” if the urine culture is positive with a recognised urinary pathogen, or “possible” if the culture is negative or shows contamination.

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**Is the rationale for, and objectives of, the study clearly described?**
Yes

**Is the study design appropriate for the research question?**
Yes

**Are sufficient details of the methods provided to allow replication by others?**
Yes

**Are the datasets clearly presented in a useable and accessible format?**
Not applicable

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Laboratory Diagnostics Specialist

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

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Susanna Dunachie

1 Centre for Tropical Medicine and Global Health, University of Oxford, Oxford, UK
2 Mahidol-Oxford Tropical Medicine Research Unit, Bangkok, Thailand

This article describes the study protocol for a prospective study of prevalence, risk factors, and mechanisms of resistance of AMR in Gram-negative bacteria in urine from primary care clinics in Harare, Zimbabwe.
The article is well written with a very nice review of the (limited) literature on AMR in sub-Saharan Africa and the excellent Figure 1.

The proposed study is sound and will be a very welcome addition to our understanding of AMR in Zimbabwe. Given the paucity of high-quality microbiological data that is representative of the wider community, this data will also have relevance to other low-income countries with similar population structures and health care provision. The opportunity to explore the high rates of culture-negative urines in this setting by measuring urinary antibiotics, maximising sensitivity, trialling point of care tests, and testing for STIs with cutting edge diagnostics is especially welcome.

Some minor points:
1. There is still some debate about the evidence base on what drives AMR - advise softening the 1st sentence of the 2nd paragraph in the Introduction or at least citing some eminent opinion.

2. Introduction 4th paragraph: A major issue with existing microdata from LMIC settings is data quality. Advise mentioning this, and a sentence in your discussion on how the micro lab to be used demonstrates quality (use of EUCAST already described, can add the use of standard controls, plus the fact that the isolates will be sequenced. See ref (1)). You can also add that existing AMR data is biased towards the data from the more wealthy population due to more microdata coming from private labs and cities. Your community-based design will capture a much more representative population than most of the published literature.

3. The data analysis plan is good. Consider including as a variable in the screening univariate analysis some metrics for each clinic such as clinic size and district as I imagine there will be heterogeneity in the types of clinics. Do all the clinics have the same funding source? How many clinics will be used?

4. Very minor, but most international style guides advise using a capital G from Gram, after the Danish microbiologist. However, I do concede that some US journals style guides prefer the lower case g.

Overall this is the sort of well thought-out, comprehensive study in a representative population that is very much needed for understanding the global burden and mechanisms of AMR.

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Is the rationale for, and objectives of, the study clearly described?
Yes

Is the study design appropriate for the research question?
Yes

Are sufficient details of the methods provided to allow replication by others?
Yes

Are the datasets clearly presented in a useable and accessible format?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Global health researcher and clinical microbiologist with experience of working in low and middle income settings. Highly experienced in reviewing data on AMR from LMIC settings

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.