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One Health and Antimicrobial Resistance in Ethiopia: A Structured Literature Review

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Abstract

One Health and Antimicrobial Resistance in Ethiopia:
A Structured Literature Review

By Kaitlyn Werner

Antimicrobial resistance (AMR) is an increasingly important issue in global health which has led to less effective antimicrobials and more deadly infections. AMR occurs when an antimicrobial agent has a decreased ability or is unable to kill bacteria. Given AMR bacteria or mobile genetic elements conferring resistance can be exchanged between humans and the environment and animals in multidirectional pathways, a One Health approach integrating human, animal, and environmental health is required to address the problem. AMR has only recently been recognized as a major health problem and health priority in low-income countries included Ethiopia. We carried out a structured narrative literature review to synthesize all published data on rates of bacterial AMR among human, animal, and environmental studies conducted in Ethiopia from 2016-2020. The goal of this review was to use a One Health perspective to provide a detailed review of the AMR literature which can be used to help guide AMR prevention and management strategies. Utilizing 6 databases we found a total of 1534 articles of which 46 met our inclusion criteria. Overall, there very high rates of resistance were reported against several World Health Organization Global Antimicrobial Resistance Surveillance System (GLASS) organisms (*Escherichia coli, Klebsiella pneumoniae, Acinetobacter spp., Staphylococcus aureus/Methicillin resistant staphylococcus aureus (MRSA), Streptococcus pneumoniae, Salmonella spp., and Shigella spp.*) as well as *Enterobacter spp., Serratia spp., Proteus spp., and Citrobacter spp.* antimicrobials across human, animal, and environmental studies. A majority of isolates across studies were Gram negative organisms. Many isolates showed resistance over 25% and many were 100% resistant to an antimicrobial. Human studies reported the most consistently high rates of resistance (over 25%) with the highest rates seen against ampicillin, gentamicin, sulfamethoxazole-trimethoprim (cotrimoxazole), ciprofloxacin, ceftazidime, ceftriaxone, meropenem, cefepime, and cefoxitin. Fewer antimicrobials were tested in animal studies, however high rates were reported against ampicillin, SXT, cefoxitin, and cefuroxime. As in human and animal studies, environmental studies reported high ampicillin resistance (≥39%). This study recommends further research on the drivers of AMR from a One Health perspective due to the gaps in literature as well as lack of comprehensive knowledge of the issue.

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Table of Contents

Abbreviations

AMR	Antimicrobial Resistance
AST	Antimicrobial Susceptibility Test
AWaRe	Access, Watch, Reserve
CDC	Centers for Disease Control and Prevention
CSF	Cerebral Spinal Fluid
EPHI	Ethiopian Public Health Institute
ESBLs	Extended Spectrum Beta-Lactamase
GDP	Gross Domestic Product
GLASS	Global Antimicrobial Resistance Surveillance System
GNI	Gross National Income
HIV	Human Immunodeficiency Virus
LMIC	Low- and Middle-Income Country
MDR	Multidrug Resistant
MRSA	Methicillin Resistant Staphylococcus Aureus
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
STD	Sexually Transmitted Disease
SXT	Sulfamethoxazole-Trimethoprim
TB	Tuberculosis
UN	United Nations
UTI	Urinary Tract Infections
WHO	World Health Organization

1. Introduction

a. Overview of AMR

Since the discovery of penicillin in 1928, antimicrobial agents have been essential medicines used to successfully treat infectious diseases in both humans and animals. However, increasing levels of inappropriate and indiscriminate use has led to high and increasing rates of antimicrobial resistance (AMR)[1] resulting in less effective antibiotics and more deadly AMR infections across all socioeconomic strata. In addition to inappropriate use, poor hygiene and sanitation, lack of access to affordable and high quality antimicrobials, suboptimal infection and disease prevention practices, and needed improvements in food safety and waste management practices are major contributors to the rise of AMR.[1] AMR has made common infections harder and more complicated to treat and has led to major social and health impacts on populations throughout the world.

With lack of access to effective antibiotics, an estimated 6 million people are dying annually of AMR infections per year and this number is expected to rise if no substantial action is taken soon.[1] AMR is also a tremendous economic problem. In 2015, the World Bank published a report in which they simulated the economic impact of low and high rates of AMR among countries of all income levels.[2] In the "low-AMR" scenario simulations, the losses in world output after 2030 were $1 trillion per year and by 2050 would be upwards of $2 trillion per year.[2] In the "high-AMR" scenario, which the World Bank considers the more pessimistic scenario, the losses in world output after 2030 were $3.4 trillion and by 2050 would reach $6.1 trillion.[2] The World Bank defines LMICs as those whose Gross National Income (GNI) is between $1036 and $4015.[3] The World Bank anticipates that AMR will be more costly for low- and middle- income countries (LMICs), given they experience higher incidences of infectious

diseases.[2] AMR organisms require more expensive or less readily available treatments therefore leading to patients in LMICs not getting the treatment they need or receiving inappropriate antibiotics.[4] Since 2016, combatting AMR has become a major priority for the United Nations (UN) and the World Health Organization (WHO).[5]

To provide needed and current data on the epidemiology of AMR, the WHO launched their Global Antimicrobial Resistance Surveillance System (GLASS) in 2015.[6, 7] Using this system, participating countries around the world can share data on AMR and can use this data as a basis for national and global strategies to fight resistance.[6] Countries participate by establishing a national AMR surveillance system that can then gather resistance data and share this with GLASS.[6] The initial focus of GLASS is on 8 priority bacterial pathogens in humans (*E. coli, K. pneumoniae, Acinetobacter spp., S aureus, S. pneumoniae, Salmonella spp., Shigella spp., and N. gonorrhea)* from 4 specimen types (blood, urine, stool, and genital).[6] Additionally, there are 12 drug classes and 24 drugs under GLASS surveillance (see Appendix Table 1).[8] Ethiopia is a participating country, and they launched their AMR surveillance plan in 2017 with 16 hospitals and laboratories having the ability for AMR testing reporting, and with 7 hospitals and 2 outpatient facilities participating in the initial implementation of the surveillance system.[8] The WHO lists certain antibiotics as "Critically Important" because they meet certain criteria such as being used to treat pathogens that cause foodborne disease and/or are the only therapy or one of the few options to treat serious human disease or infection.[9] They are becoming less effective as AMR rates continue to climb and fewer treatment options become available.

In 2017, WHO launched its Access, Watch, Research (AWaRe) classification system to provide a framework for the antibiotic risk category and as a tool to guide antimicrobial stewardship.[10] The AWaRe system includes 48 antimicrobials listed in the "Access" group, 110

listed in the "Watch" group, and 22 listed in the "Reserve" group.[10] Antimicrobials listed under "Access" are utilized to treat commonly encountered susceptible bacteria and are more likely to show lower rates of resistance than the other AWaRe groups.[10] Antimicrobials in the "Watch" group have higher rates of resistance and include most of the high priority antimicrobials used in human medicine.[10] Antimicrobial agents in this group are recommended to be prioritized in surveillance and stewardship programs.[10] The "Reserve" group contains antimicrobials that should only be used in treatment of infections caused by multidrug resistance (MDR) organisms.[10] These are "last resort" agents that are used in specific patients and settings when all other options have failed.[10] Similar to antibiotics in the second group, they should be prioritized in surveillance and stewardship programs in an effort to preserve their effectiveness.[10]

b. One Health and AMR

The human population is just one sector facing the burden and continued threat of increasing AMR. Animals and the environment are also direct recipients of the harmful consequences of AMR. As in humans, antimicrobials are essential to combat and prevent infectious diseases in animals and plants/crops. Of all the antimicrobials used globally, 73% are used in food animals for treating infectious disease and more controversially as growth promoters.[11] A large portion of antibiotic use in food animals is considered inappropriate and this misuse is a major driver of AMR.[1] This increase in antimicrobial usage is concerning because it has been shown that AMR can spread between humans, animals, and the environment.[12] Animal to human transmission can occur through food animal movement (i.e., moving herds) and through the consumption of contaminated meat.[12, 13] In some settings, people commonly sleep in the same vicinity as their livestock, which increases risk of transmission of AMR organisms and genes (including through fecal shedding and close contact with feces).[12] Food animals can spread

AMR organisms into the environment through urine or feces, which are also used as fertilizer in soil or ponds.[12, 14] In addition, disposing of waste, such as blood, feces and wastewater from slaughterhouses and markets, into drains has also been shown to contaminate the environment and water sources.[12] Shared water sources can be a source of transmission as humans can use a single source for multiple purposes such as bathing, washing laundry, and fishing.[12] Animals may also use these water sources for drinking and bathing, and may also contaminate these waters with urine or feces.[12]

Additional factors responsible for AMR organisms also include the increasing disease burden in animals, increase in food animal production, and low investment in veterinary care and animal health.[1] Thus, to effectively combat AMR requires a One Health approach. As defined by the Centers for Disease Control and Prevention (CDC), One Health is a multidisciplinary approach that recognizes that human health is closely connected to animal and environmental health.[15] It uses a collaborative approach to designing and implementing programs, policies, legislation and research in which multiple sectors communicate and work together to achieve improved public health outcomes.[15] With the growing human population, the expansion into animal habitats, the increase in food animal production, and thus increased risk for disease transmission, this is becoming an increasingly important concept.[15] As the drivers and impacts of AMR are seen across the human, animal, and environmental populations, the WHO highlights the importance of implementing a One Health national action plan to respond to this global threat.[1] While some national action plans against AMR have included human and livestock health.[1] More attention toward and integration of environmental health, human food production, animal feed production and waste-management are needed.[1] Recommended components of a One Health plan to combat AMR include creating antimicrobial stewardship programs,

recognizing current behaviors and knowledge towards antibiotic use and AMR, AMR awareness activities, strengthening surveillance and monitoring programs, increasing advocacy and stakeholder commitment, and developing professional educational resources for providers.[1]

c. AMR in Low- and Middle- Income Countries

All countries are affected by AMR regardless of their socioeconomic status or level of development.[1] However, low-income countries with higher infectious disease burdens face increased difficulties in responding to AMR and are seeing rising rates of resistance that are increasing more rapidly than in higher income countries.[16] There are several proposed reasons why LMICs are experiencing high rates of AMR. First, there is often little to no regulation or quality control for antimicrobials.[1, 17] In addition, inadequate personal hygiene and environment cleanliness are also possible drivers of AMR in LMICs.[17]

Other drivers of AMR can include user-related factors (i.e., self-medication, poor patient adherence, lack of access to appropriate facilities, poverty), and healthcare provider related factors (i.e., lack of training, lack of diagnostic and laboratory facilities).[4] There are several other issues in LMICs. First, regulatory issues with antimicrobials including quality control, including counterfeiting, and over the counter use. Secondly, cultural factors can impact how antimicrobials are used, including differing conceptions and beliefs.[4] Lastly, many challenges with antimicrobials are rooted in dysfunctional healthcare systems. These include incorrectly stored antimicrobials, use of expired antimicrobials, inadequate infection control practices, and lack of targeted susceptibility testing and surveillance.[18, 19] A number of the studies revealed several causes of increasing AMR, including knowledge gaps relating to AMR and appropriate usage. This includes inappropriate prescribing habits, and lack of access to appropriate therapeutics.[18, 19] Absence of treatment guidelines, inadequate facilities, challenges with supply

and demand, and lack of antimicrobial stewardship programs are also additional drivers of AMR in healthcare settings.[19]

d. Ethiopia and AMR

In Ethiopia, AMR is a major and emerging public health concern. Ethiopia is a landlocked country located in East Africa with a population estimated at 108 million people.[20] Of this, 3 million people live in the country's largest city Addis Ababa.[21] This is a predominantly agricultural society making up 75% of the country's workforce and 40% of the GDP.[22] About 80% of the population lives in rural areas and uses farming as a source of income.[22] Keeping livestock is also a major part of agriculture in Ethiopia and makes up about 45% of production.[23] About 14 million households (70% of the population) keep livestock with cattle and chicken being the most common.[23] As agriculture is a major part of life, humans have substantial interaction with food animals and crops, thus creating opportunities for transmission of AMR bacteria and resistance elements.[12]

As with other LMICs, Ethiopia experiences a high burden of infectious diseases including bacterial and protozoal diarrhea, tuberculosis, malaria, HIV, and schistosomiasis.[20] With about 85% of the population without access to sanitation facilities, disease risk remains high.[20]

The Ethiopian government and the Federal Ministry of Health (FMOH) have recognized the growing threat of AMR and the urgent need prevent its spread.[24] However, to date, data on drivers of resistance are limited. In addition, there are 0.1 physicians per 1000 people and 0.3 hospital beds per 1000 people, making access to appropriate and timely treatment difficult.[20] In 2015, the Ethiopian Public Health Institute (EPHI), along with the FMOH, put together a Strategy for the Prevention and Containment of Antimicrobial Resistance.[24] The goal of this

strategy was to slow down, prevent, and ultimately contain the spread of AMR through the availability of safe, high-quality, and appropriately used antimicrobials.[24] In 2017, Ethiopia adopted its first AMR Surveillance Plan which served to strengthen both knowledge and evidence of AMR using both a coordinated and standardized clinical laboratory-based surveillance system.[24] The goals of the system were to assess and support building of laboratory capacity to provide quality, lab-based AMR surveillance data and to establish a nationwide surveillance network.[24] In addition, the system wanted to estimate the burden and extent of priority resistant pathogens (*E. coli, K. pneumoniae, S. aureus, Acinetobacter spp., P. aeruginosa,* and *Enterobacteriaceae*), to report data regularly, to analyze data regularly, and to detect emerging resistance and map its spread across the country.[24] Lastly, an overarching goal was to utilize evidence in the implementation of prevention and control programs, and to develop a One Health surveillance system in the future.[24] Although this system successfully closed many gaps in AMR, has increased awareness of this major public health issue, and has paved the way for an integrated One Health, quality antimicrobial susceptibility testing for patient care and surveillance data was still not readily available.[24] The EPHI has identified several needs and priorities that will ensure continued success of its program including: (1) retaining experienced clinical microbiologists at the facility level, (2) promoting and ensuring appropriate use of microbiology in patient care, (3) ensuring availability and access to microbiology supplies and equipment, and (4) integrating AMR surveillance into public health emergency response.[24]

Although Ethiopia has made advances against AMR, it still remains a major public health problem. The country is very early on in their response and have developed plans but has had slow implementation due to limited resources and existing infrastructure. Recently, Ethiopia released a 5-year “Strategy for the Prevention and Containment of AMR” that includes a One

Health approach to minimize the high resistance rates they are seeing.[25] The goal of this plan is to continue prevention, control, and treatment of infectious diseases in animals, plants/environment, and humans through the prevention and containment of AMR using a One Health approach.[25]

Due to the threats of AMR in Ethiopia, there is a need to review and evaluate available information and existing activities in humans, animals, and the environment, as well as identify any gaps regarding AMR. The goal of this review is to use a One Health perspective to provide a detailed review of the AMR literature published within the last 5 years which can be used to help guide AMR prevention and management strategies. The proposed aims of this review are to describe available data and resources for the rates and drivers of AMR in humans, animals and the environment in Ethiopia.

2. Methods

a. Search Strategy

A structured literature review was conducted to identify rates of AMR in Ethiopia from a One Health perspective. The following online databases were used to conduct our literature search: PubMed, CINAHL, Global Health Database, AgriCOLA, Embase, and MEDLINE. We aimed to identify all articles on AMR from the country of Ethiopia that were published in English from 2016 to 2020. The literature search was conducted from October 6, 2020 to November 30, 2020. The search strategy used the following search string: (“antimicrobial resistance” OR “antibiotic resistance” OR “drug resistance” OR “Gram negative” OR “Gram positive”) AND (“Escherichia coli “OR “E. coli” OR “Salmonella” OR “Staphylococcus aureus “OR “Enterobacter cloacae” OR “Shigella “OR “Methicillin resistant staphylococcus aureus” OR “Klebsiella pneumoniae “OR “Acinetobacter baumannii” OR “Streptococcus pneumoniae)”

AND (“foodborne infections” OR “healthcare infections”) AND (“Animal” OR “livestock” OR “cattle” OR “cows” OR “beef” OR “poultry” OR “chickens” OR “pig” OR “swine”) OR “human” OR “environment” OR “One Health”) AND (“Ethiopia”). Throughout the literature review process, assistance was provided by the Head of Information Services at the Woodruff Health Sciences Center Library at Emory University.

b. Selection Criteria

Full-text articles on AMR in humans, clinical settings (hospitals, pharmacies, clinics, veterinary clinics), animals, animal products (cows, pigs, chicken, poultry), or the environment (water, slaughterhouses, drains, wastewater), and foodborne infections were screened. These articles were included for review if they reported on AMR in Ethiopia and provided data and information collected from sources in Ethiopia.

As indicated by our search strategy our review concentrated on *Escherichia coli, Klebsiella pneumoniae, Acinetobacter spp., Staphylococcus aureus/Methicillin resistant staphylococcus aureus (MRSA), Streptococcus pneumoniae, Salmonella spp., and Shigella spp.* (GLASS organisms, see Appendix Table 1). Additionally, we included *Enterobacter spp., Serratia spp., Proteus spp., and Citrobacter spp.,* as there is concern of growing resistance among these organisms.

As there are no universally defined benchmark standards for categorical levels of AMR, we defined low AMR rates as 0-10%, medium AMR between11-25%, and >25% as high AMR. We graphically displayed these categorizations of AMR by color-coding calls in Microsoft Excel with green representing low AMR, yellow representing medium AMR, and red representing high AMR (see Appendix Table 2-7).

3. Results

a. Study Selection

The initial literature search yielded a total of 1534 articles. Of these, 515 were duplicates and removed. An additional 671 articles were excluded after screening titles and abstracts as they were not pertinent to AMR. A full article review was conducted for all remaining articles. An additional 302 articles were excluded, as they did not evaluate topics related to the rates of bacterial AMR among humans, animals, or environment samples in Ethiopia (see Appendix Figure 1). A total of 46 articles were included in the final data extraction. Figure 1 gives an overview of the search and selection process via a PRISMA diagram (see Appendix Figure 1).

b. Study Characteristics

Among the 46 articles included for review, 39 were cross-sectional[26-64], 5 retrospective [65-69], and 2 prospective studies.[70, 71] The studies were conducted in a total of 17 cities and 6 regions throughout Ethiopia and focused on AMR in humans, animals, and/or the environment (see Appendix Figure 2 and 3).

b. Human Studies

A total of 19 studies evaluated rates of AMR in humans. All but one of the studies included pediatric and adult participants from either an inpatient, outpatient, or combined setting.[30] Most studies took place in urban centers such as Hawassa, Addis Ababa, and Jimma (see Appendix Figure 3). Of the studies, 17 included patients with a particular infectious syndrome including surgical site infections, post-surgical infections, wound infections, urinary tract infections, otitis media, and gastrointestinal infections as outlined in Appendix Table 5.[26-29, 31, 33, 36-38, 65, 67-72] Two studies evaluated rates of AMR infections in cancer patients (see Appendix Table 5).[30, 32]

Of the 19 studies, 7 did not specify where onset of the infectious syndrome occurred, 8 specified that onset occurred in the community, one specified that the infections occurred in the hospital setting, and 3 studies observed infections occurring in both hospital and community settings (see Appendix Table 5). Sampling methods across studies included collection of sterile cotton swabs of body fluids, cups/vials for stool, and wound swabs (see Appendix Table 5).

Regarding the bacteria isolated, the majority were Gram negative organisms (80%). The Gram negative organisms isolated in human studies included: *Citrobacter spp*., *E. coli*, *Enterobacter spp*., *Klebsiella spp*., *Proteus spp*., *Salmonella spp*., *Serratia spp.*, and *Shigella spp*. The remaining 20% of organisms isolated isolates were the Gram positive organisms *Staphylococcus aureus, MRSA*, and *Streptococcus pneumoniae*.

In human studies, we found that of all the antibiotics being tested, 12 were categorized as GLASS antibiotics. In total, our review evaluated 13 of the GLASS antibiotics. A majority of the studies tested ampicillin (84%), gentamicin (90%), ciprofloxacin (79%), ceftriaxone (79%), and sulfamethoxazole-trimethoprim (cotrimoxazole)(SXT) (84%). Meropenem was the only carbapenem evaluated; it was tested in four studies with only one study evaluating for resistance among Gram positive organisms (*S. aureus*).

A total of 13 studies found *E. coli* and identified 676 isolates (range of 1-184 isolates per study). In regard to beta lactam antibiotics, all studies evaluated resistance to ampicillin and 12 revealed resistance ≥63% (range 63-100%) with one study among inpatients finding a lower rate of 33%. Twelve studies evaluate ceftriaxone susceptibility with eleven finding high rates of resistance ≥25% (range 25-67%). Fewer studies evaluated susceptibility to ceftazidime (5) and meropenem (4); however, rates of ceftazidime resistance were all between 47-67% and three studies found resistance to meropenem between 16-22% (see Appendix Table 2). Twelve studies

evaluated resistance against gentamicin and nine found resistance rates ≥28% (range of 13-71%) with three studies finding rates ≤23% (see Appendix Table 2). Eleven studies evaluated resistance against ciprofloxacin and six found resistance rates ≥20% (range of 9-59%). Twelve studies evaluated SXT and eleven found rates ≥23% (range of 11-100%) with one study among patients with infections of different sites finding a lower rate of 11%.[68] Fewer studies evaluated cefoxitin (1), amikacin (2), cefotaxime(1), and cefepime (2); however, when examined, *E. coli* was 61% resistant against cefoxitin, 5-11% resistant to amikacin, 35% resistant to cefotaxime, and 22-33% resistant to cefepime.

Similarly, 13 studies found *Klebsiella spp.,* with a total of 347 isolates (range of 2-154 isolates per study). Twelve studies evaluated resistance against ampicillin and all resulted in rates ≥67%. Of these, seven studies reported 100% resistance. Ten studies evaluated resistance to gentamicin and 9 found rates ≥21% with one study in patients with wound infections reported 0% resistance.[73] Eleven studies evaluated resistance against ciprofloxacin and six found rates ≥ 33% (range of 0-64%). Resistance against ceftriaxone was also evaluated in eleven studies, with a majority of these reporting rates ≥38% (range 11-100%).[73] Eleven studies examined resistance against SXT, with the majority reporting rates over 40% (range of 33-100%). Fewer studies evaluated ceftazidime (5), meropenem (3), cefoxitin (1), amikacin (3), cefotaxime (1), and cefepime (2); however, *Klebsiella spp.* was 29-78% resistant to ceftazidime, 0-60% resistant to meropenem, 77% against cefoxitin, 0-13% resistant against amikacin, 53% resistant against cefotaxime, and 25-50% resistant to cefepime.

Nine human studies isolated 110 *Enterobacter spp.* isolates (range of 1-53 isolates per study) with ampicillin resistance rates ≥50%. Eight studies evaluated resistance against gentamicin and five reported rates ≥25% with 3 studies reported rates 0-17%. Resistance against

ciprofloxacin was evaluated in 8 studies and four studies reported rates ≥25% with four studies reported lower rates between 0-17%. Eight studies evaluated resistance against ceftriaxone and seven studies reported resistance ≥25% with one study in patients with urinary tract infections reporting 0% resistance.[27] Resistance against SXT was evaluated in eight studies and six studies reported rates of resistance ≥33% with two studies in patient with otitis media and wound infections reporting 0% resistance.[70, 73] Fewer studies evaluated resistance against ceftazidime (4), meropenem (3), cefoxitin (1), amikacin (3), cefotaxime (1), and cefepime (2); however, *Enterobacter spp.* was 25-83% resistant to ceftazidime, 17-63% resistant to meropenem, 100% resistant to cefoxitin, 0% resistant to amikacin, 0% resistant to cefotaxime, and 33% resistant to cefepime.

Many studies (12) isolated *Citrobacter spp.* with a total of 155 isolates identified (range of 1-66 isolates per study). Eleven studies evaluated resistance against ampicillin and all reported ≥60% resistance with the majority reporting 100% resistance (see Appendix Table 2). Ten studies evaluated resistance against gentamicin and seven studies reported rates ≥20% (range of 0-64%) with three studies reported lower rates ranging from 0-8%. Resistance against ciprofloxacin was evaluated in 10 studies and 5 reported rates ≥22% (range of 0-57%). The remaining five studies reported lower rates ranging from 0-17%. Eleven studies evaluated resistance rates against ceftriaxone and seven studies reported rates ≥33% (range of 0-100%). Resistance rates against SXT were evaluated in eleven studies and 10 reported rates ≥40% with one study in patients with surgical site infections reported 25% resistance.[36] Fewer studies evaluated resistance against ceftazidime (5), meropenem (3), cefoxitin (1), amikacin (3), cefotaxime (1), and cefepime (2); however, *Citrobacter spp.* was 38-73% resistant to

ceftazidime, 18-50% resistant to meropenem, 55% resistant to cefoxitin, 0-25% resistant to amikacin, 61% resistant to cefotaxime, and 17-55% resistant to cefepime.

Proteus spp., was found in nine studies and in these studies researchers identified a total of 420 isolates (range of 2-324 isolates per study). Eight studies evaluated resistance against ampicillin with all studies reporting rates ≥50% (range of 50-100%) and of these studies, 4 reported rates of 100% in a *Proteus spp*. isolate (see Appendix Table 2). Resistance against gentamicin was evaluated in eight studies and five studies reported rates ≥25% (range of 0-50%), Seven studies evaluated ciprofloxacin and four studies reported rates ≥25% (range of 0-56%) with three studies reporting lower rates from 0-23% (see Appendix Table 2). Resistance against ceftriaxone was evaluated in eight studies and all but two studies reported rates of over 25% (range 0-95%) with 2 studies (one in cancer patients and one in patients with urinary tract infections) reporting rates of 0% resistance.[27, 32] Seven studies evaluated resistance against SXT and six reported rates of resistance ranging from 25-100% with one study in patients with urinary tract infections reported a lower rate at 4% resistance.[27] Ceftazidime (3), meropenem (3), cefoxitin (1), amikacin (2), cefotaxime (1), and cefepime (2) were evaluated in fewer studies; however, *Proteus spp.* was 25-67% resistance to ceftazidime, 0-67% resistant to meropenem, 67% resistant to cefoxitin, 13-30% resistant to amikacin, 76% resistant to cefotaxime, and 27-67% resistant to cefepime.

Fewer studies (5) observed *Salmonella spp.* and there were a total of 103 isolates (range of 5-30 isolates per study). Four studies evaluated resistance against ampicillin and all reported rates ≥40% (range 40-100%) with 3 of these studies reporting 100% resistance (see Appendix Table 2). Four studies evaluated resistance against ciprofloxacin and three reported rated ≥25% (range 7-83%) with one study in diarrhea patients reporting 7% resistance.[33] Fewer studies

evaluated resistance against gentamicin (3), ceftriaxone (3), ceftazidime (1), SXT (3), and cefoxitin (1); however, *Salmonella spp.* was 5-50% resistant to gentamicin, 3-50% resistant to ceftriaxone, 100% resistant to ceftazidime, 5-100% resistant to SXT, and 33-40% resistant to cefoxitin.

In total, seven studies found *Shigella spp.* and 55 isolates were identified (range of 2-12 isolates per study). Four studies evaluated resistance against ampicillin and all reported rated ≥50% (range 50-100%) with two of these studies reporting 100% resistance (see Appendix Table 2). Resistance was evaluated against ciprofloxacin and two studies reported rates ≥25% (range of 0-63%) with two studies (one in patients with infections of different sites and one in patients with diarrhea) reported 0% resistance.[33, 68] Three studies evaluated resistance against ceftriaxone and 2 studies reported 50% with one study in diarrhea patients reported 0% resistance.[33] Three studies evaluated SXT and reported high rates of resistance ranging from 50-100%. Fewer studies evaluated gentamicin (2), ceftazidime (1), and cefoxitin (1); however, *Shigella spp.* was 1-40% resistant to gentamicin, 100% resistant to ceftazidime, and 25-30% resistant to cefoxitin.

Serratia spp. was not commonly found in human studies. However, two studies were able to isolate it from inpatients participants with hospital acquired or wound infections (see Appendix Table 5). Across the two studies that found it, there were a total of 5 isolates (range of 1-4 isolates per study). One study reported 100% resistance against all antimicrobials evaluated (ampicillin, gentamicin, ciprofloxacin, ceftriaxone, ceftazidime, meropenem, SXT, cefoxitin, and cefepime). [28] The second study reported 100% resistance against ampicillin, 75% resistance against ceftriaxone and SXT, 50% resistance against meropenem, and 3 antibiotics showed lower resistance rates of 25%.[29]

Many human studies (15) found *Staphylococcus spp.* with a total of 1062 isolates (range of 6-266 isolates per study). Nine studies evaluated resistance against ciprofloxacin and seven reported rates ≥27% with two reported low rates ranging from 1-8%. Eleven studies evaluated ceftriaxone and eight reported rates ≥35% (range of 13-68%). Resistance against SXT was evaluated in 14 studies and 13 reported rates ≥30% (range of 11-100%) with one study in patients with wound infections[72] reporting a lower rate of 11%. In the studies that evaluated ampicillin and/or gentamicin, high rates of resistance were reported (see Appendix Table 5). Fewer studies evaluated ceftazidime (3), cefoxitin (6), amikacin (1), cefotaxime (2), oxacillin (5), and cefepime (1); however, *Staphylococcus spp.* was 43-100% resistant to ceftazidime, 35-53% resistant to cefotaxime, 18-54% resistant to oxacillin, and 3% resistant to cefepime in ear infection patients (see Appendix Table 5).[71]

In a single study evaluating patients on different inpatient units with infections from various sites (i.e., ear, nose, gastrointestinal, or blood), *Streptococcus pneumoniae* accounted for 6% of isolates with 67% being resistant to SXT.[65]

Overall, studies revealed that when isolated, Gram negative organisms showed elevated levels of resistance against most antibiotics tested, regardless of the setting or type of infectious syndrome. Of these, rates of resistance were consistently elevated for ampicillin. Gram positive organisms showed high resistance to ampicillin, SXT, gentamicin ciprofloxacin, ceftriaxone, ceftazidime, and cefoxitin.

c. Animal Studies

In total, 13 studies evaluated rates of AMR rates in various animal populations including chickens, dairy cows, and beef cattle. Ten studies focused just on animals while 3 focused on animal and environmental sources of resistant organism (see Appendix Table 6). [46, 50, 51] Animal studies spanned 15 cities. Animal studies were conducted on farms, in markets, butcher shops, or at abattoirs and were done in or near towns or cities, rather than rural locations. The focus of most studies was animal products (other than those swabbing carcasses and meat) and half examined milk, feces, or eggs. Animal or animal product samples sizes ranged from 90 to 505.[47] Most studies gave disease or infection treatment and prevention as reasons for use. Only two studies listed growth promotion as reasons for use. [47, 48] Sampling methods were similar across studies with most studies (n=8) using sterile swabs or poly wipes (for carcasses). The remaining studies scooped samples into sterile test tubes (see Appendix Table 6). Unlike the human and environment studies, those in the animal category only focused on 1 or 2 organisms. [50, 52] Only two studies tested a Gram positive organism (*Staphylococcus spp*.).[50, 74] The main organisms of focus were Gram negative and included *Salmonella spp*. (53%) followed by *E. coli/E. coli O157:H7* (23%).

Three studies found *E. coli/E. Coli O157:H7* and identified 217 isolates (range of 26-102 isolates per study). All three studies were cross-sectional with two evaluating chickens (cloacal swabs or visceral organ samples) and one evaluating raw cow's meat. Two studies evaluated resistance against ampicillin, and both reported rates ≥89%. Resistance against gentamicin was evaluated in 3 studies and 2 found lower resistance rates ranging from 4-8% with one study sampling visceral chicken organs reported 0% resistance.[44] Two studies evaluated SXT and one, which tested both *E. coli* species separately, reported 38-41% resistance. As with gentamicin, the

study testing chicken organs reported 0% resistance.[44] Fewer studies evaluated ceftriaxone (1), ceftazidime (1), cefoxitin (1), and amikacin (1); however, *E. coli/E. Coli O157:H7* was 4-7% resistant to ceftriaxone, 5-7% resistant to ceftazidime, 85% resistant to cefoxitin (in chicken cloacal swabs[39]), and 7% resistant to amikacin.

Salmonella spp. was found in seven studies with a total of 248 isolates identified (range of 8-56 isolates per study). All studies evaluated resistance against ampicillin and six reported rates ≥38% (range of 14-98%) with one study in raw chicken and cow meat reporting 14%. [45] Resistance against SXT was evaluated in five studies and four studies reported rates ≥29% (range of 11-100%) (see Appendix Table 3). Four studies evaluated ciprofloxacin and one reported a rate of 31% with the remaining studies reported lower rates of 0-7%. The three studies reporting these lower rates were all sampling from an animal product such as milk or beef (see Appendix Table 3). Fewer studies evaluated ceftriaxone (3), ceftazidime (2), and cefoxitin (3); however, *Salmonella spp.* was 0-23% resistant to ceftriaxone, 15-57% resistant to ceftazidime, and 11-98% resistant to cefoxitin.

Two studies sampled isolates from cow's milk and/or meat (see Appendix Table 6). Among the two studies that evaluated Gram positive *Staphylococcus spp.,* there were a total of 190 isolates identified (range of 92-98 isolates per study). Both studies evaluated resistance against gentamicin, and both reported low levels of resistance ranging from 0-4%. Both studies evaluated resistance to SXT and reported rates of 21% and 30%. A single study evaluating cow's milk and cattle meat isolated *Staphylococcus spp.* and found that the isolates were 56% resistant to cefoxitin. No studies evaluated Gram positive resistance against ampicillin, ceftriaxone, ceftazidime, or cefoxitin.

One study did not divide resistance rates by organism but rather by source.[51] All of the organism sources tested from animals were products that are commonly consumed and handled by humans, and all have been known to cause food-borne illness.[75]

d. *Environment Studies*

In total, 14 articles focused on AMR in the environment. In addition, three studies were also included under the animal category as they looked at both animal and environmental sources.[48, 50, 51] Studies were done in 11 cities in Ethiopia with 3 completed in Addis Ababa. All studies utilized a cross-sectional design and evaluated organisms identified from environmental sources including hospital and university wastewater, medical devices, hospital surfaces, bus surfaces, and wastewater systems (see Appendix Table 7). Studies testing human hands were included in the environmental studies, as well as the animal studies, because inadequate hand hygiene was seen as a source of contamination in the environment as well as in animals and animal products (see Appendix Tables 6 and 7).

Along with the differing testing sites, generally there were two different sampling methods across all studies. For those dealing with liquid samples, sterile containers or collection cups were used,[54-56, 60] whereas those dealing with testing of surfaces, sterile swabs were used.[57-59] Despite the differences in testing sites and sample sizes, 53% observed *E. coli*, 41% isolated *Salmonella spp*., 29% isolated *Shigella spp*., 29% isolated *S. aureus and 5% isolated Streptococcus spp*. The studies also reported that *E. coli* isolated from wastewater systems exhibited high rates of carbapenem resistance (sludge systems =18%, water stabilization ponds =37%, septic tanks=42%).[60]

All studies except two[51, 60] included AMR rates by organism. Of the studies, 82% tested for ampicillin, gentamicin, and SXT, and 89% tested for ciprofloxacin. In all studies, ampicillin

showed the highest rate of resistance in at least one of the bacteria isolated. The highest rates of resistance were reported in ampicillin, gentamicin, ciprofloxacin, ceftriaxone, SXT, cefepime, and cefoxitin. Of the GLASS antimicrobials tested in the environmental studies, 9 are listed as "Critically Important" by the WHO.[76]

Nine studies found *E. coli,* and identified 366 isolates (range of 5 to 151 isolates per study). All but three studies evaluated resistance to ampicillin and 8 studies reported rates ≥70% (range 70-100%) with one study among water sources finding lower rates of 48% and 54%. Six studies evaluated gentamicin susceptibility with 2 finding higher rates of resistance ≥25% (range 0-43%). Eight studies evaluated ciprofloxacin and 4 found resistance rates ≥28% (range 0-52%) while 4 found rates ≤18 (range 0-18%). Six studies evaluated ceftriaxone susceptibility with 4 finding higher rates of resistance ≥28% (range 0-73%). Seven studies evaluated susceptibility against SXT and 6 found rates ≥25% (range of 13-76%). Some antimicrobial agents were not tested in many studies including: ceftazidime (1), meropenem (1), amikacin (1), levofloxacin (1), cefepime (2), and cefoxitin (3). However, E. coli showed 65% resistance to ceftazidime, between 18-48% resistance to meropenem, between 27-45% resistance to amikacin, between 23-55% resistance to levofloxacin, 28-82% resistance to cefepime, and 40-60% to cefoxitin.

Klebsiella spp., was isolated in five studies. In total, there were 61 isolates identified (range of 8-20 isolates per study). Of these studies, four evaluated susceptibility to ampicillin and all reported rates ≥40% with 2 studies over 90%. Gentamicin susceptibility was evaluated in 4 studies with all resulting in lower rates of resistance ≤21% (range of 0-21%). Four studies evaluated susceptibility against ciprofloxacin and all resulted in rates ≤17% (range of 9-17%). Ceftriaxone susceptibility was tested in 4 studies and 2 found rates ≥25 (range 0-55%). Four studies evaluated SXT susceptibility and two found rates ≥28% (range 28-67%) with one study

among street food items finding 0% resistance.[63] Fewer studies evaluated ceftazidime (1), cefoxitin (2), cefepime (1), and levofloxacin (1); however, Klebsiella spp. showed 17% resistance to ceftazidime, 17-50% resistance to cefoxitin, 28% resistance to cefepime and 17% resistance to levofloxacin.

Among the four studies that found *Enterobacter spp.,* there were a total of 18 isolates (range of 3-6 isolates per study). All studies evaluated susceptibility against ampicillin and all but one study showed 100% resistance. The one study that did not find 100% resistance, still resulted in a high level of resistance at 60%. Of the 2 studies evaluating gentamicin, both resulted in lower rates of resistance between 0-17%. Three studies evaluated resistance against ciprofloxacin and two resulted in rates ≥25% (range 0-50%) and one study in street foods showing 0% resistance.[63] Two studies evaluated resistance to ceftriaxone with one resulting in 33% resistance and the other study in street foods found 0% resistance.[63] Three studies evaluated resistance against SXT and two reported rates ≥33 (range of 0-50%) and one study in street foods finding 0% resistance.[63] Fewer studies evaluated resistance against cefoxitin (1); however, Enterobacter aerogenes from wastewater showed 67% resistance and Enterobacter cloacae from wastewater showed 83% resistance.[56] No studies evaluated susceptibility to ceftazidime, meropenem, amikacin, oxacillin, cefepime, or levofloxacin.

Similarly, four studies found *Citrobacter spp*., there were a total of 36 isolates (range of 4-15 isolates per study). All studies evaluated susceptibility against ampicillin and all had high rates of resistance between 80-100%. Three studies tested for resistance against gentamicin and 2 found 0% resistance, one in food items and one in medical equipment.[59, 63] The remaining study found that in wastewater samples, there was 50% resistance to gentamicin.[56] All studies evaluated susceptibility against ciprofloxacin and two reported rates ≥38% (range of 0-75%).

Three studies tested resistance against ceftriaxone and only 1 found a high rate of resistance at 75% with the remaining two studies reporting 0% resistance. Three studies evaluated susceptibility against SXT and only 2 elevated rates at 50% and 63% were reported with the remaining study reporting 0% resistance. Only one study evaluated for resistance in hospital and abattoir wastewater and found that isolates were 75% resistant against cefoxitin.

Proteus spp., was not frequently isolated in environmental studies. In the two studies that found it, there were a total of 9 isolates (range of 2-7 isolates per study). Both evaluated resistance against ampicillin and reported high rates of 80% and 100%. Although both studies evaluated susceptibility against gentamicin and ciprofloxacin, no resistance was reported (See Appendix Table 4). The studies evaluated resistance against ceftriaxone however, only one reported resistance (50%) while the other found 0%. Only one study evaluated SXT in street foods and reported 0% resistance.[63]

Salmonella spp. was found in a total of nine studies with a total of 105 isolates (range of 2-28 isolates per study). Six of these studies evaluated susceptibility against ampicillin, five found rates ≥39% (39-100%) with four of these studies reporting 100% resistance. Four studies evaluated resistance against gentamicin and two reported rates ≥33% (range of 0-78%). Four studies evaluated susceptibility against ciprofloxacin and all but one study reported 0% resistance. The single study that found resistance was in human stool samples and found that *S. typhi* was 67% resistance to ciprofloxacin.[53] Similarly, four studies evaluated susceptibility against ceftriaxone and all but one found 0% resistance. The single study testing wastewater sources found that *S. paratyphi* was 25% resistance and *S. typhi* was 22% resistant.[53] Five studies evaluated resistance against SXT and 3 found rates ≥33% (range of 0-75%). Few studies

evaluated ceftazidime (1) or amikacin (1); however, one isolate (*S. typhi)* was resistant to ceftazidime and one study found 11% resistance to amikacin.

There were a total of 79 isolates (range of 5-32 isolates per study) identified in the five studies that found *Shigella spp.* Four studies evaluated susceptibility against ampicillin and all found high rates ≥33% (range 33-100%), The same number of studies evaluated susceptibility against gentamicin with 2 studies reporting rates of 23% and 33% and 2 reporting 0%. Although three studies evaluated ciprofloxacin, all reported 0% resistance (See Appendix Table 4). Four studies tested resistance against ceftriaxone and SXT. Ceftriaxone resistance ranged from 0-17% and SXT resistance ranged from 0-67% (see Appendix Table 4). Only one study evaluated resistant against ceftazidime in human stool samples and found that *Shigella spp.* was 17% resistant.[53] No studies evaluated meropenem, cefoxitin, amikacin, oxacillin, cefepime, or levofloxacin.

A total of six studies found 343 isolates (range of 7-92 isolates per study) of Gram positive *Staphylococcus spp.* Half of the studies evaluated resistance against ampicillin and all reported high rates of resistance ranging from 61-100%. Three studies evaluated resistance against gentamicin and 2 found resistance rates 22-23% with one reporting 0% resistance (see Appendix Table 7). Four studies evaluated resistance against ciprofloxacin and 1 reported 24% resistance with 3 reported rates ≤19% (range of 2-19%). Three studies evaluated resistance against ceftriaxone and 2 reported rates ≥28% (range of 19-57%). Resistance against SXT was evaluated in four studies and two reported higher rates ≥65% (range of 65-84%) with two finding lower rates ranging from 21-24%. Three studies evaluated resistance against cefoxitin and all reported elevated rates ranging from 32-74%. Only one study evaluated oxacillin resistance and reported 29% resistance in *Staphylococcus spp.* isolated from street foods.[63]

Streptococcus spp., was only found in one study with a total of 13 isolates. High levels of resistance ≥39% (range of 39-85%) were reported to ampicillin, gentamicin, and ciprofloxacin. Low resistance of 15% was reported against SXT. No studies evaluated resistance to ceftriaxone, meropenem, ceftazidime, cefoxitin, amikacin, oxacillin, cefepime, or levofloxacin.

4. Discussion

Our results demonstrate high resistance rates to important GLASS antimicrobials in human, animal, and environmental sources in several locations across Ethiopia. Concerningly, we found high rates of resistance among 5 antibiotics in the AWaRe "Access" group and 8 in the "Watch" group (see Appendix Table 1).[10] Our findings are concerning as many of the highest resistance rates were observed against these important antimicrobials. Our findings underscore the continued need for surveillance of AMR and implementation of stewardship programs. [26, 28, 31, 32, 37, 70]

Across the studies in our review, we observed several isolates showing high levels of resistance toward third-generation (ceftriaxone, cefotaxime, ceftazidime) and fourth-generation (cefepime) cephalosporins. Although few animal studies evaluated these agents, one study reported relatively high resistance (23%) in *Salmonella spp*. isolated from raw beef.[41] The highest levels of resistance were seen in isolates from human studies and a few environmental studies. In human studies, rates over 60% were seen in isolates from inpatient bacterial infections, hospital acquired infections, and patients with UTIs (see Appendix Table 5). Of the third- and fourth- generation cephalosporins, animal studies mainly focused on ceftriaxone. Only one study evaluated two third-generation and one fourth-generation cephalosporin against *E. coli* and *K. pneumoniae* isolated from river water and found levels of resistance (≥17%) with highest levels seen in *E. coli* (≥65%).[55] High levels of resistance among antimicrobial classes in

environmental studies are concerning because these agents are all classified under the "Watch" group as they are all considered important in human medicine.[10] This has now become a One Health concern as environmental sources are being contaminated with pathogens that are resistant to medications used in humans. These findings can help serve as markers to better understand what is going on at the population level, such as what activities are promoting increased levels of resistant pathogens in the environment. This can guide strategies to reduce AMR in the environment. As in animal studies, not many studies evaluated these antimicrobial agents and a majority of these studies tested ceftriaxone.

Many organisms across studies belong to the Enterobacterales order, which is an order of organisms that can cause infections in different hospital and community settings.[77] These include: *E. coli, Klebsiella spp., Enterobacter spp., Salmonella spp., Shigella spp., Proteus spp., Serratia spp., and Citrobacter spp.*[78] Some of these organisms produce extended spectrum beta-lactamases (EBLs) which are enzymes that can hydrolyze and render ineffective many antimicrobials in the penicillin and cephalosporin groups.[77] This can result in more complicated and expensive treatment options for patients. Carbapenems are among the few antimicrobial classes that can treat these ESBL-producing organisms, but resistance rates are increasing.[77] Only 2 human studies tested resistance rates in all Enterobacterales.[28, 29]

Several LMICs in Africa (n=19 countries) and South-East Asia (n=10 countries) have enrolled in WHO's GLASS to combat AMR caused by these drivers in their countries and regions.[8] However, understanding of the full extent of the AMR problem is limited in Africa because few countries have surveillance of drug resistance.[79] However, as with Ethiopia, some countries are starting to work towards creating surveillance collaborations.[79]

Worldwide we are seeing increasing rates of resistance, especially in LMICs. The use of antimicrobials in humans, animals, and the environment is further increasing this rate due to suboptimal regulations, limited surveillance, inappropriate prescribing practices, growing burden of animal disease, and growing number of food animals in production.[1] As seen in Africa, the increase in food animal production is also causing increased rates of resistance in food animals in Southeast Asia.[80] This aligns with our findings in which high levels of resistance were observed toward multiple antibiotics tested in animal-based food and animal-derived food products in Ethiopia.

In the present review, the highest rates of resistance across all studies were reported against ampicillin, SXT, and cefoxitin. In our review, the most commonly isolated Gram negative organisms included in human, animal, and environment studies were *E. coli* (24 studies), and *Salmonella spp.* (19 studies). The most commonly isolated Gram positive organism was *Staphylococcus spp.*(23). In human outpatient and inpatient settings, the most common isolated organisms were *E. coli, Klebsiella spp., Enterobacter spp., Citrobacter spp., Proteus spp,,* and *Staphylococcus spp.* This finding was similar to a study reviewing AMR data in Cameroon.[17] These organisms showed high rates of resistance to ampicillin, gentamicin, SXT, ceftriaxone, ciprofloxacin, and ceftazidime. The most commonly isolated organisms in animal studies, *E. coli, E. coli O157:H7,* and *Salmonella,* showed high resistance to ampicillin and SXT. This finding was similar to a finding by Founou et.al., 2018, which examined AMR in food animals across 12 African countries (Tunisia, Ethiopia, Algeria, Senegal, Ghana, Nigeria, Cameroon, Uganda, Kenya, Zambia, Zimbabwe, and South Africa).[81] In our review, *E. coli, Klebsiella spp., Salmonella spp., Shigella spp., Citrobacter spp,,* and *Staphylococcus spp.,* were the most commonly isolated organisms from the environment. These organisms showed high

resistance to ampicillin, gentamicin, ciprofloxacin, ceftriaxone, and SXT. This is similar to the review done in Cameroon which reported high rates of resistance in first-line antibiotics used in human medicine.[17] Although many of these organisms were isolated from rivers or wastewater, there were studies that showed high contamination of surfaces and foods caused by poor hygiene (see Appendix Table 7). When compared with animal and environmental studies, human studies had more consistently elevated rates across organisms and antimicrobials overall. In addition, human studies isolated more pathogens and evaluated more antimicrobials for resistance among the pathogens found. Unlike human studies, animal studies isolated fewer pathogens, which were mostly Gram negative organisms (85%). Studies were evenly divided regarding how many isolated organisms from chickens (5) and how many from cattle/dairy cows (6) with one study isolating from both.[45] Most of these organisms were isolated from cattle or dairy cows/ products (i.e., milk, meat). Many studies focused on these animal types, demonstrating the growing concern of AMR in chickens and cows. As these animals are major sources of contamination, it indicates there is a need for protocols to improve hygiene practices (i.e., farmer/abattoir worker hand hygiene and hygiene of animal stalls or enclosures). Most of the animal studies isolated *Salmonella spp.,* and/or *E. coli/E.coli O157:H7,* indicating that these organisms are frequently found in food animals and their products. With the contamination of animal food products, there is increased risk of transmission to humans who ingest them.

A major limitation of the literature included in our review is that none looked across all three sectors, similar to findings in other LMICs. This was a similar conclusion in an article by Rousham et.al., in which authors examined human, animal, and environmental contributors to AMR in LMICs.[12] This same conclusion was also made in regard to AMR in Cameroon.[17] Many LMICs may not have the resources to collect data on all three sectors simultaneously. Our

showed more human studies than the other two sectors. One reason for this is that most of the studies evaluated hospitalized patients or medical records (see Appendix Table 5). This makes gathering data much more convenient as patients are already getting a variety of tests done while in the hospital. Also, sampling from humans, especially those who are already in hospitals or visiting clinics, is easier than sampling from an animal or from environmental sources. However, without assessing the three sectors together, it makes it difficult to assess the true prevalence of AMR, the directionality of transmission, and how to effectively combat resistance across all three sectors.[12]

Our literature review also found more data on AMR in humans overall, than in animals and the environment. This aligns with a study, by Van Boeckel et.al., 2019, in which the authors examined global trends of AMR in animals in LMICs.[11] In their study, the researchers discuss that AMR trends are not well-documented in animals in LMICs as surveillance data in animals is not as readily available.[11] In addition, only two studies mention the words "One Health" or discuss the need for a One Health approach to combatting AMR.[41, 43] This continues to be a growing concern as AMR rates are growing in all domains of One Health.

Further studies should be conducted to better understand that AMR is a One Health issue and how effective a One Health approach would be to reduce resistance rates. Further research is also needed to aid in the creation of policies to plan interventions in order to prevent further growth in resistance and to promote alternative therapies. Agriculture is a major industry in Ethiopia with antibiotics used daily in animals. Treatment guidelines and surveillance of antimicrobial prescribing practices need to be implemented on farms.

Although the studies differ in many ways when it comes to organisms observed, collection sites, collection methods, antimicrobials tested, and rates of resistance found, the

themes and conclusions they present are very similar. As *E. coli* was isolated in over half of the environmental studies presented, there was a concern about sanitation and hygiene practice. Another issue, especially in the case of wastewater and other water sources, was the high level of contamination with resistant, even multidrug resistant, organisms. This was reported by Tesfaye et.al., 2019, in which they found high rates of *Salmonella* in rivers, high rates of *Klebsiella* in abattoir wastewater, and *Citrobacter* and *E. coli* found in hospital wastewater were found to be highly resistant to at least one drug.[56] Their concern was that this resistance could be spread to humans and animals who drink this water or ingest food that has been contaminated by this water (i.e. irrigation).[56] This is similar to another study that looked at wastewater where *E. coli* was found at a high prevalence in hospital wastewater and that rates of MDR were highest in wastewater coming from hospitals.[60] Studies like these that looked at water all stressed the importance of water-treatment before release into the environment. Studies looking at surfaces were strongly interested in personal and community hygiene/sanitation measures. Seven studies tested food handlers and concluded that there was a need for periodic medical checkups, training on hand hygiene protocols, and regular inspection of the surroundings to ensure the risk of infection of consumers is reduced.[50, 53, 54, 62-64, 82] The main emphasis in the studies looking at AMR and the environment was on infection control, and improved hygiene and sanitation practices/infrastructure.

Several unanswered questions remain. First, none of the articles included in this review discussed wet markets or live animal markets, which warrant investigation of which organisms and AMR rates can be attributed to animal conditions and market sanitation. Second, causal pathways between animals and humans through direct contact or between types of animals were not assessed. Third, other potential pathways, such as through fish and consumptions of plants

was not well described. Fourth, while studies collected age and gender, few stratified by these variables or by occupation. Finally, and how rates of resistance differ between gender, age, and even occupation.

Most articles did not examine resistance of resistance for critical antibiotics, such as carbapenems. This is very concerning as many of these antimicrobials are either the only or one of the few treatments available against certain pathogens.[76] Additionally, it is important to consistently evaluate all antimicrobials critical to human health. Given that many are one of the few current treatment options available for certain diseases, it is imperative to invest in drug development for newer antimicrobials.

While surveillance has paved the way for the fight against AMR, antimicrobial stewardship programs guides have also been developed in response to AMR.[83] Stewardship serves to promote the appropriate use of antimicrobials, reduce resistance, improve patient outcomes, and decrease further health effects caused by resistance.[83] However, antimicrobial stewardship still faces many implementation barriers such as lack of sufficiently trained personnel and low implementation readiness in individual hospitals.[84] Once these barriers are overcome, stewardship programs can become potential solution to improve AMR.

5. Conclusion

A structured literature review demonstrated high rates of AMR among humans, animals and environmental samples in Ethiopia emphasizing that antimicrobial resistance continues to be a major public health concern. While the number of studies are still limited, our results suggest AMR rates are high and that a One Health approach is needed to combat AMR comprehensively. It is imperative that appropriate strategies be used in order to prevent further increase in rates of resistance. This study concludes that high levels of resistance are seen in GLASS organisms and for antimicrobials in humans, animals, and the environment. With the high rates of resistance seen in humans, animals, and the environment, it is important to implement and build One Health plans that will help countries better prioritize their plans against AMR.

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Appendix

Figure 1: *PRISMA Diagram of Study Selection Process*

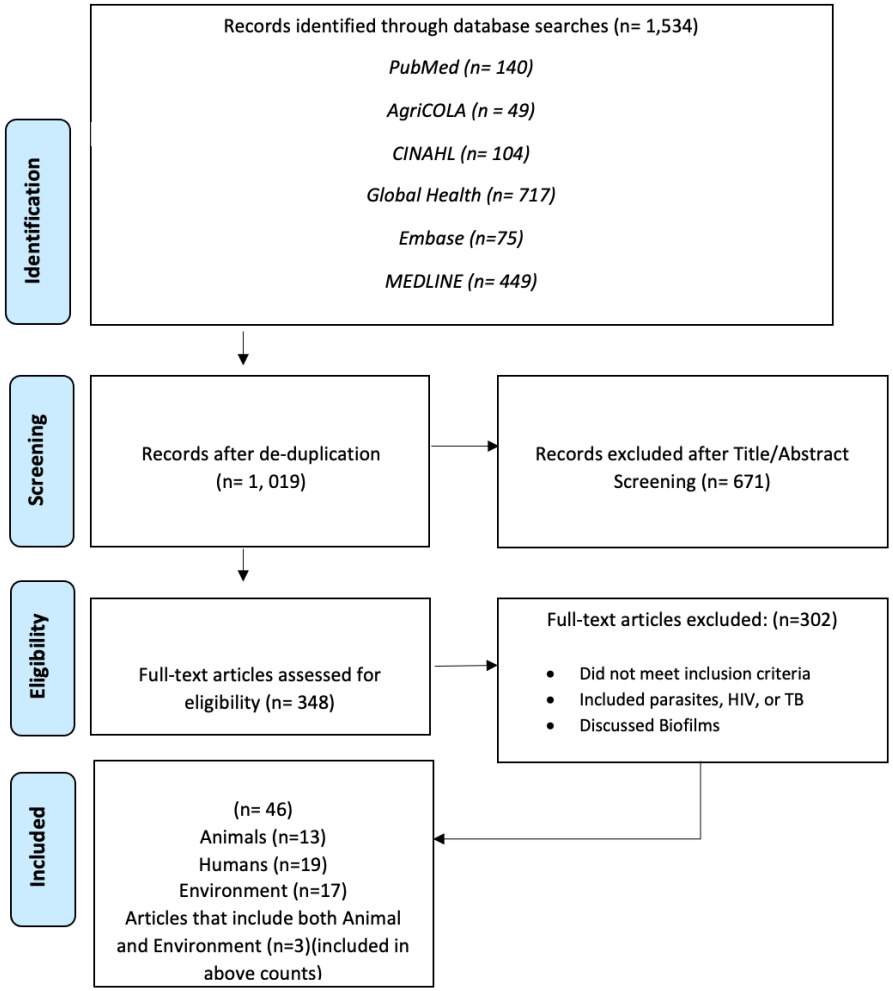


Figure 2: Number of articles by category and by publication year

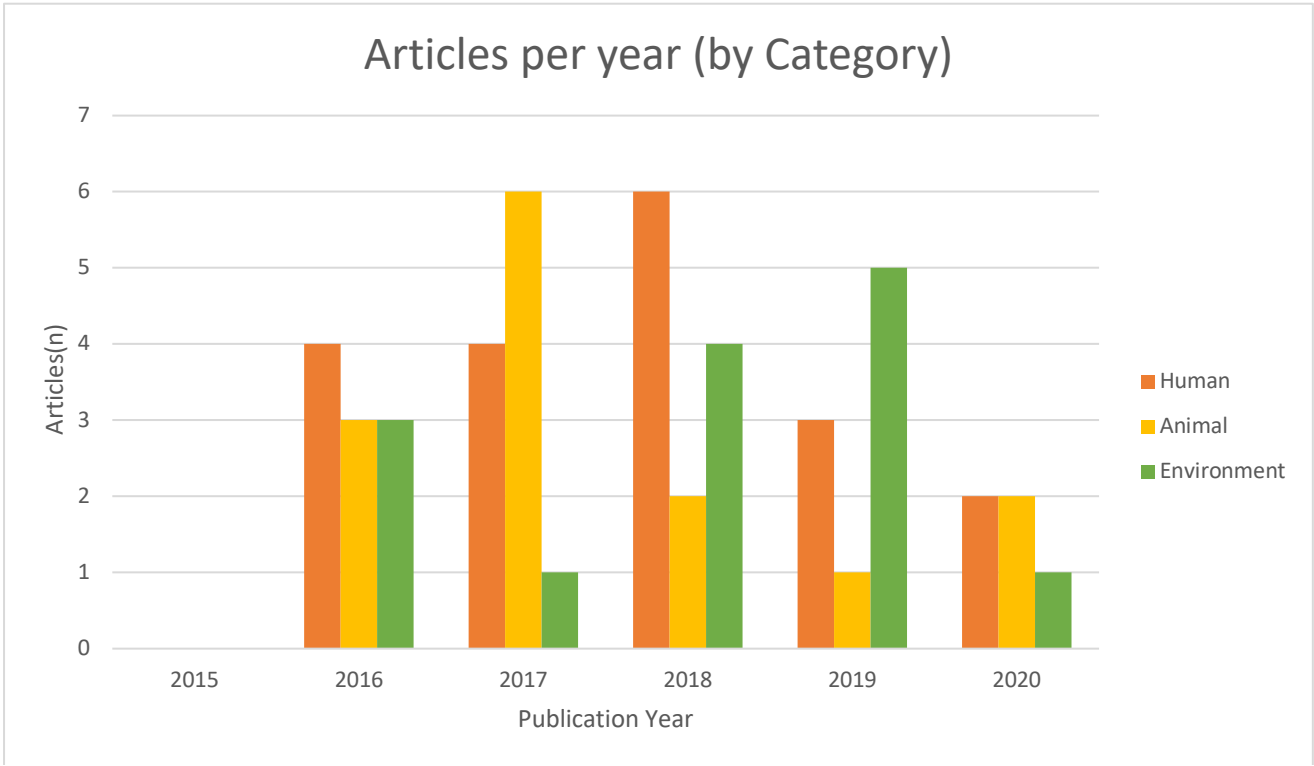
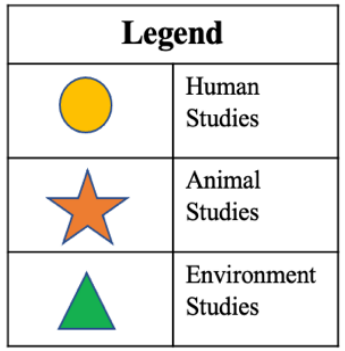


***Figure 3**: Geographical Locations of AMR Studies*



*Blanc, J., (n.d.). Wikipedia [Map of Ethiopia]. Retrieved March 2, 2021, from https://upload.wikimedia.org/wikipedia/commons/thumb/2/21/Regions_of_Ethiopia_EN.svg/1200px-Regions_of_Ethiopia_EN.svg.png (Map published to Wikipedia under Creative Commons License by Joan Francés Blanc(*Jfblanc) on *Wikimedia Commons) - https://creativecommons.org/licenses/by-sa/4.0/deed.en)* * We added some city names and the star, circle, and triangle study location indicators to map for this review.

***Table 1**: Glass Surveillance Organisms and Antimicrobials/Classes*

GLASS (organism-antimicrobial combinations under GLASS)			WHO AWaRe Classification[10]
Organism	**Antibacterial/antimicrobial Class**	**Antibacterial Agents that may be used for susceptibility tests (AST)**	
Escherichia coli (Gram Negative)	Sulfonamides and trimethoprim	Co-trimoxazole	ACCESS*
	Fluoroquinolones	Ciprofloxacin or levofloxacin	WATCH*
	Third-generation cephalosporins	Ceftriaxone, cefotaxime, or ceftazidime	WATCH*
	Fourth-generation cephalosporins	Cefepime	WATCH*
	Carbapenems (Imipenem or meropenem)	Imipenem, meropenem, ertapenem, or doripenem	WATCH*
	Polymyxins	Colistin	RESERVE
	Penicillins	Ampicillin	ACCESS*
Klebsiella pneumoniae (Gram Negative)	Sulfonamides and trimethoprim	Co-trimoxazole	ACCESS*
	Fluoroquinolones	Ciprofloxacin or levofloxacin	WATCH*
	Third-generation cephalosporins	Ceftriaxone, cefotaxime, or ceftazidime	WATCH*
	Fourth-generation cephalosporins	Cefepime	WATCH*
	Carbapenems (Imipenem or meropenem)	Imipenem, meropenem, ertapenem, or doripenem	WATCH*
	Polymyxins	Colistin	RESERVE
Acinetobacter spp. (Gram Negative)	Tetracyclines	Tigecycline or minocycline	RESERVE
	Aminoglycosides	Gentamicin and amikacin	ACCESS*
	Carbapenems (Imipenem or meropenem)	Imipenem, meropenem, or doripenem	WATCH*
	Polymyxins	Colistin	RESERVE
Staphylococcus aureus (Gram Positive)	Penicillinase-stable beta-lactams	Cefoxitin	WATCH*
	Penicillins	Oxacillin	ACCESS*
Streptococcus pneumoniae (Gram Positive)	Penicillins	Oxacillin	ACCESS*
	Penicillins	Penicillin G	ACCESS
	Sulfonamides and trimethoprim	Co-trimoxazole	ACCESS*
	Third-generation cephalosporins	Ceftriaxone or cefotaxime	WATCH*
Salmonella spp. (Gram Negative)	Fluoroquinolones	Ciprofloxacin or levofloxacin	WATCH*
	Third-generation cephalosporins	Ceftriaxone, cefotaxime or ceftazidime	WATCH*
	Carbapenems (Imipenem or meropenem)	Imipenem, meropenem, ertapenem, or doripenem	WATCH*
Shigella spp. (Gram Negative)	Fluoroquinolones	Ciprofloxacin or levofloxacin	WATCH*
	Third-generation cephalosporins	Ceftriaxone, cefotaxime, or ceftazidime	WATCH*
	Macrolides	Azithromycin	WATCH

Table Modified from WHO GLASS Report-Early Implementation 2020[8]

Note: Neisseria gonorrhoeae is another GLASS organization but was not included in our review.

* Agent or Class is Evaluated in our Review

Table 2: *Condensed Table of Human Study Data*

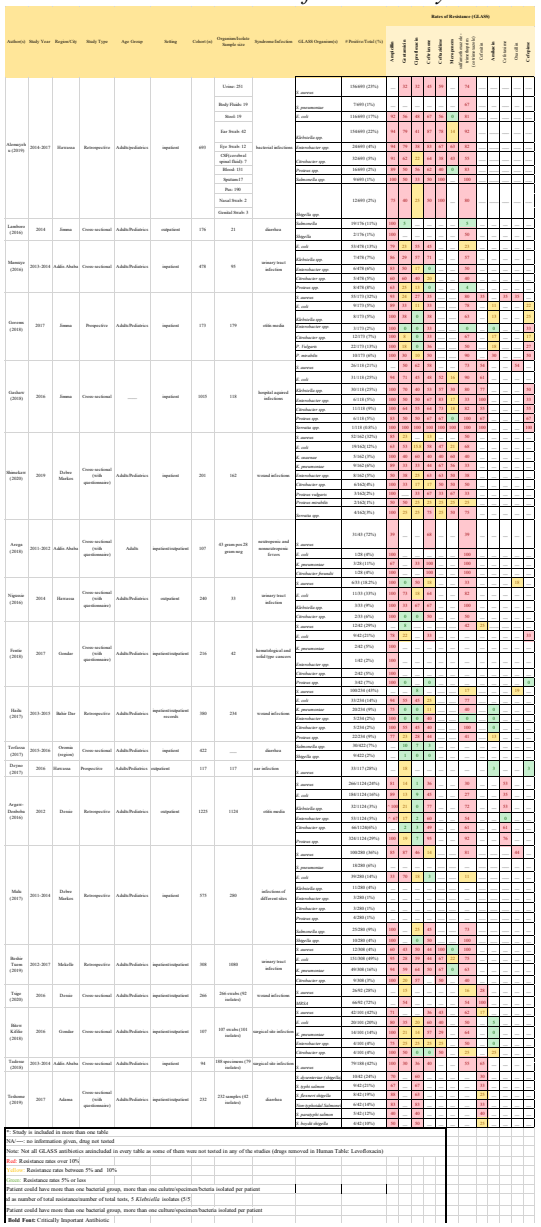


Table 3: *Condensed Table of Animal Study Data*

Author(s) (first, et.al.)	Study Year	Study Type	Region/City	Type(s) of Animal	Animal Product	Animal/Animal Product Sample Size	Number of samples/isolates	All Bacteria (GLASS)	Positive Samples (%)	% Glass Antimicrobial Resistance								
										Ampicillin	Gentamicin	Ciprofloxacin	Ceftriaxone	Ceftazidime	Sulfamethoxazole-trimethoprim (cotrimoxazole)	Cefoxitin	Amikacin	Cefuroxime
Shecho (2017)	2015-2016	Cross-sectional	Haramaya	chickens	NA	194	194 swabs (26 isolates)	***E. Coli O157:H7***	26/194 (13%)	92	8	0	__	__	__	85	__	__
Mulaw (2017)	2012-2013	Cross-sectional	Bahir Dar	Dairy cows	Milk and milk products	384	384 samples (36 isolates)	***Salmonella spp.***	36/384 (9%)	94	0	0	__	__	39	31	__	__
Wabeto (2017)	2015-2016	Cross-sectional	Wolaita Sodo	cattle	raw beef	448	448 samples (56 isolates)	***Salmonella spp.***	56/448 (13%)	46	13	7	23	__	__	__	__	__
Kemal (2016)	2012-2013	Cross-sectional (with questionnaire)	Haramaya	chickens	eggs	300 eggs and 75 humans	300 egg samples (8 isolates)	***Salmonella spp.***	8/300 (3%)	38	13	__	__	__	__	__	__	__
Asfaw Ali (2020)	2013-2014	Cross-sectional	Debre Zeit and Modjo	chickens	meat	384	56 isolates	***Salmonella spp.***	56/384 (15%)	70	__	__	6	__	56	__	__	__
Sarba (2019)	2015-2016	Cross-sectional	5 locatoins in West Shewa Zone (district)	chickens	chicken visceral organs	191 chickens (694 visceral organ samples)	62 isolates (chickens) 80 isolates (organs)	***E. coli***	62/191 (33%) (chickens) 80/694 (12%) (organs)	__	0	0	__	15	0	__	7	93
Ejo (2016)	2014-2015	Cross-sectional	Gondar	chickens/dairy cows, cattle	raw/cooked meat, uncooked eggs, milk	384	21 isolates	***Salmonella spp.***	21/384(6%)	14	10	__	0	__	29	__	__	__
Duguma Abdi (2017)	2014-2015	Cross-sectional	Hawassa and Bonga	chickens	N/A	270	45	***Salmonella spp.***	45/270 (17%)	98	0	31	__	__	100	98	__	__
Sebsibe (2020)	2018	Cross-sectional	Jimma	cattle	raw meat	90 cattle (505 swab samples)	505 swabs (129 isolates)	***E. coli***	102/505 (20%)	91	5	3	4	5	38	__	__	3
								E. Coli O157:H7	27/505 (5%)	89	4	4	7	7	41	__	__	7
Abunna (2017)*	2016	Cross-sectional	Modjo	dairy cows	milk, feces, and evironment	266	266	***Salmonella spp.***	28/266 (11%)	39	0	0	__	__	11	11	__	__
Beyene (2017)*	2013-2014	Cross-sectional (with questionnaire)	Addis Ababa	dairy cows, cattle	meat, raw udder milk,	193	193 samples	***Staphylococcus spp***	92/193 (48%)	__	0	2	__	__	21	56	__	__
Shiferaw (2016)	2012-2013	Cross-sectional	Bahir Dar	Dairy cows	milk	218	98	***S. aureus***	98/218 (45%)	__	4	0	__	__	30	__	__	__
Takele (2018)*	2016	Cross-sectional	Jimma	Cattle	Cattle Carcass	195	___	***Cattle Carcass***	22/195 (11%)	59	14	0	__	__	14	__	32	__
					Cattle Feces	195		***Cattle feces***	11/195 (6%))	54	27	0	__	__	18	__	36	__
					Human Stool	50		***Human stool***	9/50 (18%)	44	0	0	__	__	11	__	22	__

*: Study is included in more than one table

____: no information given, drug not tested

Red: Resistance rates over 10%

Yellow: Resistance rates between 5% and 10%

Green: Resistance rates 5% or less

Note: Not all GLASS antibiotics areincluded in every table as some of them were not tested in any of the studies (drugs removed in Animal Table: Meropenem, Levofloxacin, Cefepime, Oxacillin)

Bold Font: Critically Important Antibiotic

Table 4: *Condensed Table of Environmental Study Data*

Author(s) (first, et.al)	Study Year	Study Type	City (Region) Delete city in parentheses and leave region	Specimen Source	Specimen Source Sample Size (i.e. number of rivers)	Isolates	All Bacteria (GLASS)	Positive Samples (%)	% GLASS Antimicrobial Resistance													
									Ampicillin	**Gentamicin**	**Ciprofloxacin**	**Ceftriaxone**	**Ceftazidime**	**Meropenem**	**Sulfamethoxazole-trimethoprim (Cotrimoxazole)**	**Co-Amoxiclav**	**Azithromycin**	**Oxacillin**	**Cefepime**	**Levofloxacin**
Getie (2019)	2018	Cross-sectional (with questionnaire)	Gondar	stool samples from participants	257 food handlers	34	***E. coli O157:H7***	5/257(2%)	80	0	0	0	__	__	39	__	__	__	__	__	__	__
							Salmonella spp.	3/257 (1%)	0	33	0	0	__	__	33	__	__	__	__	__	__	__
							Shigella spp.	26/257 (10%)	62	23	0	8	__	__	33	__	__	__	__	__	__	__
Belachew (2018)	2017	Cross-sectional	Addis Ababa	river water	32 rivers (90 samples)	90	***E. coli***	23/90(26%)	91	43	52	70	65	__	67	48	__	__	70	35
							K pneumoniae	20/90 (22%)	94	17	17	22	33	__	28	33	__	__	28	17
Tesfaye (2019)	2017	Cross-sectional	Addis Ababa	wastewater from hospitals (x2) and abattoir and downstream water	24 samples(6 collections points)	54	***E. coli***	18/24 (75%)	100	__	28	28	__	__	____	56	__	__	__	__	__	__
							K pneumoniae	8/24 (33%)	__	__	13	25	__	__	13	50	__	__	__	__	__	__
							Enterobacter aerogenes	3/24(13%)	100	__	__	33	__	__	__	67	__	__	__	__	__	__
							Enterobacter cloacae	6/24(25%)	100	17	50	33	__	__	33	83	__	__	__	__	__	__
							Citrobacter spp.	4/24(17%)	100	50	75	75	__	__	50	75	__	__	__	__	__	__
							Salmonella spp.	12/24(50%)	100	__	__	0	__	__	8	58	__	__	__	__	__	__
Bodena (2019)	2018	Cross-sectional (with questionnaire)	Harar	physician mobile phones	226 phones	216	***S. aureus***	31/226 (14%)	61	23	10	10	__	__	65	__	__	__	__	__	__	__
							Streptococcus spp.	13/226(6%)	46	85	39	__	__	__	15	__	__	__	__	__	__	__
							E. coli	14/226(6%)	79	__	14	29	__	__	57	__	__	__	__	__	__	__
							Klebsiella spp.	15/226(7%)	40	21	__	__	__	__	67	__	__	__	__	__	__	__
							Citrobacter spp.	8/226(4%)	75	__	38	__	__	__	63	__	__	__	__	__	__	__
Gebrekidan Kahsay (2019)	2017	Cross-sectional	Mekelle	6 city buses (handles)	300 handles	66	***S. aureus***	54/300 (18%)	__	__	11	__	__	__	24	32	__	__	__	__	__	__
							E.coli	8/300 (3%)	100	__	38	__	__	__	13	__	__	__	__	__	__	__
							Enterobacter spp	4/300 (1%)	100	__	25	__	__	__	50	__	__	__	__	__	__	__
Darge (2019)	2016-2017	Cross-sectional	Mekelle	medical equipment and surfaces	130 swabs	156	***S. aureus***	46/156 (30%)	89	22	24	28	__	__	___	74	__	__	__	__	__	__
							E.coli	11/156 (7%)	73	9	18	73	__	__	___	__	__	__	__	__	__	__
							K. pneumoniae	11/156 (7%)	91	0	9	55	__	__	___	__	__	__	__	__	__	__
							C. freundii	15/156(7%)	80	0	7	0	__	__	___	__	__	__	__	__	__	__
							P. vulgaris	2/156 (1%)	100	0	0	50	__	__	___	__	__	__	__	__	__	__
Teshome (2020)	2018-2019	Cross-sectional	Dire Dawa, Haramaya, Harar	sludge system, waste stabilization pond, septic tank	water sources	722 (151 E. coli)	***Sludge systems (E. coli)***	61/722(9%)	48	25	28	__	__	18	25	__	27	__	31	23
							Water stabilization Pond (E. coli)	52/722(7%)	54	25	37	__	__	29	29	__	27	__	37	33
							Septic tank (E coli)	38/722(5%)	95	39	50	__	__	42	76	__	45	__	82	55
*Beyene (2017)	2013-2014	cross-sectional (with questionnaire)	Addis Ababa	environment, cows, milk,	193 samples	193	***Staphylococcus spp***	92/193 (48%)	__	0	2	__	__	__	21	56	__	__	__	__
Garedew (2016)	2013	Cross-sectional	Gondar	meat, swab samples from	306	32	***Shigella***	32/306 (11%)	48	__	__	10	__	__	__	__	__	__	__	__
Efa (2018)	2016	Cross-sectional	Jimma	noses	371	371	***S. aureus/ MRSA***	82/371 (22%)/ 31/371(8%)	__	__	52	__	__	__	84	__	__	__	__	__
Mengist (2018)	2015-2016	Cross-sectional	Debre Markos	fingernails and human stool	220	13	***Salmonella spp.***	8/220 (4%)	100	0	0	__	__	__	38	__	__	__	__	__
							Shigella spp.	5/220 (3%)	100	0	0	__	__	__	20	__	__	__	__	__
Marami (2018)	2015-2016	Cross-sectional (with questionnaire)	Haramaya	stool samples	417	21	***S. paratyphi salmon***	4/21(19%)	100	50	0	25	0	__	75	__	__	__	__	__
							S. typhi salmon	9/21(43%)	78	78	67	22	100	__	11	__	__	__	__	__
							Other Salmonella spp	2/21(10%)	100	0	0	0	0	__	50	__	__	__	__	__
							Shigella spp.	6/1(29%)	33	33	0	17	17	__	67	__	__	__	__	__
Eromo (2016)	2014	Cross-sectional	Hawassa	street foods	12 street food items (72 samples)	71	***S. aureus***	7/71(10%)	100	__	__	57	__	__	__	__	__	29	__	__
							E. coli	21/71(30%)	100	10	__	14	__	__	29	__	__	__	__	__
							Klebsiella spp.	7/71(10%)	86	0	14	0	__	__	0	__	__	__	__	__
							Enterobacter spp.	5/71(7%)	60	0	0	0	__	__	0	__	__	__	__	__
							Citrobacter spp.	9/71(13%)	89	0	0	0	__	__	0	__	__	0	__	__
							Proteus spp.	7/71(10%)	80	0	0	0	__	__	0	__	__	__	__	__
							Salmonella spp.	9/71(13%)	100	__	__	__	__	__	__	__	__	__	__	__
Mama (2016)	2015	Cross-sectional (with questionnaire)	Arba Minch	human stool	376	345	***Salmonella spp.***	24/345 (7%)	__	0	__	0	__	__	0	__	__	__	__	__
							Shigella spp.	10/345 (3%)	__	0	__	0	__	__	0	__	__	__	__	__
Abunna (2017)*	2016	Cross-sectional	Modjo	milk, feces, and environment	266	266	***Salmonella spp.***	28/266 (11%)	39	0	0	__	__	__	__	11	11	__	__	__
Takele (2018)*	2016	Cross-sectional	Jimma	Cattle Carcass	195	42	***Carcass***	22/195 (11%)	59	14	0	___	___	___	14	___	32	__	__	__
				Cattle Feces	195		***Cattle feces***	11/195 (6%))	54	27	0	___	___	___	18	___	36	__	__	__
				Human Stool	50		***Human stool***	9/50 (18%)	44	0	0	___	___	___	11	___	22	__	__	__
Tadesse, et.al. (2018)	2016-2017	Cross-sectional	Mekelle	Milk Shop	86	115	***E. coli***	55/86 (64%)	70	0	0	__	__	__	60	40	__	__	__	__
				Fruit Juice	86			27/86 (31%)												
				Dairy Farm	86			33/86 (38%)												

*: Study is included in more than one table

____: no information given, drug not tested

Note: Not all GLASS antibiotics are included in every table as some of them were not tested in any of the studies (drugs removed from Environment Table: Cefotaxime)

Red: Resistance rates over 10%

Yellow: Resistance rates between 5% and 10%

Green: Resistance rates 5% or less

Bold Font: Critically Important Antibiotic

Table 5: *Full Human Study Data*

													Rates of Resistance (GLASS)											
Author(s) (first, et.al.)	Study Year	Region/City	Study Type	Age Group	Setting	Cohort (n)	Organism/Isolate sample size	Method of Sampling	Source	Syndrome	All Bacteria (GLASS)	# Positive/Total (%)	**Ampicillin**	**Gentamicin**	**Ciprofloxacin**	**Ceftriaxone**	**Ceftazidime**	**Meropenem**	sulfamethoxazole-trimethoprim	Cefoxitin	**Amikacin**	Cefotaxime	Oxacillin	**Cefepime**
Alemayehu, et.al. (2019)	2014-2017	Hawassa	Retrospective	Adults/Pediatrics	Inpatient	693	Urine: 251 Body Fluids: 19 Stool: 19 Ear Swab: 42 Eye Swab: 12 Cerebral Spinal Fluid: 7 Blood: 131 Sputum:17 Pus: 190 Nasal Swab: 2 Genital Swab: 3	review of patient data using a designed chart; Age, sex, specimen type, bacterial isolates and antibiotic susceptibility pattern were collected using a data extraction sheet: swabs and samples of differnt body fluids/discharge	blood, urine, pus, genital swab, eye swab, ear discharge, sputum, nasal swab, body fluids, cerebral spinal fluid (CSF) and stool	bacterial infections	*S. aureus*	156/693 (23%)	—	32	32	45	59	—	74	—	—	—	—	—
											S. pneumoniae	7/693 (1%)	—	—	—	—	—	—	67	—	—	—	—	—
											E. coli	116/693 (17%)	92	56	48	67	56	0	81	—	—	—	—	—
											Klebsiella spp.	154/693 (22%)	94	79	41	87	78	14	92	—	—	—	—	—
											Enterobacter spp.	24/693 (4%)	94	79	38	83	67	63	82	—	—	—	—	—
											Citrobacter spp.	32/693 (5%)	91	62	22	64	38	43	55	—	—	—	—	—
											Proteus spp.	16/693 (2%)	89	50	56	62	40	0	83	—	—	—	—	—
											Salmonella spp.	9/693 (1%)	100	50	33	50	100	—	100	—	—	—	—	—
											Shigella spp.	12/693 (2%)	75	40	25	50	100	—	80	—	—	—	—	—
Lamboro, et.al. (2016)	2014	Jimma	Cross-sectional	Adults/Pediatrics	Outpatient	176	21	1 gram stool sample	human stool	diarrhea	*Salmonella*	19/176 (11%)	100	5	—	—	—	—	5	—	—	—	—	—
											Shigella	2/176 (1%)	100	—	—	—	—	—	50	—	—	—	—	—
Mamuye (2016)	2013-2014	Addis Ababa	Cross-sectional	Adults/Pediatrics	Inpatient	478	95	mid-urine (10ml) samples using wide mouthed urine collection cups (	urine	urinary tract infection	*E. coli*	53/478 (13%)	79	23	55	45	—	—	23	—	—	—	—	—
											Klebsiella spp.	7/478 (7%)	86	29	57	71	—	—	57	—	—	—	—	—
											Enterobacter spp.	6/478 (6%)	83	50	17	0	—	—	50	—	—	—	—	—
											Citrobacter spp.	5/478 (5%)	60	60	40	20	—	—	40	—	—	—	—	—
											Proteus spp.	8/478 (8%)	63	25	13	0	—	—	4	—	—	—	—	—
Gorems, et.al. (2018)	2017	Jimma	Prospective	Adults/Pediatrics	Inpatient	173	179	ear discharge was collected with sterile cotton swab of the ear (after cleaning of external ear)	ear drainage	otitis media	*S. aureus*	55/173 (32%)	93	24	27	35	—	—	80	35	—	35	35	—
											E. coli	9/173 (5%)	89	33	11	33	—	—	78	—	11	—	—	22
											Klebsiella spp.	8/173 (5%)	100	38	0	38	—	—	63	—	13	—	—	25
											Enterobacter spp.	3/173 (2%)	100	0	0	33	—	—	0	—	0	—	—	33
											Citrobacter spp.	12/173 (7%)	100	8	0	33	—	—	67	—	17	—	—	17
											P. Vulgaris	22/173 (13%)	100	18	0	36	—	—	50	—	18	—	—	27
											P. mirabilis	10/173 (6%)	100	30	10	50	—	—	90	—	30	—	—	50
Gashaw, et.al. (2018)	2016	Jimma	Cross-sectional	—	Inpatient	1015	118	Different clinical specimens (blood, urine, wound swab, pus, and sputum) were collected aseptically from the patients with signs of healthcare associated infection.	(55%),wound swab/pus (24.2%), blood (15%), and sputum (5.8%).	hospital aquired infections	*S. aureus*	26/118 (21%)	—	50	62	58	—	—	73	54	—	—	54	—
											E. coli	31/118 (25%)	94	71	45	48	52	16	90	61	—	—	—	—
											Klebsiella spp.	30/118 (25%)	100	70	40	53	57	30	80	77	—	—	—	50
											Enterobacter spp.	6/118 (5%)	100	50	50	67	83	17	33	100	—	—	—	33
											Citrobacter spp.	11/118 (9%)	100	64	55	64	73	18	82	55	—	—	—	55
											Proteus spp.	6/118 (5%)	83	50	50	67	67	0	100	67	—	—	—	67
											Serratia spp.	1/118 (0.8%)	100	100	100	100	100	100	100	100	—	—	—	100
Shimekaw, et.al. (2020)	2019	Debre Markos	Cross-sectional (with questionnaire)	Adults/Pediatrics	Inpatient	201	162	wounds were swabbed before they were cleaned with an antiseptic solution	wounds	wound infections	*S. aureus*	52/162 (32%)	85	23	—	13	—	—	50	—	—	—	—	—
											E. coli	19/162(12%)	63	53	15.8	58	47	21	68	—	—	—	—	—
											K. ozaenae	5/162 (3%)	100	40	60	40	40	60	40	—	—	—	—	—
											K. pneumoniae	9/162 (6%)	89	33	33	44	67	56	33	—	—	—	—	—
											Enterobacter spp.	8/162 (5%)	50	38	25	63	63	50	38	—	—	—	—	—
											Citrobacter spp.	6/162(4%)	100	33	17	17	50	50	50	—	—	—	—	—
											Proteus vulgaris	3/162(2%)	100	—	33	67	33	67	33	—	—	—	—	—
											Proteus mirabilis	2/162(1%)	50	50	25	25	25	25	25	—	—	—	—	—
											Serratia spp.	4/162(3%)	100	25	25	75	25	50	75	—	—	—	—	—
Arega, et.al. (2018)	2011-2012	Addis Ababa	Cross-sectional (with questionnaire)	Adults	Inpatient/Outpatient	107	43 gram pos 28 gram neg	2 sets of 10ml each of venous blood was collected from each patient within 24 hours	blood	neutropenic and nonneutropenic fevers	*S. aureus*	31/43 (72%)	39	—	—	68	—	—	39	—	—	—	—	—
											E. coli	1/28 (4%)	100	—	—	—	—	—	100	—	—	—	—	—
											K. pneumoniae	3/28 (11%)	67	—	33	100	—	—	100	—	—	—	—	—
											Citrobacter freundii	1/28 (4%)	100	—	—	100	—	—	100	—	—	—	—	—
Nigussie, et.al. (2016)	2014	Hawassa	Cross-sectional (with questionnaire)	Adults/Pediatrics	Outpatient	240	33	clean catch mid-stream urine samples (5-10ml)	urine	Urinary Tract Infections	*S. aureus*	6/33 (18.2%)	100	0	50	18	—	—	33	—	—	—	18	—
											E. coli	11/33 (33%)	100	73	18	64	—	—	82	—	—	—	—	—
											Klebsiella spp.	3/33 (9%)	100	33	67	67	—	—	100	—	—	—	—	—
											Citrobacter spp.	2/33 (6%)	100	0	0	50	—	—	50	—	—	—	—	—
Fentie, et.al. (2018)	2017	Gondar	Cross-sectional (with questionnaire)	Adults/Pediatrics	Inpatient/Outpatient	216	42	blood samples (5ml adults and 1ml children), absolute neutrophil count (2 ml and 1 ml from adults and children), urine samples, wound and ear swabs (discharge)	blood, urine, wound and ear discharge	hematological and solid type cancers	*S. aureus*	12/42 (29%)	—	8	—	—	—	—	42	25	—	—	—	—
											E. coli	9/42 (21%)	78	22	—	33	—	—	—	—	—	—	—	33
											K. pneumoniae	2/42 (5%)	100	—	—	—	—	—	—	—	—	—	—	—
											Enterobacter spp.	1/42 (2%)	100	—	—	—	—	—	—	—	—	—	—	—
											Citrobacter spp.	2/42 (5%)	100	—	—	—	—	—	—	—	—	—	—	—
Hailu, et.al. (2017)	2013-2015	Bahir Dar	Retrospective	Adults/Pediatrics	Inpatient/Outpatient records	380	234	aseptic swabs of wounds	wounds	wound infections	*E. coli*	33/234 (14%)	94	55	45	25	—	—	77	—	—	—	—	—
											K. pneumoniae	20/234 (9%)	75	0	0	11	—	—	40	—	0	—	—	—
											Enterobacter spp.	5/234 (2%)	100	0	0	40	—	—	0	—	0	—	—	—
											Citrobacter spp.	5/234 (2%)	100	55	45	40	—	—	100	—	0	—	—	—
											Proteus spp.	22/234 (9%)	77	23	28	44	—	—	41	—	13	—	—	—
Terfassa, et.al. (2017)	2015-2016	Oromia (region)	Cross-sectional	Adults/Pediatrics	Inpatient	422	—	stool samples taken in sterile containers	stool	diarrhea	*Salmonella spp.*	30/422 (7%)	—	10	7	3	—	—	—	—	—	—	—	—
											Shigella spp.	9/422 (2%)	—	1	0	0	—	—	—	—	—	—	—	—
Deyno, et.al. (2017)	2016	Hawassa	Prospective	Adults/Pediatrics	Outpatient	117	117	ear discharge was collected with sterile cotton swab of ear	ear discharge	ear infection	*S. aureus*	33/117 (28%)	—	18.2	—	—	—	—	—	—	3	—	—	3
Argaw-Denboba, et.al. (2016)	2012	Dessie	Retrospective	Adults/Pediatrics	Outpatient	1225	1124	sterilized cotton swabs of ear discharge	ear discharge	otitis media	*S. aureus*	266/1124 (24%)	81	14	1	36	—	—	30	—	—	53	—	—
											E. coli	184/1124 (16%)	89	13	9	45	—	—	27	—	—	35	—	—
											Klebsiella spp.	32/1124 (3%)	^ 100	21	0	77	—	—	72	—	—	53	—	—
											Enterobacter spp.	53/1124 (5%)	^ 67	17	2	60	—	—	54	—	—	0	—	—
											Citrobacter spp.	66/1124(6%)	—	2	3	49	—	—	61	—	—	61	—	—
											Proteus spp.	324/1124 (29%)	100	19	7	95	—	—	92	—	—	76	—	—
Mulu, et.al. (2017)	2011-2014	Debre Markos	Retrospective	Adults/Pediatrics	Inpatient	575	280	collection/swabs of pus from wounds, urine, ear discharge, blood, stool, urethral or cervical discharge, nasal or throat swab and CSF.	pus, urine, ear discharge, blood, stool, urethral or cervical discharge, nose,throat and CSF	infections of different sites	*S. aureus*	100/280 (36%)	85	87	46	14	—	—	81	—	—	—	44	—
											S. pneumoniae	18/280 (6%)	—	—	—	—	—	—	—	—	—	—	—	—
											E. coli	39/280 (14%)	33	70	18	3	—	—	11	—	—	—	—	—
											Klebsiella spp.	11/280 (4%)	—	—	—	—	—	—	—	—	—	—	—	—
											Enterobacter spp.	3/280 (1%)	—	—	—	—	—	—	—	—	—	—	—	—
											Citrobacter spp.	3/280 (1%)	—	—	—	—	—	—	—	—	—	—	—	—
											Proteus spp.	4/280 (1%)	—	—	—	—	—	—	—	—	—	—	—	—
											Salmonella spp.	25/280 (9%)	100	—	25	45	—	—	73	—	—	—	—	—
											Shigella spp.	10/280 (4%)	100	—	0	50	—	—	100	—	—	—	—	—
Beshir Tuem, et.al. (2019)	2012-2017	Mekelle	Retrospective	Adults/Pediatrics	Inpatient/Outpatient	308	1080	Urine cultures	urinary tract	Urinary Tract Infections	*S. aureus*	12/308 (4%)	60	43	50	44	100	0	100	—	—	—	—	—
											E. coli	151/308 (49%)	95	28	59	44	67	22	75	—	—	—	—	—
											K. pneumoniae	49/308 (16%)	94	59	64	50	67	0	63	—	—	—	—	—
											Citrobacter spp.	9/308 (3%)	100	20	57	—	50	—	40	—	—	—	—	—
Tsige, et.al. (2020)	2016	Dessie	Cross-sectional	Adults/Pediatrics	Inpatient/Outpatient	266	266 swabs (92 isolates)	wound swab samples	wounds	wound infections	*S. aureus*	26/92 (28%)	—	15	—	—	—	—	16	28	—	—	—	—
											MRSA	66/92 (72%)	—	54	—	—	—	—	54	100	—	—	—	—
Bitew Kifilie, et.al. (2018)	2016	Gondar	Cross-sectional	Adults/Pediatrics	Inpatient/Outpatient	107	107 swabs (101 isolates)	wound swabs, aspirate and biopsies were collected	surgical site wounds(C section and episiotomy sites)	surgical site infection	*S. aureus*	42/101 (42%)	71	—	—	36	43	—	62	17	—	—	—	—
											E. coli	20/101 (20%)	80	35	20	60	40	—	50	—	5	—	—	—
											K. pneumoniae	14/101 (14%)	100	21	14	57	29	—	64	—	0	—	—	—
											Enterobacter spp.	4/101 (4%)	75	25	25	25	25	—	50	—	0	—	—	—
											Citrobacter spp.	4/101 (4%)	100	50	0	0	50	—	25	—	25	—	—	—
Tadesse, et.al. (2018)	2013-2014	Addis Ababa	Cross-sectional	Adults/Pediatrics	Inpatient	94	188 specimens (79 isolates)	wound and nasal swabs	surgical wounds, ear discharge	surgical site infection	*S. aureus*	79/188 (42%)	100	30	36	40	—	—	55	65	—	—	—	—
Teshome, et.al. (2019)	2017	Adama	Cross-sectional	Adults/Pediatrics	ìInpatient/Outpatient	232	232 samples (42 isolates)	stool samples (1g per participant) in collection tube containing 9mL buffered peptone water	stool	diarrhea	*S. dysenteriae*	10/42 (24%)	70	—	60	—	—	—	—	30	—	—	—	—
											S. typhi	9/42 (21%)	67	—	67	—	—	—	—	33	—	—	—	—
											S. flexneri	8/42 (19%)	88	—	63	—	—	—	—	25	—	—	—	—
											Non-typhoidal Salmonell	6/42 (14%)	83	—	83	—	—	—	—	33	—	—	—	—
											S. paratyphi	5/42 (12%)	40	—	40	—	—	—	—	40	—	—	—	—
											S. boydii	4/42 (10%)	50	—	50	—	—	—	—	25	—	—	—	—

*: Study is included in more than one table

Red: Resistance rates over 10%

Yellow: Resistance rates between 5% and 10%

Green: Resistance rates 5% or less

tested

Note: Not all GLASS antibiotics areincluded in every table as some of them were not tested in any of the studies (drugs removed in Human Table: Levofloxacin)

Bold Font: Critically Important Antibiotic

^ : resistance was calculated as number of total resistance/number of total tests, 5 *Klebsiella* isolates (5/5) and 2 *Enterobacter (2/3)*

Patient could have more than one bacterial group, more than one culture/specimen/bacteria isolated per patient

***Table 6*: Full Animal Study Data**

Author(s) (first, et.al.)	Study Year	Study Type	Region/City	Type(s) of Animal	Animal Product	Animal/Animal Product Sample Size	Method of Sampling	Reason for antiomicrobial use	Source	Number of samples/isolates	All Bacteria (GLASS)	Positive Samples (%)	% Glass Antimicrobial Resistance							
													Ampicillin	Gentamicin	Ciprofloxacin	Ceftriaxone	Ceftazidime	Sulfamethoxazole-trimethoprim	Cloxacin	Amikacin
Shecho, et.al. (2017)	2015-2016	Cross-sectional	Haramaya	chickens	__	194	cloacae swabs from health chickens	Treatment of E. coli infections in humans and animals	cloacae of chickens	194 swabs (26 isolates)	*E. Coli O157:H7*	26/194 (13%)	92	8	0	__	__	__	85	__
Mulaw (2017)	2012-2013	Cross-sectional	Bahir Dar	dairy cow	Milk and milk products	384	milk samples from dairy farms collected with sterile tubes	sub therapeutic and prophylactic	milk samples from lactating cows	384 samples (36 isolates)	*Salmonella spp.*	36/384 (9%)	94	0	0	__	__	39	31	__
Wabeto, et.al. (2017)	2015-2016	Cross-sectional	Wolaita Sodo	cattle	raw beef	448	samples areas (flank, thorax, crutch, breast) were swabbed (horizontally then vertically) with a sterile cotton swab soaked in buffered peptone water and then the areas were swabbed again with a dry, sterile swab.	food-borne illness from the consumption of raw meat contaminated with Salmonella species	raw meat	448 samples (56 isolates) (2 carcass samples from each cow)	*Salmonella spp.*	56/448 (13%)	46	13	7	23	__	__	__	__
Kemal, et.al. (2016)	2012-2013	Cross-sectional (with questionnaire)	Haramaya	chickens	eggs	300 eggs and 75 humans	sterile cotton swab dipped in sterile buffered peptone water was used to sample intact egg shell, then shells were sterilised (70% alcohol) and egg contents sampled	treatment of enteric infections	eggs (raw egg consumption, improper handling and storage)	300 egg samples (8 isolates)	*Salmonella spp.*	8/300 (3%)	38	13	__	__	__	__	__	__
Asfaw Ali, et.al. (2020)	2013-2014	Cross-sectional	Debre Zeit and Modjo	chickens	meat	384	Each chicken's ceacum was punctured with a sterile scalpel, and around 5 grams of caecal contents were collected	foodborne illness, control of salmonella infections in chickens sprading to humans through fecal shedding into environment	ceacal contents of slaughtered chickens	56 isolates (1 ceacal sample per chicken)	*Salmonella spp.*	56/384 (15%)	70	__	__	6	__	56	__	__
Sarba, et.al. (2019)	2015-2016	Cross-sectional	5 locations in West Shewa Zone (district)	chickens	chicken visceral organs	191 chickens (694 visceral organ	chickens humanely euthanized and necropsies were done on 694 organ samples (liver, spleen, kidney, ovaries)	diseases in chickens/disease prevention	chicken visceral organs	62 isolates (chickens) 80 isolates (organs) (liver (n = 191) spleen (n = 191), kidney (n = 191) and ovaries (n = 121))	*E. coli*	62/191 (33%) (chickens) 80/694 (12%) (organs)	____	__	0	__	15	0	__	7
Ejo, et.al. (2016)	2014-2015	Cross-sectional	Gondar	chickens /dairy cows, cattle	raw/cooked meat, uncooked eggs, milk	384	stratified random sampling from catering businesses, cafeterias, retail, restaurants, hotels and study foods of animal origin. Food was transferred from dining plate to sampling containers using sterile forceps and spoons	therapeutic or prophylactic use in humans and animals	animal-origin food products	21 isolates,	*Salmonella spp.*	21/384(6%)	14	10	__	0	__	29	__	__
Duguma Abdi, et.al. (2017)	2014-2015	Cross-sectional	Hawassa and Bonga	chickens	N/A	270	bedding samples collected, hand swabs of 9 personnel working in the poultry houses, and interviews of farm attendants, sterile cotton swab soaked in buffered peptone water was used to take cloacal/fecal samples of chickens and swabs were also used to swab both sides of each farm attendants' hands	prescribed based on symptoms without diagnosis of sick animals, blanket prescription (one chicken is sick but farmers give antibiotics to entire flock), to prevent disease outbreak	cloacal swabs, chicken bedding, farmer/worker hands	amples, 17 bedding samples	*Salmonella spp.*	45/270 (17%)	98	0	31	__	__	100	98	__
Sebsibe, et.al. (2020)	2018	Cross-sectional	Jimma	cattle	raw meat	90 cattle (505 swab samples)	swab samples of meat (n= 90), cecal contents of slaughtered animals (n= 90), eviscerator's knife (n= 20), hands (n= 30), cutting boards (n= 20), transporter clothes (n= 20) and transport vehicles (n=15)), and from the butchers shops, meat (n= 90) , of knives (n= 30), butcher's hand (n= 40), cutting board (n= 30) and protective clothing (n= 30) were sampled collected over 8 weeks. Using a structured checklist as well as observation, data on hygienic practices of abattoir and butcher shop were collected.	growth promotion and disese treatment	raw meat	505 swabs (129 isolates)	*E. coli*	102/505 (20%)	91	5	3	4	5	38	__	__
											E. Coli O157:H7	27/505 (5%)	89	4	4	7	7	41	__	__
Abunna, et.al. (2017)*	2016	Cross-sectional	Modjo	dairy cows	milk, feces, and evironment	266	simple random sampling for selection of farms, fecal samples collected from rectum of health lactating dairy cows using disposable gloves into sterile bags, milk samples were taken after teats scrubbed with 705 ethyl alcohol (first 3-4 streams thrown out), milkers' hands were swabbed along with swabs of tanks and buckets befoer the milking process with sterile cotton swabs	growth promotion, treatment and prophylaxis of bacterial infections	lactating cows, personnel (hands), and equipment	266	*Salmonella spp.*	28/266 (11%)	39	0	0	__	__	11	11	__
Beyene, et.al. (2017)*	2013-2014	Cross-sectional (with questionnaire)	Addis Ababa	dairy cows, cattle	meat, raw udder milk,	193	Samples were collected aseptically (swabbing milker's hands before milking, milk samples from cow udders and milking buckets, swabs of butcher hands, cattle carcasses, meat cutting surfaces and equipment	Treatment of E. coli infections in humans and animals	butcher hands, knives, slaughter lines, carcasses, milking buckets, milker hands, udder milk, milk tanks, milk kept in tanks	193 samples raw pooled udder milk (n = 40), tank milk (n = 8), pooled tank swabs (n = 8), pooled bucket swabs (n = 8) and pooled milkier hand swabs (n = 8). From the abattoir carcass swabs (n = 103), pooled slaughter lines swab from hanging materials (n = 6), pooled knife swabs (n = 6), pooled hand swabs (n = 6)	*Staphylococcus spp*	92/193 (48%)	__	0	2	__	__	21	56	__
Shiferaw, et.al. (2016)	2012-2013	Cross-sectional	Bahir Dar	Dairy cows	milk	218	10ml of milk collected aseptically through sterilized test tunes	disease/infection treatment	raw milk	98 isolates (218 raw milk samples)	*S. aureus*	98/218 (45%)	__	4	0	__	__	30	__	__
Takele, et.al. (2018)*	2016	Cross-sectional	Jimma	Cattle	Cattle Carcass	195	carcasses were sampled on four different regions (100 cm squared in each) using carcass sampling poly wipe kits, 1 g of feces from the rectum of the cattle and 1 g of stool sampled from abattoir personnel was collected and transferred to 9ml of buffered peptone water (seperately)	_____	cattle carcasses, cattle feces, human stool	195 carcass swabs, 195 cattle feces (1 g) and 50 human stool (1 g)	*Cattle Carcass*	22/195 (11%)	59	14	0	__	__	14	__	32
					Cattle Feces	195					*Cattle feces*	11/195 (6%))	54	27	0	__	__	18	__	36
					Human Stool	50					*Human stool*	9/50 (18%)	44	0	0	__	__	11	__	22

____: no information given, drug not tested

Note: Not all GLASS antibiotics areinclueded in every table as some of them were not tested in any of the studies (drugs removed in Animal Table: Levofloxacin, Cefepime, Oxacillin)

Red: Resistance rates over 10%

Yellow: Resistance rates between 5% and 10%

Green: Resistance rates 5% or less

Bold Font: Critically Important Antibiotic

Table 7: Full Environmental Study Data

Author(s) (first, et.al.)	Study Year	Study Type	Region/City	Specimen Source	Specimen Source Sample Size (i.e. number of rivers)	Isolates	Method of Sampling	Source	All Bacteria (GLASS)	Positive Samples (%)	% GLASS Antimicrobial Resistance												
											Ampicillin	Gentamicin	Ciprofloxacin	Ceftriaxone	Cefuroxime	Meropenem	Third-generation cephalosporin (Gentamicin)	Cefoxitin	Amikacin	Oxacillin	Cefepime	Levofloxacin
tie, et.al. (20	2018	Cross-sectional (with questionnaire)	Gondar	stool samples from participants	257 food handlers	34	stool collection cups	human stool	*E. coli O157:H7*	5/257(2%)	80	0	0	0	—	—	39	—	—	—	—	—
									Salmonella spp .	3/257 (1%)	0	33	0	0	—	—	33	—	—	—	—	—
									Shigella spp.	26/257 (10%)	62	23	0	4	—	—	33	—	—	—	—	—
Belachew, et.al. (2018)	2017	Cross-sectional	Addis Ababa	river water	32 rivers (94 samples)	90	Grab sampling (from 10 rivers three water samples from 3 different parts of the river in the first round. In the second round 2 water samples were taken at 2 different points in the river, from the remaining 22 rivers, samples were collected in the first and second round.	untreated liquid waste	*E. coli*	23/90(26%)	91	43	52	70	65	—	67	43	—	—	70	35
									K pneumoniae	20/90 (22%)	94	17	17	22	17	—	28	17	—	—	28	17
Tesfaye, et.al. (2019)	2017	Cross-sectional	Addis Ababa	wastewater from hospitals (x2) and abattoir and downstream water	24 samples(6 collections points)	54	wastewater samples from 6 collection points in two rounds were collected into 200ml sterile bottles	wastewater	*E. coli*	18/24 (75%)	100	—	28	28	—	—	—	56	—	—	—	—
									K pneumoniae	8/24 (33%)	—	—	13	25	—	—	13	50	—	—	—	—
									Enterobacter aerogenes	3/24(13%)	100	—	—	33	—	—	—	67	—	—	—	—
									Enterobacter cloacae	6/24(25%)	100	17	50	33	—	—	33	83	—	—	—	—
									Citrobacter spp.	4/24(17%)	100	50	75	75	—	—	50	75	—	—	—	—
									Salmonella spp .	12/24(50%)	100	—	—	0	—	—	8	58	—	—	—	—
Bodena, et.al. (2019)	2018	Cross-sectional (with questionnaire)	Harar	physician mobile phones	226 phones	216	simple random sampling of physician mobile phones and a self administered questionnaire (types of mobile phone, cleaning habits) . phone keyboards, screens, sides, and back were swabbed with a sterile cotton swab moistened with sterile normal saline	mobile phones	*S. aureus*	31/226 (14%)	61	23	10	19	—	—	65	—	—	—	—	—
									Streptococcus spp.	13/226(6%)	46	85	39	—	—	—	15	—	—	—	—	—
									E. coli	14/226(6%)	79	—	14	29	—	—	57	—	—	—	—	—
									Klebsiella spp.	15/226(7%)	60	33	—	—	—	—	67	—	—	—	—	—
									Citrobacter spp.	8/226(4%)	75	—	38	—	—	—	63	—	—	—	—	—
Gebrekidan Kahsay, et.al. (2019)	2017	Cross-sectional	Mekelle	6 city buses (handles)	300 handles	66	50 swab samples from each bus swabbed from front to back (bus surfaces) and of the 600 surfaces seabbed, 300 were of handles	bus surfaces	*S. aureus*	54/300 (18%)	—	—	11	—	—	—	24	32	—	—	—	—
									E coli	8/300 (3%)	100	—	38	—	—	—	13	—	—	—	—	—
									Enterobacter spp	4/300 (1%)	100	—	25	—	—	—	50	—	—	—	—	—
Darge, et.al. (2019)	2016-2017	Cross-sectional	Mekelle	medical equipment and surfaces	130 swabs	156	Sterile cotton-tipped applicator sticks, moistened with sterile normal saline, was used to collect swab speci- men	medical equipment and inanimate surfaces in ICU setting	*S. aureus*	46/156 (30%)	89	22	14	28	—	—	—	59	—	—	—	—
									E coli	11/156 (7%)	73	9	18	73	—	—	—	—	—	—	—	—
									K. pneumoniae	11/156 (7%)	91	0	9	55	—	—	—	—	—	—	—	—
									C. freundii	15/156(7%)	80	0	7	0	—	—	—	—	—	—	—	—
									P. vulgaris	2/156 (1%)	100	0	0	50	—	—	—	—	—	—	—	—
Teshome, et.al. (2020)	2018-2019	Cross-sectional	Dire Dawa, Haramaya, Harar	sludge system, waste stabilization pond, septic tank	water sources	722 (151 E. coli)	sterilized plastic containers were used for sampling. The containers were rinsed three times with sample water before filling with the sample.	activated sludge system, waste stabilization pond, and septic tank system	*Sludge systems (E. coli)*	61/722(9%)	48	35	28	—	—	18	25	—	27	—	31	23
									Water stabilization Pond (E. coli)	52/722(7%)	54	25	37	—	—	29	29	—	27	—	37	33
									Septic tank (E.coli)	38/722(5%)	95	39	50	—	—	42	76	—	45	—	82	55
*Beyene, et.al. (2017)	2013-2014	Cross-sectional (with questionnaire)	Addis Ababa	environment, cows, milk,	193 samples	193	Samples were collected aseptically (swabbing milker's hands before milking, milk samples from cow udders and milking buckets, swabs of butcher hands, cattle carcasses, meat cutting surfaces and equipment	butcher hands, knives, slaughter lines, carcasses, milking buckets, milker hands, rubber milk, milk bucket	*Staphylococcus spp*	92/193 (48%)	—	0	2	—	—	—	21	56	—	—	—	—
Garedew, et.al. (2016)	2013	Cross-sectional	Gondar	Cattle raw meat, swab samples from knives, chopping boards, butcher hands and noses	306	32	raw meat samples were taken from areas considered to be associated with contamination by using sterile plastic bags while swab samples used sterile test tubes. Swabs were taken of 15-20cm squared of the surface of meat cutting equipment and hands of meat handlers.	raw meat, butcher hands, meat cutting surfaces,	*Shigella*	32/306 (11%)	46	—	—	10	—	—	—	—	—	—	—	—
Efa, et.al. (2018)	2016	Cross-sectional	Jimma	noses	371	371	self-sampling technique inserting sterile and moistened swab into nostril and rotating	med student nasal canals	*S. aureus/ MRSA*	82/371 (22%)/ 31/371(8%)	—	—	52	—	—	—	84	—	—	—	—	—
Mengist, et.al. (2018)	2015-2016	Cross-sectional	Debre Markos	fingernails and human stool	220	13	sterile cotton swabs were used to collect samples from under fingernails, stool cups used to take stool samples	human stool	*Salmonella spp .*	8/220 (4%)	100	0	0	—	—	—	38	—	—	—	—	—
									Shigella spp.	5/220 (3%)	100	0	0	—	—	—	20	—	—	—	—	—
Marami, et.al.(2018)	2015-2016	Cross-sectional (with questionnaire)	Haramaya	stool samples	417	21	stool was collected into test tubes containing Cary-Blair transporting media	human stool	*S. paratyphi (Salm)*	4/21(19%)	100	50	0	25	0	—	75	—	—	—	—	—
									S. typhi (Salm)	9/21(43%)	78	78	67	22	100	—	11	—	—	—	—	—
									Other Salmonella spp	2/21(10%)	100	0	0	0	0	—	50	—	—	—	—	—
									Shigella spp.	6/1(29%)	33	33	0	17	17	—	67	—	—	—	—	—
Eromo, et.al. (2016)	2014	Cross-sectional	Hawassa	street foods	12 street food items (72 samples)	71	samples of food items were collected into sterile plastic containers (aseptically)	street foods	*S. aureus*	7/71(10%)	100	—	—	57	—	—	—	—	—	29	—	—
									E. coli	21/71(30%)	100	10	—	14	—	—	29	—	—	—	—	—
									Klebsiella spp.	7/71(10%)	86	0	14	0	—	—	0	—	—	—	—	—
									Enterobacter spp.	5/71(7%)	60	0	0	0	—	—	0	—	—	—	—	—
									Citrobacter spp .	9/71(13%)	89	0	0	0	—	—	0	—	—	0	—	—
									Proteus spp.	7/71(10%)	86	0	0	0	—	—	0	—	—	—	—	—
									Salmonella spp.	9/71(13%)	100	—	—	—	—	—	—	—	—	—	—	—
Mama, et.al. (2016)	2015	Cross-sectional (with questionnaire)	Arba Minch	human stool	376	345 participated in stool	stool collections cups (2 g stool samples from each participant)	human stool/human hands (unwashed)	*Salmonella spp.*	24/345 (7%)	—	0	—	0	—	—	0	—	—	—	—	—
									Shigella spp.	10/345 (3%)	—	0	—	0	—	—	0	—	—	—	—	—
Alnuma, et.al. (2017)*	2016	Cross-sectional	Modjo	milk, feces, and evironment	266	266	simple random sampling for selection of farms, fecal samples collected from rectum of health lactating dairy cows using disposable gloves into sterile bags, milk samples were taken after teats scrubbed with 70% ethyl alcohol (first 3-4 streams thrown out), milkers' hands were swabbed along with swabs of tanks and buckets before the milking process with sterile cotton swabs.	lactating cows, personnel, and equipment	*Salmonella spp.*	28/266 (11%)	59	0	0	—	—	—	—	11	11	—	—
Takele, et.al. (2018)*	2016	Cross-sectional	Jimma	Cattle Carcass	195	42	———	carcasses were sampled on four different regions (100 cm squared in each). using carcass sampling poly wipe kits, 1 g of 25ß (1 per milk/juice) (172 milk samples, of which 86 were from milk shops and 86 from	*Carcass*	22/195 (11%)	59	14	0	—	—	—	14	—	32	—	—	—
				Cattle Feces	195				*Cattle feces*	11/195 (6%))	54	27	0	—	—	—	18	—	36	—	—	—
				Human Stool	50				*Human stool*	9/50 (18%)	44	0	0	—	—	—	11	—	25	—	—	—
Tadesse, et.al. (2018)	2016-2017	Cross-sectional	Mekelle	Milk Shop	86	115	aseptic collection		*E. coli*	55/86 (64%)												
				Fruit Juice	86					27/86 (31%)	70	0	0	—	—	—	60	40	—	—	—	—
				Dairy Farm	86					53/86 (38%)												

*: Study is included in more than one table

—: no information given, drug not tested

Red: Resistance rates over 10%

Yellow: Resistance rates between 5% and 10%

Green: Resistance rates 5% or less

Note: Not all GLASS antibiotics are included in every table as some of them were not tested in any of the studies (drugs removed from Environment Table: Cefotaxime)

Bold Font: Critically Important Antibiotic