Antimicrobial Use in Extensive Smallholder Livestock Farming Systems in Ethiopia: Knowledge, Attitudes, and Practices of Livestock Keepers

Biruk Alemu Gemeda 1*, Kebede Amenu 2, Ulf Magnusson 3, Ian Dohoo 4, Gunilla Ström Hallenberg 3, Gezahegn Alemayehu 1, Hiwot Desta 1 and Barbara Wieland 1

1 Animal and Human Health Research Program, International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia, 2 Department of Microbiology, Immunology and Veterinary Public Health, College of Veterinary Medicine and Agriculture, Addis Ababa University, Bishoftu, Ethiopia, 3 Department of Clinical Sciences, Swedish University of Agricultural Sciences, Uppsala, Sweden, 4 Department of Health Management, Atlantic Veterinary College, University of Prince Edward Island, Charlottetown, PE, Canada

Antimicrobial resistance (AMR) is a major public health threat, and inappropriate antimicrobial use (AMU) in food animal production can contribute to the global burden of AMR in humans. This study was conducted to understand knowledge, attitude, and practice (KAP) of smallholder livestock owners regarding antimicrobial use, residue, and resistance in three agro-ecological zones and production systems in Ethiopia. A cross-sectional study based on structured interviews was conducted. Twenty-one items were used to assess farmers' KAP. Item response theory (IRT) model and Cronbach’s alpha were used to assess the KAP measurement scales. Inferential analyses were used to compare the differences in the practices in terms of the farm and socio-economic characteristics. There was a difference in the type of antimicrobials reported use between agro-ecological zones and production systems. Pastoralists most commonly used antibiotics (86.7%) followed by anthelmintics (70.8%). Overall, tetracyclines (36.4%), aminoglycosides (31.3%), and trimethoprim-sulfonamides (6.2%) were the most frequently used classes of antibiotics across the study sites. Human preparation antibiotics (tetracyclines) were also being used for veterinary purposes by 18.5% of pastoralist households. About 81.6% of livestock owners surveyed reported to have access to veterinary drugs although access varied between agro-ecological zones and production system. About 72.3% of pastoralists administered antibiotics by not following through the full treatment course. Moreover, 70% of respondents were not aware of the recommended withdrawal periods of milk and meat after antibiotic treatment. It was noticed that around 80 and 70% of respondents had a tendency to give doses higher or lower than recommended of antimicrobials, respectively. The study confirms the need for interventions to increase knowledge among smallholder farmers to improve the way antimicrobials in general and antibiotics in particular are used in these settings. In addition, professional involvement, supervision, and guidance can
INTRODUCTION

Antimicrobials are applied in livestock farming for number purposes such as therapeutic (treating sick animals), metaphylaxis (control treatment of whole herd in case of disease outbreak), prophylaxis (preventive treatment), and growth promotion (1). The increasing demand for animal protein especially in developing parts of the world is causing an increase in animal production, and in connection with this, antimicrobial use in food-animal production was estimated to rise by 67% between 2010 and 2030 (2). Apart from the historical and the current positive contribution of antimicrobial use in animal health and production management, there exist a number of possible drawbacks associated with the use of antimicrobials in food-animals. Misuse of antimicrobials in food animals is potentially causing the emergence of antimicrobial-resistant bacteria strains by increasing selection pressure on bacteria to become resistant (2, 3). Other negative consequences associated with antimicrobial use in food animals is the occurrence of unacceptable level of drug residues in food of animal origin. The inappropriate use of antimicrobials in food animals can result in accumulation of toxic and harmful residues in animal products that can further affect the health of consumers largely by causing allergic reactions (4, 5). Therefore, the antimicrobial usage in food animals is indeed becoming a global issue associated with food safety and public health.

The growing concern regarding emergence of bacteria resistant to antimicrobials and their potential for transmission to humans via animal production has led various authorities worldwide to implement measures to decrease antimicrobial use in livestock production (6–9). Though some studies indicate the occurrence of naturally resistant bacteria, the substantial use of antimicrobial agents in animal production is suspected as one of the important factors driving the emergence of antimicrobial resistance in bacterial strains (10–12). Antimicrobial resistance is a major public health crisis (13, 14), threatening the return of untreatable infections and deaths on a massive scale if appropriate actions are not taken (15). To reduce the problem of human infections caused by resistant bacteria transferred from animals, there is continuous pressure to restrict the use of antimicrobials in animals (7, 9).

Apart from the public health impact, an increasing prevalence of antimicrobial resistance, particularly to frequently used antimicrobials in livestock, could also lead to reduced treatment options and increased animal disease and production losses (16). For instance, the World Bank (17) has estimated a 10% production loss in the livestock sector in low- and middle-income countries by 2050. In addition, infected animals may shed these bacteria, posing a threat to other farm animals, household pets, and humans, through direct contact or environmental contamination (11, 18). Infected animals may also act as a reservoir for resistant bacteria, which might enter the food chain (19).

Nowadays, several high-income countries monitor trends in AMU and AMR in livestock (20). These data, however, are generally scarce, particularly from low- and middle-income countries (LMIC) (2). Although access and usage of antimicrobials is improving in LMIC (21), information on actual AMU practices (volume, mode, and reasons for use) is lacking. Specifically, there is a huge gap in the availability of data that can be used to understand the trends over time and to evaluate the linkages between AMU and AMR. The availability of such data can potentially support informed decision-making process especially in connection with the framework of the global action plans formulated by international organizations such as the Food and Agriculture Organization (7), World Organization for Animal Health (9), and WHO (6).

Ethiopia has one of the largest livestock population in Africa with 60.4 million cattle, 31.3 million sheep, 32.7 million goats, and 1.4 million camels (22). Different production systems and agroecological zones coexist, making the process of nationally harmonized guidelines for livestock health and production challenging. This necessitates consideration of representative sampling considering the different agroecological zones of the country in research and development. Similar to many other developing countries, regulations on AMU in livestock in Ethiopia are poorly enforced and farmers have easy access to veterinary drugs; in the worst cases, the drugs may sometimes be falsified or substandard. Moreover, use of drugs in these settings is not commonly supervised by a trained veterinarian. Currently, information regarding AMU in livestock is scarce in Ethiopia, specifically the factors and incentives influencing the use of antimicrobial agents in animals at the farm level are poorly understood. Information on the knowledge, attitudes, and practices (KAP) of farmers regarding antimicrobials and their application will help in formulating strategies to maximize and preserve the benefits of AMU in livestock production with minimal jeopardy to public health. Therefore, we conducted a study to understand knowledge, attitude, and practice of smallholder livestock owners regarding antimicrobial use, resistance and residue in Ethiopia, which can serve as a case study for other comparable production systems.

MATERIALS AND METHODS

Study Area

This study was conducted in three, representative agro-ecological zones and production systems in the Amhara and Oromia regions in Ethiopia: (i) highland mixed crop-livestock production system (Menz Mama and Menz Gera district), (ii) lowland mixed...
crop-livestock system (Abergelle and Zequwala district), and (iii) pastoral system (Yabello and Eleweya districts).

The highland agroecology with a mixed crop-livestock system is typical for areas above 2,200 m above sea level (masl) and is characterized as a system in which livestock husbandry and rain-fed cropping are closely interlinked. Livestock provide inputs (draft power, transport, and manure) to other parts of the farm system and generate consumable or saleable outputs (milk, meat, eggs, hides and skins, wool, hair, and manure). Crop residues are used as livestock feed; animals can be sold and revenues can be reinvested in agriculture or sold when the crop is failing because of weather or pests; cereals and most staple foods are produced in quantities that cover the needs of the family and excess is sold. The principal objective of farmers engaged in mixed farming is to gain complementary benefit from an optimum mixture of crop and livestock production (23).

The lowland agroecology with mixed crop-livestock system denotes elevation of ≤1,500 masl where farmers herd livestock in rangelands and produce crops on fertile land. The system is understood in a dual sense: firstly, it refers to farming systems entirely based on livestock but practiced in proximity to and perhaps functional association with cropping farming systems; secondly, it refers to the livestock subsystem of crop-livestock farming.

The lowland agroecology with the pastoral production system is characterized by sparsely populated pastoral rangelands, where subsistence of pastoralists is mainly based on livestock and livestock products. Livestock husbandry in this system is dominated by goats, cattle, sheep, and camels. Since the main source of food is milk, pastoralists tend to keep large herds to ensure sufficient milk supply and generate income by selling dairy products or live animals. The pastoral production system in some areas has been evolving into an agro-pastoral system (24).

Study Design and Sampling
A cross-sectional study was conducted with 379 smallholder livestock owners in 12 villages in six districts. The agro-ecological zones, districts, and villages were purposively selected to address the representation of different agroecological conditions and production systems. To determine the sample size required for the cross-sectional household survey, the sample size and power calculation tool of Epi InfoTM 7 (CDC, Atlanta, GA) was used. The required sample size of 374 was calculated (assuming allowable error of 6%; design effect of 1.4) and equally distributed to the clusters (agro-ecological zones and production systems). A sampling frame of all households from each of the selected villages was obtained from administration office and 423 households were randomly selected to account for non-participation of the selected households. Finally, the survey was conducted in 379 households. Five households were omitted from the final data analysis due to incomplete information. Each household was visited once.

Assessment Tool
The antimicrobial use assessment tool was developed and set up in Open Data Kit (ODK) on mobile tablet devices. The tool included open-ended and closed questions about household demographics, farm characteristics, management of manure, feed types, animal health constraints, disease prevention, animal health services, antimicrobial use, animal product consumption, and costs related to animal health. Prior to the study, veterinarians in the localities were trained as enumerators and the questionnaire was piloted with 40 livestock owners as a first step of validating the tool. Each interview took approximately 40 min to complete. Commonly available and used drugs at each study site were bought at the local veterinary drug stores and put in a demonstration box to facilitate interaction of enumerators with livestock keepers in gathering information on which drugs are used on the farm.

Data Analysis
Descriptive statistics were computed to describe household demographics and farm characteristics. Answers to open questions were coded into categorical variables and analyzed. Chi-square test was used to test potential associations between categorical variables and a p < 0.05 was considered as statistically significant.

Twenty-one items were used to assess farmers’ knowledge (n = 6), attitudes (n = 6), and practices (n = 9) related to antimicrobial use and resistance. The outcomes concerning knowledge were initially multiple choice or “yes vs. no,” and these were all reclassified as “correct” vs. “incorrect.”

The attitude questions were either “yes vs. no” or on a five-point Likert scale “Strongly disagree” to “Strongly agree.” The five-point Likert scale was grouped as follows: When a respondent indicated “strongly agree” and “agree” with a negative or “undesirable” statement, the response was classified as an “undesirable” attitude. The reverse was considered as a “desirable” attitude. Responses of “neither disagree nor agree” were not included in the analysis.

The response to questions regarding farmer practices were either “yes vs. no” or multiple choice, with the latter being dichotomized as “desirable” vs. “undesirable.” Data were coded by giving 1 to correct or desirable answers and 0 to the wrong or undesirable response to a given question or item.

The percentages of “appropriate” answers (i.e., correct answers in the knowledge section, desirable attitude in the attitude question, and application of appropriate management practices in the practice section) were calculated for each KAP item.

Cronbach’s alpha and the item response theory (IRT) model were used to assess the knowledge, attitude, and practice measurements. Internal consistency was evaluated using Cronbach’s alpha, a parameter that describes the extent to which all the items in a test measure the same concept and it is thus connected to the inter-relatedness of the items within the test (25).

IRT analysis, which provides information on the discrimination and difficulty of each item across different levels of the underlying trait, was used. IRT is based on the assumption of unidimensionality [there is a single unmeasured (latent) trait underlying all items]. The assumption of unidimensionality was evaluated by subjectively evaluating the eigenvalues and factor loadings derived from an exploratory factor analysis.
along with an evaluation of relationships among items within a correspondence analysis. Only questions related to practices met the assumption of unidimensionality.

A two-parameter logistic (2PL) model was used for practice items to calculate the probability that a person with a given level of management expertise would implement a specific item. This model is represented by the following equation (26):

\[ P_{ij} (ui = 1 | \theta = t) = 1/1 + \exp \left[ -1.7a_i (t - bi) \right] \]

where \( a_i \) is the discrimination parameter for item \( i (i = 1, \ldots, n) \), \( b_i \) is the difficulty parameter for item \( i \), \( u_i \) is the response of the person with trait level \( \theta \) to item \( i \), and 1.7 is a scaling constant.

The discrimination parameter is allowed to vary between items. Henceforth, the Item Characteristic Curve (ICC) of the different items can intersect and have different slopes. The steeper the slope, the higher the discrimination of the item, as it will be able to detect subtle differences in the management ability of the respondents. The difficulty parameter reflects how difficult it was for an individual to adopt the appropriate management practice (a high difficulty parameter would indicate that relatively few individuals adopted this practice).

A single composite trait (latent variable) called theta (\( \theta \)) was used for description or analysis of the ability of person. Predicted values of theta were computed for each respondent based on their aggregate response to the practice questions. Inferential statistics (Mann–Whitney \( U \)-test) was used to compare the mean values of the predicted thetas across farm and socio-economic characteristics. A \( p < 0.05 \) was taken as significant for Mann–Whitney \( U \)-test.

Data was analyzed using Stata software version 14 (Texas, USA).

RESULTS

Sociodemographic and Farm Characteristics

Sociodemographic and farm characteristics are summarized in Table 1. Most of the respondents had long experience in keeping livestock but more than half of them reported that they had never been to school (Table 1).

Cattle and sheep were the main livestock species raised by the majority of the respondents (Table 1). The majority of the respondents had mixed type of livestock business with more than three livestock species kept at their farm. Only 16% of the respondents reported to have hired workers on the farm. The main income source for the households was most commonly small ruminant production and crop farming. Most of the respondents reported selling live animals, while sale of milk appeared to be less common. About 50% of respondents reported drinking cow or goat milk at least once per day. Children below 12 years of age were mentioned as the primary milk consumers by the family members in the 69.3% of the surveyed households.

Animal Diseases and Mortality

Table 2 summarizes the type of reported diseases in the past 12 months. Respiratory diseases were the most commonly mentioned diseases in cattle, sheep, and goat, followed by enteric illnesses. In addition, the proportion of respondents reporting an estimated mortality rate of more than 10% are included in Table 2.

Drug Use

From the livestock species present, livestock owners used drugs mostly for sheep, cattle, and goats. There was a difference in the type of drugs used between agro-ecological zones and production systems (Table 3). In the highland mixed crop livestock system, the most frequently reported use drugs were anthelmintics (95%), antibiotics (24%), and acaricides (4.7%). Pastoralists mostly used antibiotics (86.7%) followed by anthelmintics (70.8%) (Table 3). The proportion of anthelmintics usage was higher in highland mixed crop-livestock and pastoral than in the lowland crop-livestock system. The use of acaricides was less common compared to the use of other drugs in all agroecologies and production systems studied. Moreover, only 13% of the pastoralists did not have any antibiotic at hand during the survey. Drugs at hand were mostly stored under suboptimal conditions and exposed to change of temperature, sunlight, and dust. Human preparation antibiotics (tetracyclines) were also being used for veterinary purposes by 18.5% of pastoralist households, indicating high level of crossover use. Overall, tetracyclines (36.4%), aminoglycosides (31.3%), and trimethoprim-sulfonamides (6.2%) were the most frequently used classes of antibiotics across the study sites. Benzimidazoles (49.5%) were the most frequently used anthelmintic drugs followed by macrocyclic lactones (29.9%) and triclabendazole (24.6%). Triclabendazole and fenbendazole were only reported from highland mixed crop-livestock systems (Table 4).

Reasons for Use of Antimicrobials

Use of antimicrobials for prophylactic purposes was common. For the most frequently used drugs over the 12 months prior to the survey, antibiotics were mainly used for treatment purposes, whereas anthelmintics were used for disease prevention and livestock fattening purposes (Figure 1). Respiratory diseases and digestive/enteric parasitic infections were the main reasons for therapeutic use of antimicrobials.

Access and Source of Veterinary Drugs

Overall, about 81.6% of livestock owners surveyed had access to veterinary drugs, although access varied between agro-ecological zones and production systems. Farmers in the highland mixed crop-livestock systems and the lowland pastoral systems reported access to veterinary drugs (97.7 and 93.3%, respectively), while the corresponding figure for livestock owners in the lowland mixed crop-livestock systems was 54%. The main source of veterinary drugs for livestock owners in both the highland and lowland mixed crop-livestock systems was the government or official veterinarian, whereas pastoralists most commonly accessed drugs from private suppliers (Figure 2).

Source of Information and Advice

Almost all respondents in the highland (99%) and 82% of respondents in the lowland mixed crop-livestock systems revealed that they received information and advice on veterinary
TABLE 1 | Household demographics and farm characteristics from a study of antimicrobial use in 374 households in 12 villages in six districts within three agro-ecological zones in Ethiopia.

| Categorical variable | Category | Highland mixed crop-livestock (n = 128) | Lowland mixed crop-livestock (n = 126) | Mid/lowland pastoral (n = 120) | Total (n = 374) |
|----------------------|----------|-----------------------------------------|----------------------------------------|-------------------------------|-----------------|
|                      |          | n %                                     | n %                                    | n %                          | n %             |
| Sex of the household head | Male     | 116 90.6                                | 117 92.9                               | 105 87.5                     | 338 90.4        |
|                       | Female   | 12 9.4                                  | 9 7.1                                  | 15 12.5                      | 36 9.6          |
| Sex of respondent     | Male     | 109 85.2                                | 105 83.3                               | 83 69.2                      | 297 79.4        |
|                       | Female   | 19 14.8                                 | 21 16.7                                | 37 30.8                      | 77 20.6         |
| Age of respondent     | ≤25      | 18 14.1                                 | 8 6.3                                  | 25 20.8                      | 51 13.6         |
|                       | 25–65    | 90 70.3                                 | 95 75.4                                | 67 55.8                      | 252 67.4        |
|                       | ≥ 55     | 20 15.6                                 | 23 18.3                                | 28 23.3                      | 71 18.9         |
| Education level       | Never went to school | 11 5.6                                  | 92 24.6                                | 86 23.2                      | 195 52.1        |
|                       | Primary school | 62 53                                   | 30 25.6                                | 25 21.4                      | 117 31.3        |
|                       | Secondary school/College | 55 88.7                               | 4 6.5                                  | 3 4.8                        | 62 16.6         |
| Illiteracy level      | Female   | 5 26.3                                  | 21 0                                   | 35 94.5                      | 61 79           |
|                       | Male     | 6 5.5                                   | 71 67.6                                | 57 68.7                      | 134 45          |
| Type of livestock species | Cattle | 128 100                                 | 115 91.3                               | 110 91.6                     | 353 94.39       |
|                       | Sheep   | 127 99.2                                | 110 87.3                               | 115 95.8                     | 352 94.12       |
|                       | Goat    | 21 16.4                                 | 124 98.4                               | 117 97.5                     | 262 70.05       |
|                       | Poultry | 122 95.3                                | 65 51.6                                | 79 65.8                      | 266 71.12       |
|                       | Equine  | 111 86.7                                | 119 94.4                               | 119 99.2                     | 271 72.45       |
| Livestock species mix | Keep >3 species | 116 90.6                                | 100 79.4                               | 86 71.7                      | 302 80.75       |
|                       | Keep ≤3 species | 12 9.4                                 | 26 20.6                                | 34 28.3                      | 72 19.25        |
| Hired worker on the farm | Yes     | 4 3.1                                   | 54 42.9                                | 1 0.8                        | 59 15.8         |
|                       | No      | 124 96.9                                | 72 57.1                                | 119 99.2                     | 315 84.2        |
| Main income source for the household | Crop farming | 90 70.3                                 | 36 28.6                                | 47 39.2                      | 173 46.3        |
|                       | Cattle keeping | 1 0.8                                  | 4 3.2                                  | 11 9.2                       | 16 4.3          |
|                       | Small ruminants | 34 26.2                                 | 84 66.7                                | 59 49.2                      | 177 47.3        |
|                       | Other   | 3 2.3                                   | 2 1.6                                  | 3 2.5                        | 8 2.1           |

**GRAZING MANAGEMENT**

|                      | Cattle beef (n = 353) |                      | Cattle dairy (n = 353) |                      | Small ruminant (n = 371) |          |
|----------------------|----------------------|----------------------|-----------------------|----------------------|-------------------------|----------|
|                      | Zero grazing | 65 50.5               | 33 28.7               | 4 4.2               | 63 17.3                | 66 17.8 |
|                      | Fenced individual farm grazing | 27 21.1          | 2 1.7                 | 3 4.0               | 63 17.3                | 66 17.8 |
|                      | Communal grazing | 12 9.4              | 78 67.8              | 8 6.7               | 63 17.3                | 66 17.8 |
|                      | Pastoral | 0 0                   | 2 1.7                | 88 80              | 90 25.5                | 111 31.4 |
|                      | Zero grazing | 4 3.1               | 7 6.1                 | 0 0                 | 11 3.1                | 4 1.1    |
|                      | Fenced individual farm grazing | 69 19.5         | 3 0.8                | 0 0                 | 63 17.3                | 66 17.8 |
|                      | Communal grazing | 55 43             | 104 90.4            | 0 0                 | 63 17.3                | 66 17.8 |
|                      | Pastoral | 0 0                   | 1 0.9                | 110 100            | 90 25.5                | 111 31.4 |
|                      | Zero grazing | 1 0.8             | 3 2.4                 | 0 0                 | 11 3.1                | 4 1.1    |
|                      | Fenced individual farm grazing | 63 17.3         | 3 2.4                | 0 0                 | 63 17.3                | 66 17.8 |
|                      | Communal grazing | 63 17.3         | 118 94.4            | 1 0.8               | 63 17.3                | 66 17.8 |
|                      | Pastoral | 0 0                   | 1 0.9                | 118 99.2           | 90 25.5                | 111 31.4 |
|                      | Free range | 116 95.1           | 27 41.5             | 79 100             | 90 25.5                | 111 31.4 |
|                      | Housed | 6 4.9                   | 38 58.5              | 44 16.5            | 63 17.3                | 66 17.8 |
|                      | Zero grazing | 0 0                | 17 15.5             | 17 6.3             | 63 17.3                | 66 17.8 |
|                      | Fenced individual farm grazing | 62 17.3         | 3 2.7                | 0 0                 | 63 17.3                | 66 17.8 |

(Continued)
drug use from a range of sources: veterinarians and animal health workers (78.3% of respondents), drug stores (9.4%), markets (2.7%), and other farmers (8.6%). Among the pastoralists, 74% reported not to depend on any of these sources and reported to commonly decide based on their own judgement on the kind of drugs to use, dose, and treatment duration.

**KAP Related to Antimicrobial Use, Resistance, and Residue**

Regarding the knowledge about antibiotic use, 84.2% of respondents were well aware that antibiotics are useful for treating and preventing infections. However, more than 50% of the respondents had inadequate understanding of antibiotics and they thought antibiotics could help to treat any kind of diseases, regardless of the cause. Moreover, a relatively high proportion of the respondents (70%) were not aware of the recommended withdrawal periods of milk and meat after antibiotic treatment. Only 20% of livestock owners reported to have heard about antimicrobial resistance and at least 12% mentioned that they had experienced situations where drugs did not work.

About 82% of the respondents were aware that vaccines are generally administered as a preventive measure against infections. There was variation in livestock owners’ knowledge of antibiotics between the different agro-ecological zones and production systems (Table 5).

Regarding the attitudes and perceptions related to antimicrobial use, around 50% stated that they would use antimicrobials more often if antimicrobials were more accessible and cheaper. It was noticed that around 80 and 70% of respondents had a tendency to use doses that were higher or lower than recommended for their animals during treatment, respectively.

About 69% were of the opinion that once the animal started to recover, there was no need to continue giving the full treatment course. Around 21.7% of the respondents had a tendency of keeping leftover antimicrobials at home, as they might be useful in the future (Table 6).

Regarding practices related to antimicrobial use (Table 7), a large proportion of the respondents reported that they commonly consumed milk (36.4%) and meat (51.8%) from animals that had just been treated with antimicrobials, although they assumed it might not be good for human health. The majority of pastoralists

---

**TABLE 1 | Continued**

| Categorical variable | Category | Highland mixed crop-livestock (n = 128) | Lowland mixed crop-livestock (n = 126) | Mid/lowland pastoral (n = 120) | Total (n = 374) |
|----------------------|----------|----------------------------------------|----------------------------------------|-------------------------|-----------------|
|                      |          | n | % | n | % | n | % | n | % |
| Communal grazing     |          | 57 | 47.5 | 88 | 80 | 0 | 0 | 145 | 53.5 |
| Pastoral             |          | 1 | 0.8 | 2 | 1.8 | 41 | 100 | 44 | 16.2 |
| Sale of milk         | Yes      | 3 | 2.3 | 7 | 5.6 | 38 | 31.7 | 48 | 12.8 |
|                      | No       | 125 | 97.7 | 119 | 94.4 | 82 | 68.3 | 326 | 87.2 |
| Sale of live animals | Yes      | 128 | 100 | 125 | 99.2 | 117 | 97.5 | 370 | 98.9 |
|                      | No       | 0 | 0 | 1 | 0.8 | 3 | 2.5 | 4 | 1.1 |
| Continuous Variable  |          | mean | sd | mean | sd | mean | sd | mean | sd |
| Size of the household|          | 5.2 | 1.8 | 6.3 | 2.1 | 7.3 | 2.8 | 6.25 | 2.4 |
| Age of respondent    |          | 39.9 | 12.9 | 41.7 | 12.1 | 40.9 | 16.4 | 40.9 | 13.9 |
| Year of livestock keeping experience |          | 19.9 | 11.4 | 20.7 | 11.1 | 22.5 | 15.2 | 21 | 12.7 |
| Flock size           | Cattle   | 4.5 | 1.6 | 4.9 | 5.7 | 15.9 | 20.5 | 8.3 | 13.2 |
|                      | Sheep    | 18.8 | 12.1 | 16.8 | 16.1 | 26.2 | 39.5 | 20.5 | 25.5 |
|                      | Goat     | 0.5 | 1.2 | 30.6 | 25.1 | 32.7 | 33.5 | 21 | 28 |
|                      | Poultry  | 5.5 | 4.9 | 6.4 | 4.3 | 7.3 | 3.9 | 6.3 | 4.6 |
|                      | Donkey   | 1.7 | 0.8 | 1.5 | 0.7 | 1.7 | 1.6 | 1.6 | 0.9 |

**TABLE 2 | Owner reported occurrence of animal diseases from a total of 374 households in Ethiopia.**

| Disease                        | Cattle (n = 350) | Sheep (n = 352) | Goat (n = 262) |
|--------------------------------|-----------------|-----------------|---------------|
|                                | n | % | n | % | n | % |
| Respiratory diseases           | 95 | 26.9 | 147 | 41.7 | 100 | 38.2 |
| Digestive tract/enteric illnesses | 57 | 16.2 | 86 | 24.4 | 84 | 32.1 |
| Reproductive diseases          | 2 | 0.6 | 5 | 1.42 | 5 | 1.9 |
| Sudden death                   | 6 | 1.7 | 8 | 2.3 | 5 | 1.9 |
| Skin disease                   | 17 | 4.8 | 2 | 0.6 | 1 | 0.4 |
| Gastro-intestinal parasites    | 8 | 2.3 | 2 | 0.6 | 0 | 0 |
| Neurological                   | 0 | 0 | 17 | 4.9 | 20 | 7.6 |
| Systemic disease               | 17 | 4.9 | 0 | 0 | 0 | 0 |
| Other                          | 16 | 4.57 | 11 | 3.1 | 9 | 3.44 |
| No disease                     | 132 | 37.4 | 73 | 20.7 | 38 | 14.5 |
| Mortality >10%                 | 34 | 9.7 | 131 | 37.2 | 121 | 46.2 |
(88.6% consumed milk and 98.3% consumed meat) reported this practice.

Overall, the majority of the respondents (70%) administered antibiotics as advised, but 72.3% of pastoralists administered antibiotics by not following through the full treatment course: “until the animal cured,” “until package empty,” “as long as they can afford,” “one time treatment or continuously over extended period.” All pastoralists self-administered antibiotics to their animals without any laboratory diagnosis. About 98% of pastoralists had good practice with regard to care of expired veterinary drugs, which they either disposed of by burying or returning to the vendor. Indeed, during data collection, 97% of veterinary drugs, which they either disposed of by burying or returning to the vendor. Indeed, during data collection, 97% of pastoralists had good practice with regard to care of expired antimicrobial at hand.

Half of the respondents (50%) reported to have an isolation pen for sick animals and 40% indicated that they would allow animals currently receiving treatment to immediately freely graze with other animals without quarantine. Only 9% of the respondents implemented proper practices regarding disposal of dead animals, either through burial or incineration. The majority (97.5%) of the pastoralists and 4% of respondents from each of the highland and lowland mixed crop production systems revealed consumption of dead animals.

### Assessment of the KAP Measurement Scales

Cronbach’s alphas were poor for the knowledge (0.478) and attitude (0.319) scales, and the inter-item correlations were low. But the Cronbach’s alpha was high for practice scale (0.816). “P4” from the practice scale presented a negative biserial coefficient and was therefore excluded from further analyses. The factor and correspondence analysis suggested that the knowledge and attitude scales were not unidimensional, and consequently, these scales were not used to develop IRT models. Based on a factor analysis of the practice scale, the assumption of unidimensionality seemed to be met. The first eigenvalue was 15 times larger than the second and accounted for 97% of the total variation.

The discrimination ($a_i$) and difficulty ($b_i$) parameters from the IRT analysis of the practice scale are presented in Table 8. Most of the practice items have a similar discrimination level and a similar low level of difficulty except for the item “P8” with higher difficulty ($b_1 = 2.59$), but low discrimination ($a_1 = 1.66$). Items “P5” ($a_1 = 4.53$) and “P9” ($a_1 = 4.47$) had relatively high discrimination power, whereas “P7” had very low discrimination ($a_1 = 0.59$), suggesting that it contributed little to the scale (Table 8). On the basis of all this information, it appears that we
can make a useful, unidimensional seven-item scale (P1, P2, P3, P5, P6, P8, and P9) (Figure 3). Therefore, the scale was able to differentiate among people with a level management expertise of theta between −1.5 to 1 (Figure 4), respectively, answering between 0 and 7 questions correctly.

**Association of Household Demographics and Farm Characteristics, With Desirable Practices**

A single composite trait or variable called theta ($\theta$) was used to characterize the ability of person to perform desirable practices instead of a descriptive summative scale for practice. The composite variable provides an overall estimate of the quality being measured (management ability of person). It takes into account the difficult and discrimination values for each item and hence is a more reliable overall measure than a simple sum of the individual items in the scale. For each respondent, a theta ($\theta$) score was computed and the mean theta of different groups, based on farm and socio-economic characteristics, were compared. Higher means indicated better desirable practice in a specific group of respondents (Table 9).

Among the variables, there were significant differences in the mean theta for agro-ecology/production system, education level, having hired workers on the farm, having more than 3 different livestock species, and household size ($p < 0.05$) (Table 9). Respondents from highland mixed crop livestock production system had a higher mean for theta than those of lowland mixed crop livestock and pastoral production system. However, there were no significant differences in the mean theta according to age group of the respondents or their livestock keeping experience.

**DISCUSSION**

Antimicrobial resistance (AMR) has been recognized as a global health problem. Monitoring of antimicrobial use (AMU) provides useful information for policy development to mitigate AMR risks and therefore has been recommended by international organizations (6, 7, 9).
In Ethiopia, like other sub-Saharan countries, it is generally believed that antimicrobial agents are widely used in animal production systems; however, evidence on antimicrobial usage is limited and often anecdotal. We found only a single survey that evaluated the rational use of veterinary drugs, and it focused only on the college of veterinary medicine and agriculture veterinary teaching hospital and Ada district veterinary clinic of central Ethiopia (27).

This study characterized antimicrobial (includes anthelmintic) use knowledge, attitude, and practice in smallholder settings in three different agro-ecology and production system. To our knowledge, this study is the first
TABLE 6 | Attitudes and perceptions on antimicrobial use, resistance and residues (n = 374).

| Questions                                                                 | Levels                      | Responses          | Highland crop-livestock (n = 128) | Lowland crop-livestock (n = 126) | Mid/lowlnd pastoral (n = 124) | Overall          |
|---------------------------------------------------------------------------|-----------------------------|--------------------|-----------------------------------|-------------------------------|-------------------------------|------------------|
|                                                                           | freq | %   | freq | %   | freq | %   | freq | %   |
| A1. Is consuming milk or meat from animals who were just treated with    |       |      |      |      |      |      |      |      |
| antimicrobials good for human health?                                    | Undesirable | Yes | 2    | 1.6 | 12   | 10.3 | 8    | 7   | 22   | 6.2   |
|                                                                           | Desirable | No  | 125  | 98.4 | 104  | 89.7 | 106  | 93  | 335  | 93.8  |
| A2. If antimicrobials were more accessible and at a lower price, would    | Desirable | No  | 67   | 52.3 | 79   | 62.7 | 44   | 36.7 | 190  | 50.8  |
| you use antimicrobials more often?                                       | Undesirable | Yes | 61   | 47.7 | 47   | 37.3 | 76   | 63.3 | 184  | 49.2  |
| A3. To get a better response, I sometimes give more antimicrobials to    | Desirable | Strongly disagree, disagree | 8    | 6.3 | 49   | 41.2 | 14   | 12.8 | 71   | 20    |
| animals than the dose advised by the veterinary clinician or pharmacist. | Undesirable | Strongly agree, agree | 119  | 93.7 | 70   | 58.8 | 95   | 87.2 | 284  | 80    |
| A4. It is advisable to always reduce the amount/dose of antimicrobial     | Desirable | Strongly disagree, disagree | 9    | 7.1 | 76   | 63.9 | 19   | 17.8 | 104  | 29.5  |
| advised by the veterinary clinican to avoid harming animals.             | Undesirable | Strongly agree, agree | 118  | 92.9 | 43   | 36.1 | 88   | 82.2 | 249  | 70.5  |
| A5. Once the animal starts to feel better, there is no need to continue   | Desirable | Strongly disagree, disagree | 8    | 6.3 | 21   | 17.2 | 81   | 75  | 110  | 30.8  |
| giving the full dose.                                                    | Undesirable | Strongly agree, agree | 119  | 93.7 | 101  | 82.8 | 27   | 25  | 247  | 69.2  |
| A6. I normally keep leftover antimicrobials for a long time at home      | Desirable | Strongly disagree, disagree | 18   | 14.1 | 24   | 20   | 35   | 33  | 77   | 21.7  |
| because they might be useful in the future.                              | Undesirable | Strongly agree, agree | 110  | 85.9 | 96   | 80   | 71   | 67  | 277  | 78.3  |

to investigate antimicrobial usage in livestock by smallholder farmers and pastoralists in Ethiopia. Most of the respondents were adults with many years of experience in keeping livestock.

We found that the use of antimicrobial agents in livestock production was very common among the livestock producers in the study areas. Antimicrobial use may vary widely between and within countries, species, production systems, and individual farms (28). This is also what we found in our study. The data on use of antimicrobial agents were not restricted to any particular livestock species but cut across mainly three livestock species (cattle, sheep, and goat) and equine and poultry in few cases. We observed large variation in the choice of drugs and proportion of respondents who had used antimicrobials among smallholder farmers in the three agro-ecology and production systems included in the study.

Livestock producers in mid/lowland pastoral systems appeared to use antibiotics more frequently than their counterparts in highland and lowland mixed crop-livestock systems. Tetracyclines, aminoglycosides, and trimethoprim-sulfonamides were the most dominantly used classes of antibiotics. Penicillins and macrolides were only reported to be used by the pastoral production systems. This is consistent with studies elsewhere that reported these antimicrobials to be frequently used in food animals in Africa (16, 27, 29–33). The penicillin, tetracycline, and aminoglycoside classes were also the most commonly reported antimicrobial usages across pig production systems in Thailand and Vietnam (34).

Despite known deficits in animal health services in Ethiopia, the livestock owners had good access to veterinary drugs. The main source of veterinary drugs in both the highland and lowland mixed crop-livestock systems was the government or official veterinarians, whereas the pastoralists most commonly accessed drugs from private suppliers. The study found that farmers tended to give higher or lower doses of antimicrobials than recommended. Medically irrational use of antimicrobials in food animals is known to contribute to the emergence, persistence, and spread of resistant bacteria from animals to humans (7). Regarding information and advice on antimicrobial usage in livestock, this study found that a high proportion of the pastoralists rely on their own judgment. Hence, it was not surprising that we found high levels of potentially wrong use of antibiotics. Access to antimicrobials without prescriptions results in increased risk for antimicrobial resistant pathogens, which has also been shown elsewhere in Africa (16, 30).

The inappropriate antimicrobial use by pastoralists might be linked with this ease of access and inadequate advice for farmers (35). Restricting access to antimicrobials by removing...
over-the-counter sales has been identified as a potential route to better antimicrobial use in animals (6, 36).

Moreover, the reported frequent use of cow or goat milk in their meal coupled with a relatively high proportion of farmers not being aware of the recommended withdrawal periods of milk and meat after antibiotic treatment may lead to the potential hazard of repeatedly ingested residues altering the intestinal microbiome and promoting emergence and selection for resistant bacteria in the gastrointestinal tract of humans (37, 38). Withdrawal times are recommended in order to prevent the presence of drug residues in food products (39).

There is a possible risk of an infectious disease being transmitted from animals to human due to a habit of consumption of dead animals. The poor experience of isolating sick animals and improper disposal of dead animals by the majority of the farmers in this study illustrates the negligence of biosecurity practices and other precautionary measures to prevent infectious agents. However, infection prevention and control measures are crucial in order to reduce the incidence of infections and, therefore, reduce the need for antibiotics (40–42). Besides, the non-involvement of laboratory investigations in disease diagnosis prior to antimicrobial further fuels inappropriate use of antimicrobials, which may subsequently lead to the development and spread of AMR (43, 44), which definitely is a big challenge in Ethiopia.
TABLE 8 | Discrimination and difficulty values of the items in the practice scale (sorted by decreasing discrimination).

| Items                                                                 | Coef. | Std. Err. | 95% Conf. Interval |
|-----------------------------------------------------------------------|-------|-----------|--------------------|
| Discrimination                                                       |       |           |                    |
| P5_How do you manage manure?                                         | 4.53  | 0.58      | 3.379 5.685        |
| P9_Who administers the antibiotics?                                  | 4.48  | 0.58      | 3.334 5.685        |
| P1_Do you consume milk from animals who were just treated with antimicrobials? | 3.51  | 0.51      | 2.492 4.52         |
| P2_Do you consume meat from animals who were just treated with antimicrobials? | 3.18  | 0.49      | 2.196 4.154        |
| P3_How long do you use antibiotics in animals?                       | 2.59  | 0.38      | 1.844 3.342        |
| P6_Do you have isolation pen for sick animals?                       | 1.69  | 0.27      | 1.158 2.23         |
| P8_What do you do if an animal dies from disease?                    | 1.67  | 0.92      | −0.146 3.484       |
| P7_Do you allow animals on treatment to immediately freely graze with other animals without quarantine for few days? | 0.59  | 0.12      | 0.344 0.853        |
| Difficulty                                                            |       |           |                    |
| P5_How do you manage manure?                                         | −0.47 | 0.07      | −0.611 −0.321      |
| P9_Who administers the antibiotics?                                  | −0.45 | 0.07      | −0.598 −0.308      |
| P1_Do you consume milk from animals who were just treated with antimicrobials? | −0.32 | 0.08      | −0.478 −0.171      |
| P2_Do you consume meat from animals who were just treated with antimicrobials? | 0.21  | 0.08      | 0.056 0.37         |
| P3_How long do you use antibiotics in animals?                       | −0.63 | 0.09      | −0.814 −0.469      |
| P6_Do you have isolation pen for sick animals?                       | 0.2   | 0.09      | 0.0153 0.396       |
| P8_What do you do if an animal dies from disease?                    | 2.59  | 0.69      | 1.248 3.946        |
| P7_Do you allow animals on treatment to immediately freely graze with other animals without quarantine for few days? | −0.63 | 0.23      | −1.092 −0.184      |

Despite the frequent use of antimicrobials by smallholder farmers to maintain good livestock health and production in the studied areas, there was overall poor knowledge about the purpose of antibiotics and their proper use. Poor knowledge may be the result of the fact that more than half of the smallholder farmers never went to school or have otherwise poor education. Farmers generally thought antibiotics could help treat any kind of diseases regardless of the causes. This could result in inappropriate antibiotic use with potential risks of antibiotic-resistant pathogens that will lead to treatment failures, increased mortality and production losses, and also possible human health risks (45). Founou et al. (46) also indicated that 86.6% of multidrug-resistant bacteria were detected in food animals at farms in Africa, which may be indicative of widespread use of antibiotics in farming practices, whereas 52.4% detected at abattoirs reflected bacteria surviving the processing stage and, therefore, able to reach the consumer.

Another finding of our study was the difference in the ability of respondents to give desirable response for practice on the basis of the agro-ecology and production system. Respondents
from highland mixed crop livestock production systems were more likely to have higher ability to give desirable response for practice questions than those in lowland mixed crop livestock and pastoral production systems. There was a link between better ability of a person to perform desirable practices and higher education level. Besides the education barrier, limited professional supervision can also have an impact on a farmer’s practice as reflected in the pastoral production system. Wrong public perception, attitudes, and beliefs about antibiotics are strong determinants of medically irrational use of antibiotics (43). It has been suggested that increasing knowledge and awareness about antibiotics and antibiotic resistance are key components of rational antibiotic use in human medicine (6, 7). While improving the knowledge and attitudes of smallholders can encourage them to practice medically rational use of antimicrobials, addressing the drivers for use is as important to achieve lasting behavior change.

IRT methods allow researchers to improve measurement scale construction and evaluate the quality of individual items. In this study, the 2PL logistic models fitted practice scales reasonably well. The Cronbach’s alpha for knowledge and attitude scales was low, reflecting that the items were not internally consistent. But the corresponding value yielded for practice was high. The likely reason for low reliability may be that knowledge and attitude measurement items cover different dimensions like purpose of antimicrobial use, disease prevention, antimicrobial residue, and biosecurity issues and evaluate different concepts. The implications of these findings are that future research should focus on assessment of more extensive knowledge and attitude measurement scales toward AMU, AMR, and residues. Approaches that identify the quality of individual items that specifically measure one thing at a time for the knowledge and attitude scale construction should be attempted. The focus should be on the coverage of the content the instrument is supposed to measure. It is also necessary to include new items with high discrimination of knowledge and attitude and greater accuracy of measurement.

Findings of this study help to target future interventions to reduce antimicrobial use and resistance in the smallholder livestock systems of Ethiopia. While it is impossible to extrapolate data from this study to other sub-Saharan African countries, tools and methods used here can easily be applied elsewhere.

**LIMITATION OF THE STUDY**

Though the study was piloted with 40 participants, there was no instrument to objectively assess the honesty and recall ability of the participants. The training of enumerators on data collection and use of a demonstration box with drugs to facilitate the enumerator in gathering antimicrobial usage information helped to reduce this possible bias. In addition, as with most surveys, there is the possibility of social desirability bias that respondents may be over- or underreporting antimicrobial use.

The scale used to assess the knowledge and attitudes regarding antimicrobial use consists of a mix of different topics like disease prevention, drug residue, and biosecurity. The number of questions was also minimized with the intention of reducing the time taken to complete the questionnaire.

**DATA AVAILABILITY STATEMENT**

The datasets generated for this study are available on request to the corresponding author.

**ETHICS STATEMENT**

Ethics approval (Certificate Ref. No: VM/ERC/01/07/10/2018) was obtained from the Addis Ababa University, College of Veterinary Medicine and Agriculture Animal Research Ethics Review Committee, and the Institutional Research Ethics Committee of the International Livestock Research Institute (ILRI-IREC2018-24). Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.
**AUTHOR CONTRIBUTIONS**

BG, BW, KA, and UM conceived and designed the study. BG, BW, HD, and GA followed up and monitored data collection. BG, ID, and GH analyzed the data. BG, BW, ID, GH, and KA conceptualized and drafted the paper. All authors read, commented on, and approved the final manuscript.

**FUNDING**

This work was funded by the Animal Health Flagship of the CGIAR Research Program on Livestock, CGIAR Research Program on Agriculture for Nutrition and Health (A4NH), and the German Academic Exchange Service (DAAD). The funder played no role in the design or conclusion of the study.

**ACKNOWLEDGMENTS**

The authors thank the Amhara and Oromia regional agricultural research institutes and their technical staff who were involved in field research and data collection. Mr. Louis Omoya who set up the Open Data Kit (ODK) survey tool and individuals who commented on the tool are highly acknowledged. Farmers and pastoralists are greatly appreciated for sharing their experience and knowledge.

**REFERENCES**

1. Economou V, Gousia P. Agriculture and food animals as a source of antimicrobial-resistant bacteria. *Infect Drug Resist.* (2015) 8:49–61. doi: 10.2147/IDR.S55778
2. Van Boeckel TP, Brower C, Gilbert M, Grenfell BT, Levin SA, Robinson TP. Global trends in antimicrobial use in food animals. *Proc Natl Acad Sci USA.* (2015) 112:5649–54. doi: 10.1073/pnas.1503141112
3. Aarestrup FM, Wegener HC, Collignon P. Resistance in bacteria of the food chain: epidemiology and control strategies. *Expert Rev Anti Infect Thy.* (2008) 6:733–50. doi: 10.1586/14787210.6.5.733
4. Mensah SE, Koudandé OD, Sanders P, Laurentie M, Mensah GA, Abiola FA. Antimicrobial residues in foods of animal origin in Africa: public health risks. *Rev Sci Tech.* (2014) 33:987–96. doi: 10.20506/rst.33.3.2335
5. Baynes RE, Dedonder K, Kissell L, Marmulak T, Smith G, et al. Health concerns and management of select veterinary drug residues. *Food Chem Toxicol.* (2016) 88:112–22. doi: 10.1016/j.fct.2015.12.020
6. World Health Organization (WHO). Global Action Plan on Antimicrobial Resistance. Geneva: WHO (2015). Available online at: http://www.wpro.who.int/entity/drug_resistance/resources/global_action_plan_eng.pdf (accessed January 15, 2019).
7. Food and Agriculture Organization of the United Nations (FAO). The FAO Action Plan on Antimicrobial Resistance 2016-2020. Rome (2016). Available online at http://www.fao.org/3/a-i5996e.pdf
8. World Health Organization (WHO). Use of Antimicrobials Outside Human Medicine and Resultant Antimicrobial Resistance in Humans. Fact sheet No. 268. WHO: Geneva (2002).
9. World Organization for Animal Health (OIE). The OIE Strategy on Antimicrobial Resistance and the Prudent Use of Antimicrobials. Paris: OIE (2016).
10. Chantziaras I, Boyen F, Callens B, Dewulf J. Correlation between veterinary antimicrobial use and antimicrobial resistance in food-producing animals: a report on seven countries. *J Antimicrob Chemother.* (2014) 69:827–34. doi: 10.1093/jac/dkt443
11. Marshall BM, Levy SB. Food animals and antimicrobials: impacts on human health. *Clin Microbiol Rev.* (2011) 24:718–33. doi: 10.1128/CMR.00002-11
12. Aarestrup FM. Veterinary drug usage and antimicrobial resistance in bacteria of animal origin. *Basic Clin Pharmacol Toxicol.* (2005) 96:271–81. doi: 10.1111/j.1742-7843.2005.pto960401.x
13. Centers for Disease Control (CDC) (2013) Antibiotic Resistance Threats in the United States. Atlanta, GA: CDC.
14. World Health Organization (WHO). Antimicrobial Resistance: Global Report on Surveillance. Geneva: WHO (2014).
15. O’Neill J. Antimicrobial Resistance: Tackling a Crisis for the Health and Wealth of Nations. London: World Health Organization (2014).
16. Alhaij NB, Isola TO. Antimicrobial usage by pastoralists in food animals in North-central Nigeria: the associated socio-cultural drivers for antimicrobials misuse and public health implications. *One Health.* (2018) 6:41–7. doi: 10.1016/j.onehlt.2018.11.001
17. World Bank. Drug-Resistant Infections: A Threat to Our Economic Future. Washington, DC: World Bank. License: Creative Commons Attribution CC BY 3.0 IGO (2017). Available online at: http://documents.worldbank.org/curated/en/323311493969937578/pdf/114679-REVISED-v2-Drug-Resistant-Infections-Final-Report.pdf
18. Hartanyo, SH, Chau ML, Fillon L, Ariff, AZBM, Kang JSL, Aung KT, et al. Sick pets as potential reservoirs of antibiotic-resistant bacteria in Singapore. *Antimicrob Resist Infect Control.* (2018) 7:106. doi: 10.1186/s13756-018-0399-9
19. Chang Q, Wang W, Regev-Yochay G, Lipsitch M, Hanage WP. Antibiotics in agriculture and the risk to human health: how worried should we be? *Evol Appl.* (2015) 8:240–7. doi: 10.1111/eva.12185
20. EMA and ESVAC. Available online at: https://www.ema.europa.eu/en/documents/report/sales-veterinary-antimicrobial-agents-30-european-countries-2016-2016-eighth-esvac_en.pdf (2018).
21. Klein E, Boeckel T, Martinez E, Pant S, Gandra S, Levin SA, et al. Global increase and geographic convergence in antibiotic consumption between 2000 and 2015. *Proc Natl Acad Sci USA.* (2018) 112:5649–54. doi: 10.1073/pnas.1712951115
22. CSA (Central Statistics Agency). Agricultural Sample Survey 2017/18. Statistical Bulletin 587, Vol. 2 Report on Livestock and Livestock Characteristics (Private Peasant Holdings). (2018) Addis Ababa: Central Statistical Agency (CSA).
23. Lemma G, Smit GN. Crude protein and mineral composition of major crop residues and supplemented feeds produced Vertisols of Ethiopia. *J S Afr Vet Assoc.* (2011) 83:15–23. doi: 10.4102/jsava.v83i1.16
24. Gizaw S, Tegegne A, Gebremedhin B, Hoekstra D. Sheep and goat production in Ethiopia: current status and perspectives. *J Anim Feed Sci.* (2004) 13:293–300. doi: 10.1177/1547843005009004
25. Klein E, Boeckel T, Martinez E, Pant S, Gandra S, Levin SA, et al. Global increase and geographic convergence in antibiotic consumption between 2000 and 2015. *Proc Natl Acad Sci USA.* (2018) 112:5649–54. doi: 10.1073/pnas.1712951115
26. Oleksandr SC, Stark S, Chan K, Drasgow F, Williams B. Fitting item response theory models to two personality inventories: issues and insights, multivariate. *Behav Res Multivariate.* (2015) 3604_03
27. Beyene T, Endalamaw D, Tolossa Y, Feyisa A. Evaluation of rational antibiotic usage in dairy herds in Pennsylvania. *J Dairy Sci.* (2008) 91:6535–46. doi: 10.3168/jds.S0022-0302(05)73004-3
28. Sawant AA, Sordillo LM, Jayarao BM. A survey on antibiotic usage in dairy herds in Pennsylvania. *J Dairy Sci.* (2005) 88:2991–9. doi: 10.3168/jds.S0022-0302(05)72979-9
29. Edgar H, Swan G, Van Vuuren M. A survey of antimicrobial usage in animals in South Africa with specific reference to food animals. *J S Afr Vet Assoc.* (2012) 83:15–23. doi: 10.4102/sava.v83i1.16
30. Eltayb A, Barakat S, Marrone G, Shaddad S, Lundborg CS. Antibiotic use and resistance in animal farming: a quantitative and qualitative study on knowledge and practices among farmers in Khartoum. *Sudan Zoosones Public Health.* (2012) 39:330–8. doi: 10.1111/j.1863-2378.2012.01458.x

31. Katakweba A, Miamo MMA, Olsen JE, Muhairwa A. Awareness of human health risks associated with the use of antibiotics among livestock keepers and factors that contributes to selection of antibiotic resistance bacteria within livestock in Tanzania. *Livest Res Rural Dev.* (2012) 24:170. Available online at: http://www.lrrd.org/lrrd24/10/kata24170.html

32. Ojo OE, Fabusoro E, Majasan AA, Dipoeul MA. Antimicrobials in animal production: usage and practices among livestock farmers in Oyo and Kaduna States of Nigeria. *Trop Anim Health Prod.* (2016) 48:189–97. doi: 10.1007/s11250-015-0939-8

33. Ojo OE, Fabusoro E, Obaweda RA. Pattern of antimicrobial usage in livestock animals in south-western Nigeria: the need for alternative plans. *Onderstepoort J Vet Res.* (2015) 82:1–6. doi: 10.4102/ojvr.v82i1.816

34. Coyne L, Arief R, Benigno C, Giang V, Huong LQ, Jeamsripong S, et al. Antimicrobial use and resistance in animal farming: a systematic review and database searches. *Bull World Health Organ.* (2018) 96:101–9. doi: 10.2471/BLT.17.199679

35. Sommanustweechai A, Chanvatik S, Sermsinsiri V, Sivilaikul S, Patcharanarumol W, Yeung S, et al. Antibiotic distribution channels in Thailand: results of key-informant interviews, reviews of drug regulations and database searches. *Ball World Health Organ.* (2018) 96:101–9. doi: 10.2471/BLT.17.199679

36. Adesokan HK, Akanbi IO, Akanbi IM, Obaweda RA. Pattern of antimicrobial use in livestock animals in south-western Nigeria: the need for alternative plans. *Onderstepoort J Vet Res.* (2015) 82:1–6. doi: 10.4102/ojvr.v82i1.816

37. Cerniglia CE, Pineiro SA, Kotarski SF. An update discussion on the current status and in the risk for the development of human intestinal epithelial cells. *Food Chem Toxicol.* (2017) 109:253–63. doi: 10.1016/j.fct.2017.09.004

38. Gokulan K, Cerniglia CE, Thomas C, Pineiro SA, Khare S. Effects of residual levels of tetracycline on the barrier functions of human intestinal epithelial cells. *Food Chem Toxicol.* (2017) 109:253–63. doi: 10.1016/j.fct.2017.09.004

39. Oladele P, Eltayb A, Barakat S, Marrone G, El Shaddad S, Lundborg CS. Factors that contribute to the selection of antibiotic resistance bacteria in livestock in Khartoum. *Sudan Zoosones Public Health.* (2012) 39:330–8. doi: 10.1111/j.1863-2378.2012.01458.x

40. Anonymous. *A New Animal Health Strategy for the European Union (2007-2013) Where Prevention is Better Than Cure.* (2007). Available online at: https://ec.europa.eu/food/sites/food/files/animals/docs/ah_policy_strategy_2007-13_en.pdf

41. Lauen N, Persoons D, Ribbens E, de Jong E, Callens B, Strubbe M, et al. Relationship between biosecurity and production/antimicrobial treatment characteristics in pig herds. *Vet J.* (2013) 198:508–12. doi: 10.1016/j.tvjl.2013.08.029

42. Courtenay M, Castro-Sanchez E, Fitzpatrick M, Gallagher R, Lim R, Morris G. Tackling antimicrobial resistance 2019–2024—the UK’s five-year national action plan. *J Hosp Infect.* (2019) 101:426–7. doi: 10.1016/j.jhin.2019.02.019

43. Machowska A, Lundborg CS. Drivers of irrational use of antibiotics in Europe. *Int J Environ Res Public Health.* (2019) 16:27. doi: 10.3390/ijerph16020027

44. Chokshi A, Sifri Z, Cennimo D, Hornig H. Global contributors to antibiotic resistance. *J Global Infect Dis.* (2019) 11:36–42. doi: 10.4103/jgid.jgid_110_18

45. Chan YH, Fan MM, Fok CM, Lok ZL, Ni M, Sin CF, et al. Antibiotics nonadherence and knowledge in a community with the world’s leading prevalence of antibiotics resistance: implications for public health intervention. *Am J Infect Control.* (2012) 40:113–7. doi: 10.1016/j.ajic.2011.03.017.

46. Founou LL, Amoako DG, Founou RC, Essack SY. Antibiotic resistance in food animals in Africa: a systematic review and meta-analysis. *Microbial Drug Resist.* (2018) 24:648–65. doi: 10.1089/mdr.2017.0383

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2020 Gemeda, Amenu, Magnusson, Dohoo, Hallenberg, Alemayehu, Desta and Wieland. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.