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Examining antibiotic use in Kenya: farmers' knowledge and practices in addressing antibiotic resistance

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Abstract

Background Antibiotics hold the promise of mitigating the spread of livestock diseases while enhancing productivity. However, there is global concerns surrounding the improper handling and administration of antibiotics, which has led to an alarming rise in antimicrobial resistance (AMR). Kenya is currently listed as an AMR hotspot. This study assesses farmers' knowledge and practices on antibiotics in livestock production, knowledge on AMR as well as factors influencing farmers' knowledge of antibiotic safety and resistance, and antibiotics use.

Methods A across-sectional, quantitative survey was employed with 319 farming households in five counties in Kenya. Multivariate regression analysis was used to identify explanatory factors.

Results About 80% of households use antibiotics in their livestock, and 58% administer the antibiotics themselves. The vast majority of farmers buy antibiotics without a prescription. Antibiotics are used for both therapeutic and non-therapeutic purposes, the latter mainly in form of growth promoters and feed enhancers in poultry. The withdrawal periods reported by farmers are shorter than the officially recommended periods. Although the majority of farmers reported risky antibiotic practices, most (76%) were well aware of bacterial AMR. Nineteen of 21 knowledge statements on AMR and safe use of antibiotics were answered correctly by 55–89% of respondents, indicating considerable farmer knowledge on different aspects of antibiotics risk, while certain knowledge gaps remain. Number of livestock owned was the factor most positively influencing farmers' knowledge on AMR and safe use.

Conclusion Kenya has made notable progress towards creating knowledge and awareness of farming communities on the risks and requirements associated with antibiotic use in livestock. Nonetheless, farmers' antibiotics practices continue to constitute considerable risk of further AMR development. This shows that knowledge is not enough to ensure fundamental behavioral change. There needs to be an enabling environment driven by (1) effective policy interventions and enforcement to ensure compliance with set guidelines for antibiotic use; (2) research on and deployment of alternatives, such as probiotics, vaccinations and disease prevention measures, (3) continued public awareness raising and education using multiple channels to reach farmers and, (4) strengthened cross-sector, multi-stakeholder collaboration to address the multi-dimensional complexities of AMR.

Keywords Antibiotic resistance, Safe use, Knowledge and practices, Livestock

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Background

On a global scale, livestock contributes around 40% of total agricultural output in developed countries and 20% in the developing countries. The sector also employs approximately 1.3 billion people worldwide. Livestock is crucial socioeconomically in Africa, supporting the livelihoods of 250–300 million people who rely on it for a living. Notably, the African cattle sector accounts for between 30 and 80% of the continent's agricultural GDP. Sub-Saharan Africa alone accounts for nearly 85% of the world's livestock keepers (Erdaw 2023). Despite its economic importance, cattle productivity in Africa remains poor, owing in part to pest and disease outbreaks aggravated by climate change. Antibiotics have been frequently utilized in this context to reduce the spread of numerous cattle diseases and increase productivity (Durso and Cook 2014). However, the use of antibiotics in livestock has sparked public debate globally, primarily due to concerns about inappropriate use and the associated risk of antimicrobial resistance (AMR) (Livermore 2009). AMR poses a significant threat to effective infection treatment, in humans and animals, leading to increased morbidity and mortality rates, as well as escalated healthcare costs (O'Neill 2014; Murray et al. 2022).

Livestock stands as the primary and growing consumer of antibiotics, a trend that aligns with the escalating global demand for meat, particularly in developing regions of the world (van Boeckel et al. 2015). Van Boeckel et al. (2015) estimate that between 2010 and 2030, the global consumption of antimicrobials will witness a 67% increase, soaring from 63,151 ± 1560 tons to 105,596 ± 3605 tons. The surge in antibiotic usage within animal husbandry has raised concerns about further rise in the development of AMR, environmental contamination, and threats to food safety.

Murray et al. (2022) found out that the largest burden rates of bacterial AMR were in Sub-Saharan Africa, and that the size of AMR as a health problem is comparable to, if not greater than, HIV and malaria. Kenya is classified as an AMR hotspot (Kariuki et al. 2022), and the rising rate of antibiotic resistance in Kenya is primarily attributed to a lack of and/or ineffective enforcement of existing regulations, resulting in antibiotic overuse and misuse in patients, livestock, and agriculture, as well as their unrestricted release into the environment (Kariuki et al. 2013; Ayukekbong et al. 2017). Antibiotics are heavily used by chicken producers for preventative purposes, to increase productivity, and for self-prescription (Kariuki et al. 2023; Mutua et al. 2023). Antibiotic misuse is enabled in Kenya by the availability of antibiotics without a prescription and through unregulated supply chains (Kemp et al. 2021; Omolo et al. 2023). The prevalence of resistant bacteria in humans, animals, food, and the environment, combined with inadequate infection management, hygienic conditions, and incorrect food handling techniques, all contribute to the spread of AMR. Furthermore, the Kenya Veterinary Association (KVA) estimated in 2009 that 33% of antibiotics on the shelves were substandard or counterfeit, increasing the risk of resistance and other negative effects (KVA 2016). According to a comprehensive review (Tang et al. 2017), there is a substantial association between elevated AMR levels in livestock and the following consequences for farm production, either as a drop in overall productivity or an increase in disease treatment costs. However, data from Africa are conspicuously sparse, with only one study from the 179 analyzed coming from the continent. Thus, despite widespread recognition of the difficulties associated with antibiotic usage in cattle in Kenya, quantifiable research on the socioeconomic and environmental consequences of bacterial AMR is lacking.

Kenya has taken proactive measures to combat AMR, including the formation of the National Antimicrobial Stewardship Interagency Committee (NASIC) in 2015 and the adoption of the National Policy for the Prevention and Containment of Antimicrobial Resistance in 2017, which was accompanied by a corresponding National Action Plan covering the period 2017–2022. These initiatives create a shared framework for collaborative action in Kenya among all stakeholders and sectors to prevent AMR. Reinforcing AMR surveillance, increasing research and development, engaging in lobbying and public education, supporting the rational use of antimicrobials, guaranteeing robust regulation and quality assurance, and facilitating education and training programs are among the key initiatives (WHO 2022).

Despite these concerted efforts, significant challenges persist with regard to achieving the desired antimicrobial stewardship standards (Hughes et al. 2023). A prevailing gap is the limited evidence on key stakeholders' awareness, knowledge and practices related to antibiotic risks and safe use in livestock in Kenya. This paper examines key knowledge areas among farmers, identifies factors associated with that knowledge and certain behaviours. The purpose of this study was: (i) to investigate the knowledge and practices of Kenyan livestock farmers regarding the use of antibiotics, and their awareness of AMR; (ii) to assess factors contributing to the existing knowledge and practices on antibiotics and safe use among users; and (iii) to recommend further steps towards an effective response to the complex AMR problem. The study aims to provide insights that can inform targeted interventions and policy recommendations for addressing AMR in the livestock sector.

Methods

A farmer survey was carried out in Kenya between July and August of 2021. An interdisciplinary research team comprised of CABI socio-economists, animal health experts from Vétérinaires Sans Frontières Suisse (VSF Suisse), and technical support from the University of Warwick developed and implemented the study. Primary data collection employed a cross-sectional survey design.

Study location

Primary data were collected from five Kenyan counties: Trans Nzoia and Elgeyo Marakwet in the North Rift region, Narok in the South Rift region, and Machakos and Isiolo in the Eastern region (see Fig. 1). These counties comprise a diverse mix of smallholder and large-scale farmers, as well as a significant proportion of livestock farmers, primarily engaged in dairy production. These locations encompass a spectrum of environments, ranging from semi-arid areas in Isiolo to regions with higher rainfall in Trans Nzoia. Consequently, there are distinct variations in biophysical characteristics, including rainfall patterns, water availability, and accessibility to markets. These differences are pivotal in shaping the production systems adopted in different regions. These systems include pastoralist communities in Isiolo and large-scale, intensive mixed crop and livestock farmers in Narok, among others.

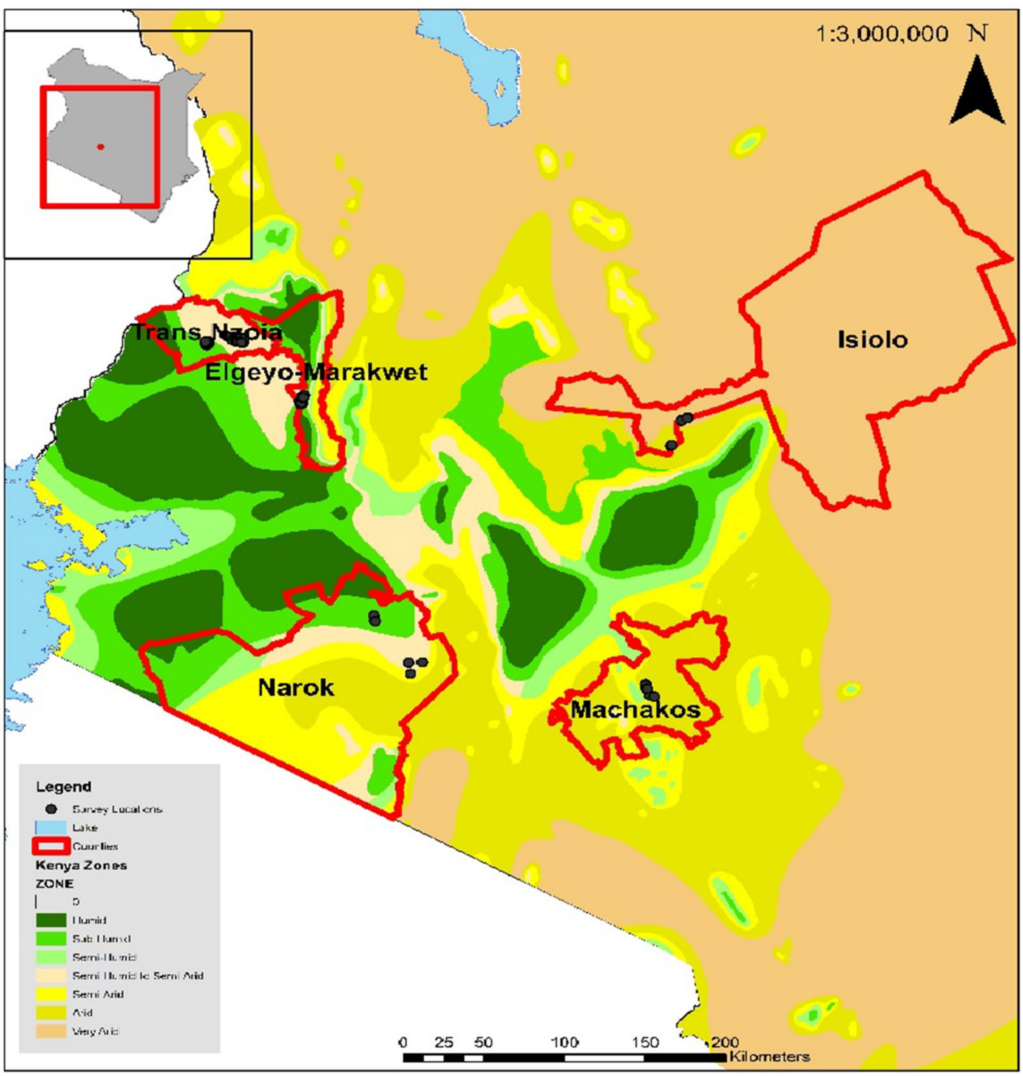

Fig. 1 Map of Kenya showing study counties (county borders marked in red)

Data collection

A systematic sampling approach was employed to ensure an unbiased representation of the target population, comprising livestock farmers in the specified counties, regardless of farm size. Following Singh's 2014 method for sample determination, a sample size of 319 was determined, with 50 respondents from large farms and 269 from small farms.

Sampling was carried out at the ward level for each of the five counties. The process involved listing the number of wards in each sub-county within every county, followed by the random selection of 3 wards in each sub-county by picking every other 5th ward from a list of all the wards. In collaboration with community leaders, ward extension officers compiled comprehensive lists of households that accurately represented the target population within each county.

For the household selection, a random sampling process was utilized where, while in the field of study, walking along rural roads, and picking the second household and skipping the next on both sides of the road alternately. This resulted in the selection of 269 small-scale livestock producers from the prepared lists, while 50 large farm owners were purposefully selected from within the wards (10 large farms in each county).

Household survey

Data were collected through face-to-face interviews using a researcher-administered questionnaire. A structured questionnaire was developed and coded on Open Data Kit (ODK) data collection app on tablet computers. The survey gathered data on various aspects, including the respondents' knowledge about antibiotics, their antibiotic use in livestock, and the associated risks. Additionally, the survey collected data on actions taken by farmers to promote prudent antibiotic use, prevent the emergence and spread of AMR.

During the interviews, household heads, spouses, or any family member responsible for making farming decisions, such as crop selection, input usage, and sales decisions, were targeted for interviews. Prior to full deployment, the questionnaire underwent a rigorous pretesting phase to ensure its reliability and effectiveness in gathering relevant information.

Empirical methods

Farmers were asked a number of questions to assess their knowledge on specific aspects of AMR and safe use. Respondents' knowledge on antibiotics resistance was rated on a 3-point Likert scale; 1 = true, 2 = false and 3 = don't know. Regarding safe use, respondents were to select 1 = agree, 2 = disagree and 3 = don't know. The knowledge statements were coded by assigning 1 to correct and 0 to incorrect responses. Using Principal Component Analysis (PCA), indices for the two knowledge categories were developed. In order to estimate the effect of interaction between user's knowledge on resistance and safe use, multiple regression models were estimated with indices for antibiotics safe use and resistance as the dependent variables. The model was specified as:

$$y_i = \alpha_i + \beta x_i + \gamma AB_i + \varepsilon_i, \tag{1}$$

where y_i is an index for the knowledge questions for household i, independent variables included; *antibiotics resistance_i* and is a vector for safe use (1 = yes, 0 = otherwise), and ε is the error term. Other explanatory variables, x was included in the model; sociodemographic characteristics (sex of respondent, age category, education level, production system, income levels), and geographical location of respondent i.

We further estimated the factors that determine a farmer's use of antibiotics, to guide design of future awareness programs. Probit regression model was estimated. The probit model assumes that while we only observe the values of 0 and 1 for the variable Y, there is a latent, unobserved continuous variable Y′ that determines the value of Y. Thus, for this study we assume that use of antibiotics (Y′) can be specified as follows:

$$Y_i' = \beta_i + \beta x_i + u_i. \tag{2}$$

And that:

$$Y_i = 1, \quad \text{if } Y' > 0,$$
$$Y_i = 0, \quad \text{otherwise.}$$

where x_i is a set of explanatory variables for respondent i, β represent a vector of unknown parameters, and u represent a random disturbance term.

Data analysis

Quantitative survey data was downloaded from ODK as xls files. Analysis was done using MS Excel for descriptive statistics and STATA 16.1 to compare means, t test and multiple regression to determine factors that influenced knowledge and practice on antibiotics safe use and resistance.

Ethical considerations

All informants provided oral consent. Prior to requesting consent, the enumerators explained the study and its aims. Participants were informed of the research purposes including the benefits and risks of participation. It was explicitly explained that participation was voluntary and no cash or direct benefits would be expected. The respondents were also assured of their right to withdraw from study participation at any point, and necessary precautions were made to ensure and maintain confidentiality and anonymity throughout the study.

Ethical clearance was obtained from the University of Warwick, Humanities and Social Sciences Research Ethics Committee (RE: HSSREC 162/20-21), and research permit in Kenya was granted by National Commission for Science, Technology and Innovation (NACOSTI), (Permit: NACOSTI/P/21/11152).

Results and discussion

Farmer demographic characteristics

The characteristics of survey respondent are summarized in Table 1. Overall, 56% of respondents were male across all counties, varying from 43% in Elgeyo Marakwet to 82% in Narok. The average household size was found to be 6 people, varying from 5 to 7 across counties. The majority of respondents, comprising 46%, fell within the age category of 36–55 years, while individuals over 55 years constituted 24%, and the youth aged 26–35 represented 23%. This demographic distribution

Table 1 Respondent characteristics (% responses). TLU source: Gilbert and Rushton (2020)

Characteristic	Elgeyo Marakwet (n = 62)	Isiolo (n = 63)	Machakos (n = 68)	Narok (n = 68)	Trans Nzoia (n = 58)	Total (n = 319)
Respondent sex						
Female	56.5	47.6	51.5	17.6	46.6	43.6
Male	43.5	52.4	48.5	82.4	53.4	56.4
HH size (mean ± SD)	6.0 (2.1)	7.0 (3.4)	5.2 (2.3)	6.9 (4.5)	6.0 (2.6)	6.2 (3.1)
Respondent age category (%)						
18–25 years	3.2	12.7	4.4	8.8	1.7	6.3
26–35 years	22.6	25.4	25.0	29.4	12.1	23.2
36–55 years	58.1	46.0	35.3	50.0	41.4	46.1
> 55 years	16.1	15.9	35.3	11.8	44.8	24.5
Where respondent resides (%)						
Urban	0.0	0.0	0.0	0.0	1.7	0.3
Suburban	0.0	0.0	2.9	2.9	51.7	10.7
Rural	100.0	100.0	97.1	97.1	46.6	89.0
Highest level of education (%)						
No schooling completed	0.0	47.6	4.4	25.0	0.0	15.7
Pre-primary	1.6	6.3	16.2	5.9	1.7	6.6
Primary	45.2	30.2	32.4	30.9	25.9	32.9
Secondary school	29.0	9.5	33.8	22.1	46.6	27.9
Tertiary education	19.4	3.2	5.9	13.2	22.4	12.5
Technical/vocational training	4.8	3.2	7.4	2.9	3.4	4.4
Primary source of income (%)						
Crop/pasture production	56.5	33.3	58.8	44.1	50.0	48.6
Livestock and poultry	25.8	36.5	11.8	45.6	27.6	29.5
Casual labour	1.6	4.8	11.8	2.9	1.7	4.7
Formal employment	12.9	12.7	7.4	4.4	8.6	9.1
Business/trading	3.2	9.5	10.3	2.9	3.4	6.0
Remittances/pension	0.0	3.2	0.0	0.0	8.6	2.2
Total monthly income (KES) (%)[a]						
< 5000	11.3	15.9	10.3	1.5	10.3	9.7
5001–10,000	48.4	36.5	39.7	26.5	25.9	35.4
10,001–40,000	32.3	41.3	42.6	42.6	39.7	39.8
40,001–70,000	4.8	4.8	7.4	25.0	12.1	11.0
> 70,000	3.2	1.6	0.0	4.4	12.1	4.1
Tropical livestock Unites (TLU) (mean ± SD)	3.0 (2.5)	5.0 (6.1)	2.1 (1.9)	21.9 (35.2)	4.0 (4.2)	7.4 (18.2)

[a] KES = Kenya Shillings; KES5,000/US$50; KES10,000/US$100; KES40,000/US$400; KES70,000/US$700

indicates that livestock keeping in the study areas predominantly involves mature individuals, accounting for approximately 70% of the respondents. The vast majority of respondents in four of the five counties live in rural settings, reflecting the predominantly agrarian nature of the surveyed regions. However, in Trans Nzoia, over half of the respondents live in sub-urban environments, indicating a higher level of urbanization or proximity to urban centres in that county. Educational attainment among the respondents varied, with 33% having attained primary education, followed by secondary education (28%), and tertiary education (13%). Livestock was reported to be kept by majority of respondents, with the majority (90%) engaging in poultry keeping, 52% involved in sheep farming, 44% in goats, 48% in cattle, and 35% in dairy farming. However, crop production was found to be the primary source of income across all counties, with Machakos, Elgeyo Marakwet, and Trans Nzoia showing a particularly strong reliance on crop agriculture. In contrast, Narok and Isiolo demonstrated a relatively higher contribution from livestock farming. Monthly household incomes varied from KES5000 to KES40,000 for the majority of households, translating to an annual income between KES60,000 and KES480,000 (approximately US$600–US$4800). Narok County stands out with a significantly higher number of Tropical Livestock Units (TLU) at 21.9 (SD 35.2), surpassing the average TLU of 7.4 (SD 18.2) across all the surveyed counties. Following closely is Isiolo County, which also exhibits a slightly elevated TLU of 5.0 (SD 6.1). This pattern is anticipated, given that these counties are predominantly pastoral, and a substantial portion of their residents engage in livestock keeping as a primary livelihood (FAO 2023). The higher TLU values in Narok and Isiolo may indicate a higher likelihood of increased antibiotic use in livestock due to the intensive and widespread practice of livestock farming in these counties, highlighting the potential for greater antibiotic resistance concerns in these pastoral regions.

Farmers' knowledge and practices on antibiotics use

Antibiotics use

Among the surveyed farmers, 80% use antibiotics agents in their animal production practices, and 58% reported to administer antibiotics themselves, a household member, or a neighbour without having sought the guidance from a trained professional. On the other hand, 42% reported to rely on technical personnel like veterinarians or extension officers for administration. The vast majority of farmers (95%) bought antibiotics without a prescription. They relied on over-the-counter antibiotics, contributing to the risk of treating undiagnosed problems, administering wrong products, and/or over- or under-dosing. As such, a considerable proportion of antibiotic use in livestock occurs without professional guidance, potentially leading to improper dosing and misuse (Oluwasile et al. 2014; Kemp et al. 2021).

The prevalent use of antibiotics for non-therapeutic purposes, notably as growth promoters in poultry, was noted as a common practice among the surveyed farmers. This finding aligns with patterns observed in other African countries, such as Ghana, Rwanda, and Nigeria, where antibiotics are routinely administered at sublethal doses, leading to concerns about the potential emergence of AMR due to continuous exposure to low levels of antibiotics (Van et al. 2020).

The continuous exposure of bacteria to antibiotics, even at levels insufficient to cause immediate death, creates an environment conducive to the evolution of antibiotic-resistant strains. Our results highlight the need for heightened awareness and regulatory measures to address the non-therapeutic use of antibiotics in agricultural practices. While acknowledging the potential benefits of appropriate antibiotic use for treatment and prevention, the study underscores the critical importance of proper diagnosis before initiating treatment. This precautionary approach is essential to avoid unnecessary antibiotic use and, subsequently, the development of antibiotic resistance (De Bruyne et al. 2014).

Approximately 61% of respondents were unable to recall any name of the antibiotics used and lacked labels to assist the research team in determining the antibiotics used, indicating a lack of awareness and tracking of antibiotic usage. Over 60 antibiotic products were commonly used by those who provided names (specific trade names not shown), representing six different antibiotic classes (Table 2). Although anticoccidials are not antibiotics, they are included here, since most manufacturers mix them with an antibiotic for potentiated sulfa in poultry. Tetracyclines were the most prevalent, found in 61% of the reported products, followed by penicillin (26%). Similar usage patterns were found by Kisoo et al. (2023) and Samuel et al. (2023) among livestock holders in Kenya and Uganda. Tetracycline's popularity can be attributed to its broad-spectrum activity and low cost, making it a commonly used antibiotic in animal health practice.

We categorised reported antibiotics based on the classification by the Antimicrobial Advice Ad Hoc Expert Group (AMEG) of the European Medicines Agency (EMA) for antibiotics used in animals: A—Avoid, B—Restrict, C—Caution and D—Prudence. This classification considers the importance of the antibiotic class in human medicine, knowledge of factors influencing the likelihood of resistance transfer, as well as the importance and availability of alternative antibiotics in veterinary medicine (EMA 2020). The colour

Table 2 Most commonly used antibiotics in the study counties (% responses) (n = 319, multiple responses)

Antibiotics used (class)[a]	Elgeyo Marakwet	Isiolo	Machakos	Narok	Trans Nzoia	Total (%)
Tetracycline, oxytetracycline, doxycycline[2]	31	81	52	72	47	61
Penicillin[3], amoxicillin[2]	8	21	16	49	27	26
Anticoccicidial[b]	62	0	23	9	20	18
Tylosin, erythromycin[1]	4	10	6	5	17	8
Gentamicin, streptomycin[1]	0	0	0	7	20	5
Sulfadiazine[2]	4	4	0	0	3	2
Potentiated sulfa drugs[c2]	0	0	0	0	3	1
Others	8	17	39	21	10	19

[a] AMEG categorisation, [1]C—caution; [2]D—prudence; [3]category varies depending on type of penicillin: A—avoid, C—caution, or D—prudence

[b] Not an antibiotic but most manufacturers mix with an antibiotic for potentiated sulfa in poultry

[c] Include sulfa/pyrimethamine and sulfa/trimethoprim combinations

coding in Table 2 shows that the reported antibiotics largely fall in the groups "Caution" (5–8% use by product) and "Prudence" (1–61% use by product), while "others" (19%) could not be categorized. For category C substances, there are in general alternatives in human medicine in the EU, but there are few alternative antibiotics in veterinary medicine for certain indications (EMA 2020). Although most of the reported products in this study are in the lower risk categories, there is considerable risk associated with the common use patterns of these antibiotics in livestock in East Africa as demonstrated by Samuel et al. (2023) who found alarmingly high resistance levels in *E. coli* against tetracycline, ampicillin and sulphonamides in western Uganda.

Antibiotic use varied by county, with some counties showing a preference for certain antibiotics over others. For example, Elgeyo Marakwet had higher anticoccidial use, while Isiolo and Narok had higher tetracycline use. The observed difference in antibiotic use, specifically higher anticoccidial use in Elgeyo Marakwet compared to higher tetracycline use in Isiolo and Narok, may be attributed to various factors such as local farming practices, prevalent livestock diseases, and regional variations in agricultural systems. The choice of antibiotics is often influenced by the specific health challenges faced by livestock in a given region. For instance, Elgeyo Marakwet may experience a higher incidence of coccidiosis, a disease caused by protozoan parasites, leading to an increased use of anticoccidials. On the other hand, Isiolo and Narok may encounter conditions that necessitate the frequent use of tetracycline for effective disease management. Factors like veterinary practices, access to veterinary services, and awareness campaigns in different regions may contribute to variations in antibiotic preferences among farmers (Emes et al. 2023).

In addition to using antibiotics to treat sick animals, 24% of respondents reported routinely adding antibiotics to animal feed or water as a preventive measure. The administration frequency of antibiotics to water/feed exhibited considerable variation among respondents, with the majority (79%) reporting doing so less than five times per month. However, a notable 5% of respondents reported a much higher frequency, adding antibiotics to livestock/poultry feed or water more than 20 times per month. This practice of frequent, preventive antibiotic use raises significant concerns about the potential consequences of prolonged exposure and the associated risk of the emergence of AMR, as highlighted by O'Neill (2014). The study's findings underscore the need for heightened awareness and regulatory measures to address the frequency and purpose of antibiotic use in agriculture. Promoting responsible antibiotic practices, emphasizing proper diagnosis before treatment, and implementing guidelines to limit preventive antibiotic use are crucial steps in mitigating the risks associated with AMR. Policymakers, veterinary professionals, and farmers alike play essential roles in ensuring the judicious use of antibiotics to preserve their effectiveness and prevent the escalation of AMR.

Sources of antibiotics

The majority of households surveyed (78%) acquired antibiotics from agro-vet shops, making these establishments the primary source of antibiotics for farmers. Veterinarians were the second most common source (37%) (multiple responses). A small proportion of respondents (2%) reported obtaining antibiotics from other sources, such as the government, friends, family, or previous purchases. The survey shows widespread, unguided use of antibiotics in Kenya to treat bacterial diseases in domestic animals and as growth promoters. This practice enhances the risk of incorrect dosages being administered, and withdrawal periods before slaughter or milking not being observed, which may contribute to the development of AMR (Muriuki et al. 2001). The data further indicates that a small proportion, specifically 6% of the respondents from Elgeyo Marakwet and Trans-Nzoia counties, who reported that agro-vet shops required a prescription for purchasing antibiotics but rely on farmers history. This finding is noteworthy as it suggests a potential gap in the regulation and enforcement of antibiotic sales in agro-vet shops in these areas. The low demand for prescriptions aligns with the study conducted by Akande-Sholabi and Oyesiji (2023), which found that antibiotic usage was often guided by past prescriptions from doctors or other healthcare professionals. The lack of prescription requirements in agro-vet shops raises concerns about the responsible use of antibiotics in livestock farming. Without proper oversight, there is a risk of indiscriminate and uninformed antibiotic use, which can contribute to the development of AMR. The findings therefore underscore the importance of strengthening regulatory mechanisms and promoting responsible antibiotic stewardship practices in the agricultural sector among both the agro-vet shops and farmers to be able to seek professional advice and prescriptions before using antibiotics for their livestock.

Withdrawal period

The recommended withdrawal period for antibiotics is variable, depending on the type, product, and animal. For example, oxytetracycline has a minimum withdrawal period of 3 days (Hassan 2012), while our findings indicate a minimum of 1 day by most farmers. Similarly, amoxicillin has a recommended minimum withdrawal period of 3 days compared to our findings that showed farmers only withdrew products for a minimum of 1 day. Non-adherence to these withdrawal periods heightens the risk of antibiotic residues persisting in animal products. In our study, observed withdrawal periods for most antibiotics were shorter than recommended. For instance, Tetracycline had a mean withdrawal period of 4 days, constituting a quarter of the recommended maximum withdrawal of 12 days (Table 3). This suggests an increased risk of antibiotic residues in consumed milk and meat, potentially compromising food safety. A comparable trend was noted in Tanzania, where varying levels of adherence to withdrawal periods were reported (Anika et al. 2019; Caudell et al. 2020). These findings underscore the need for awareness and legal enforcements to ensure adherence to recommended withdrawal periods among livestock farmers. Observing proper withdrawal periods is vital for minimizing the presence of antibiotic residues in animal products, contributing to overall food safety, and aligning with efforts to combat AMR.

Awareness and knowledge on AMR

Our study revealed a considerable awareness among respondents, with 76% being aware of AMR. Family or friends emerged as the most common source of information on AMR, accounting for 46% of respondents seeking information from this informal network. About a third of farmers (31%) received information from medical doctors and other health professionals, while only 24% received AMR information from trained veterinarians and animal health workers (Table 4). This finding highlights an opportunity for enhancing the role of veterinarians, animal health workers and other sources in disseminating accurate and up-to-date information on AMR to farmers. Strengthening the capacity of these professionals to communicate effectively with farmers could improve the overall understanding and responsible use of antibiotics. Omulo et al. (2017) showed that obtaining information from reliable sources, such as clinicians and community pharmacists, positively influenced views on antibiotic use, leading to better practices such as consulting a clinician,

Table 3 Withdrawal periods (days), recommended, and observed by farmers, for the most commonly reported types of antibiotics. Source: Caudell et al. (2017)

Antibiotic used	Recommended withdrawal period (days)[a]	Farmer practice (days)			
		Mean	Std. Dev.	Min	Max
Gentamicin, streptomycin	4	2.44	1.42	1	5
Penicillin, amoxicillin	10	3.98	2.55	1	8
Sulfadiazine	2–12	1.75	0.96	1	3
Tetracycline, oxytetracycline, doxycycline	5–10	4.37	3.22	1	12
Tylosin, erythromycin	10	2.20	1.26	1	4

[a] Withdrawal period varies depending on type of animal and product e.g. eggs, milk, meat, offal

Table 4 Farmers' sources of information on AMR (% responses) (n = 319, multiple responses)

Information source	Elgeyo Marakwet	Isiolo	Machakos	Narok	Trans-Nzoia	Total
Family member or friend	32	71	33	65	29	46
Medical doctor, or other medical health worker e.g., nurse	36	22	23	31	42	31
Vet Doctor, or another animal health worker	24	13	25	14	42	24
Media (newspaper, TV, radio)	34	4	8	8	21	15
Studied in school	6	7	19	4	15	10
Agrovet shop	14	7	8	6	6	8
Specific campaign	0	4	4	10	8	5
Extension worker/plant doctor	6	2	4	0	13	5
Books and journals	8	2	4	0	4	4
NGOs	0	9	0	2	0	2
Internet including social media	4	2	0	4	0	2
Others[a]	2			2	2	1

[a] Others: mainly own experience (e.g., one said practically from experience on his livestock in relation to ticks that have become resistant). Other farmer groups, pharmaceutical companies

not using non-prescribed antibiotics, and completing antibiotic courses. Multiple other information sources, such as media, schools, agro-vets, extension workers, accounted for 2–15% of the responses. These sources represent critical entry points for both legal enforcement and raising awareness about the safe use of antibiotics. By disseminating information on AMR via school curricula, agro-vet shops, media outlets, and extension services, it is possible to reach a wider audience and create a culture of responsible antibiotic use in the agricultural sector and beyond.

A 3-point scale was used to assess farmers' knowledge of AMR. The farmers were presented with statements about AMR and asked to rate them as true, false or 'don't know' (Table 5). The statements covered topics such as how AMR develops, how resistant bacteria spread, and potential sources of such bacteria. Care was taken when formulating the questions to avoid introducing bias, as all but three of the statements were true.

Farmers had varying levels of knowledge regarding AMR. For instance, as many as 88% of farmers correctly rated the statement "AMR occurs when your body

Table 5 Farmers' knowledge of AMR (% responses) (n = 319)

Knowledge questions	True	False	Don't know
1. AMR occurs when your body becomes resistant to antibiotics and they no longer work as well	3	**88**	9
2. If bacteria are resistant to antibiotics, it can be very difficult or impossible to treat the infections they cause	**87**	4	9
3. AMR is an issue that could affect me or my family	**82**	8	10
4. AMR is an issue in other countries but not here	11	**66**	23
5. AMR is only a problem for people who take antibiotics regularly	23	**55**	22
6. Bacteria which are resistant to antibiotics can be spread from person to person	**67**	12	21
7. Antibiotic-resistant infections could make medical procedures like surgery, organ transplants and cancer treatment much more dangerous	**72**	8	20
8. Antibiotic-resistant bacteria can spread from animals to animal products people eat, such as chicken, milk and meat	**76**	7	17
9. Antibiotic-resistant bacteria can spread from animals to crop produce, through unclean water or soil	**65**	15	20
10. Antibiotic-resistant bacteria can spread from animals to the environment, through animal feces	**65**	12	23
11. You can become sick with bacterial infections that are resistant to antibiotics if you eat food that's been infected with antibiotic-resistant bacteria and not properly prepared or cooked	**78**	7	15
12. You can become sick with bacterial infections that are resistant to antibiotics if you handle unclean animals and don't wash your hands	**73**	9	18
13. One can become sick with bacterial infections that are resistant to antibiotics if you touch or use unclean surfaces and don't wash your hands	**74**	9	17

Numbers in bold indicate correct answers becomes resistant to antibiotics and they no longer work as well" as false (statement 1), showing that these farmers were aware that AMR is not related to the body's resistance, but rather the ability of bacteria and fungi to develop mechanisms to withstand the effects of the drugs.

Farmers displayed knowledge of some aspects of AMR while lacking knowledge in others. It is worth noting that the lowest proportion of correct responses was related to the scope of the problem (statement 5), with 55% answering that 'resistance only affects those who take antibiotics regularly' to be false. In contrast, the proportion of correct responses was relatively high (65–88%) for all other statements related to hygiene, transmission and consequences of AMR. This finding demonstrates the need for addressing the misconceptions about the selective impact of AMR and emphasizing the broader consequences of AMR for both individuals and the broader community. As such, our paper recommends leveraging on the existing knowledge base, to implement educational efforts that build upon these foundations, offering more comprehensive insights into the multifaceted nature of AMR and its implications.

To assess farmers' knowledge and awareness of antibiotic safety, a series of true–false knowledge statements on antibiotic use were presented to them, and they were asked to indicate whether they agreed, disagreed, or didn't know about each statement. The results showed that, on average, majority of farmers had good knowledge on antibiotic safety. A majority (84–89%) answered correctly to statements on sources of spread and the importance of certain safeguarding practices, including withdrawal periods (Table 6). These results are in stark contrast to some of the risky practices that majority of farmers reported, including, purchase of antibiotics without prescription, and non-adherence to withdrawal periods.

Notable knowledge gaps were revealed as well. As many as 77% incorrectly believe that they are not at risk of getting infected with resistant bacteria as long as they take their antibiotics correctly. Also, 57% of farmers incorrectly agreed with the statement "It's okay to buy the same antibiotics you used to treat your animal when they had the same symptoms before," indicating a tendency to rely on previous experiences rather than seeking professional advice before administering antibiotics. Additionally, only 34% of farmers disagreed with the statement "people should not keep antibiotics and use them later for other livestock diseases," highlighting the practice of using leftover antibiotics for different purposes, which is not recommended and can contribute to AMR (Table 6).

Overall, this study indicates a growing awareness and understanding among Kenyan farmers of several AMR aspects. Kariuki et al. (2022) and WHO (2022) point out that Kenya, driven by its national action plan on AMR, has made considerable progress over the last years to build public awareness and knowledge on AMR and risky antibiotics use. However, more needs to be done. This survey showed a need for targeted education and awareness-raising to address specific knowledge gaps, and to ensure that accurate information reaches farmers through multiple channels, including trained veterinarians and animal health workers. Importantly, more research is needed to understand farmers' perceptions and decision-making processes. For example, what motivates farmers to apply practices that they know are potentially harmful to their animals and themselves? And, what would stimulate a change towards safer practices? What systemic failures prevent farmers from adopting healthier practices?

Factors influencing knowledge on AMR and safe use

The multivariate regression analysis, conducted to explore factors influencing farmers' knowledge on

Table 6 Farmers' knowledge on safe use of antibiotics (% responses) (n = 319)

Statement	Agree	Disagree	Don't know
1. People should use antibiotics on their livestock only when they are prescribed by a vet doctor	**85**	13	3
2. People should not keep antibiotics and use them later for other livestock diseases	**61**	34	5
3. It's okay to buy the same antibiotics, that you used to treat your animal when they had the same symptoms before	57	**36**	7
4. I am not at risk of getting an antibiotic resistant infection, as long as I take my antibiotics correctly	77	**12**	10
5. One needs to wait for some days before consuming or selling milk or animal products after administering antibiotics to animals	**89**	7	4
6. One needs to complete the prescribed antibiotic dosage even after the animal gets well	**85**	12	3
7. One can double the prescribed antibiotic dosage to increase recovery rate	14	**84**	2
8. One can reduce the prescribed antibiotic dosage for one animal to administer to more animals	9	**88**	3

Numbers in bold indicate correct answers antibiotic safe use and resistance, yielded unexpected outcomes. Both gender and education level were found to have no significant impact on farmers' knowledge in the realms of antibiotic safe use and resistance. This implies that, within the studied population, factors other than gender or educational background played a more influential role in shaping farmers' understanding of antibiotic-related issues. Diversity and number of livestock owned, particularly sheep, poultry, and cattle, showed a notable and statistically significant positive influence on farmers' knowledge of antibiotic safety and resistance (P < 0.01) (Kisoo et al. 2023; Emes et al. 2023). This finding suggests that individuals who manage a larger number and diverse livestock, especially, are likely to exhibit an elevated level of awareness regarding issues related to antibiotic use and resistance. The positive correlation indicates that as the number of livestock increases, farmers are more likely to possess a wider understanding of matters pertaining to antibiotics use (Hossain et al. 2022). Location also played a role in influencing farmers' knowledge. Those in rural areas appeared to have lower levels of knowledge compared to their peri-urban counterparts. Additionally, whether antibiotics were administered by trained veterinarians or not had an impact on farmers' understanding of AMR. This finding highlights the importance of proper antibiotic administration practices and the role of trained professionals in ensuring responsible antibiotic use.

Furthermore, advice from government extension agents had a significant influence on farmers' knowledge on AMR (P < 0.01). This suggests that the extension agents, who are knowledge influencers in the community, play a crucial role in disseminating information on antibiotic safety and resistance among livestock users (Table 7).

Apart from these factors, the study underscores the significance of farmers' lack of education on antibiotic use and resistance, limited awareness programs, and widespread reliance on antibiotics, all of which contribute to the expansion of the AMR problem. This is consistent

Table 7 Factors influencing knowledge on AMR and safe use of antibiotics

	Knowledge on AMR		Knowledge on safe use of antibiotic	
	Coefficient	**Std. err.**	**Coefficient**	**Std. err.**
Number of cattle	−0.004***	0.012	−0.008***	0.008
Number of goats	−0.003***	0.008	−0.008***	0.005
Number of sheep	0.006***	0.007	0.005***	0.004
Number of poultry	0.002***	0.003	0.001***	0.002
Gender (1 = male)	−0.135	0.268	−0.599	0.170
Education	0.314	0.099	0.325	0.063
Age category below 35	0.657	0.769	0.445	0.487
Age category between 36 and 60	0.814	3.038	−0.120	1.925
Income KES10,000 (100USD)	0.908	2.642	0.714	1.675
Income KES40,001 (400USD)	1.130	2.704	1.067	1.714
Income between KES10,001 and 40,000	2.456	2.716	1.228	1.721
Rural (1 = yes)	−0.030*	0.546	0.253	0.346
Antibiotics administered by a trained vet (1 = yes)	−0.044*	1.033	−0.745	0.655
Antibiotics administered by a non-trained person (1 = yes)	−0.592	0.763	−0.587	0.484
Livestock advice by government extension (1 = yes)	0.007***	0.284	−0.275	0.180
Livestock advice by private extension (1 = yes)	−0.822	1.323	0.751	0.838
Livestock advice by agro-dealer (1 = yes)	−0.669	0.370	−0.035	0.234
Livestock advice by family member or own experience (1 = yes)	−0.899	0.443	−0.148	0.281
Livestock advice from media newspaper (1 = yes)	−0.324	0.562	−0.299	0.356
Livestock advice specific campaign (1 = yes)	−0.510	0.671	−0.306	0.426
Livestock advice through internet (1 = yes)	0.666	2.500	1.709	1.585
Formal source of antibiotics (1 = yes)	1.891	2.292	−0.515	1.453
Informal source of antibiotics (1 = yes)	1.264	2.867	1.356	1.817
_cons	−2.536	2.812	−1.088	1.783

Per-urban, income above 40,000 (400USD) were taken as base for testing significance levels

*** Significant at 1%

*Significant at 10%, levels of significance with earlier research by Oluwasile et al. (2014), Omolo et al. (2023), which underscored the limited availability of information concerning antimicrobial use and resistance in animals. It also highlighted a lack of comprehension regarding the implications of AMR and the effectiveness of interventions, contributing to a general lack of awareness regarding antibiotic use and resistance.

Overall, the study sheds light on the complex interplay of various factors that influence farmers' knowledge and practices related to antibiotic safety and resistance. It suggests that targeted educational interventions, particularly involving livestock owners, trained veterinarians, and government extension agents, can play a critical role in promoting responsible antibiotic use and curbing the emergence and spread of AMR in Kenya's livestock sector. Moreover, raising awareness through comprehensive awareness programs can contribute to better practices and safeguard both animal and human health in the long run (Table 7).

Factors influencing the use of antibiotics

The multivariate regression analysis conducted to examine the factors influencing the use of antibiotics among farmers yielded significant and noteworthy findings. Livestock numbers emerged as a highly significant factor ($P < 0.01$) impacting farmers' decision to use antibiotics suggesting that farmers with larger livestock numbers are more inclined to use antibiotics, possibly due to the increased risk of disease outbreaks and the need for disease prevention and treatment in larger herds (Kiambi et al. 2021).

Another highly significant factor influencing antibiotic use among farmers was their knowledge on antibiotics resistance ($P < 0.01$). Farmers who demonstrated better awareness of antibiotics resistance tended to exercise more caution and responsibility in their antibiotic practices. They were more likely to adopt practices that avoid contributing to AMR, which is a crucial concern for public health and agriculture.

Education level also play a highly significant role in antibiotic use among farmers ($P < 0.01$). Farmers with higher levels of education had higher knowledge on antibiotic use. These farmers were more responsible in their use of antibiotics, which is likely to contribute to low AMR risk. Similarly, Omulo et al. (2017) demonstrated that education level plays a vital role in influencing farmers' antibiotic practices, with higher education potentially leading to more informed and responsible use.

Surprisingly, gender exhibited a negative correlation with antibiotic use among farmers, indicating that there may be distinct patterns or factors influencing antibiotic use based on the gender of the farmers. To better understand the reasons behind this gender disparity, further research is warranted. Exploring the underlying factors will provide valuable insights and pave the way for tailored interventions that address the specific needs of both male and female farmers in antibiotic use practices.

The location where farmers reside, particularly in rural areas, was found to be a significant factor influencing antibiotic use at a 10% level of significance. Rural farmers face different challenges and disease patterns compared to their urban counterparts, which may influence their decisions regarding antibiotic use. Tailored interventions that address the specific needs of farmers in different regions are crucial in promoting responsible and sustainable antibiotic use (Table 8).

Advisory services provided by extension workers regarding livestock health and antibiotic use were shown to significantly influence farmers' antibiotic decisions ($P < 0.01$). Farmers who received guidance from extension workers were more likely to make informed choices about antibiotic use, suggesting the importance of extension services in promoting responsible antibiotic practices. Farmers with incomes ranging from 101 to 400 USD were found to have a higher likelihood of using antibiotics in the treatment of their animals, and this association was statistically significant at a significance level of $P < 0.05$. This suggests that the financial capacity of farmers may influence their decisions and practices related to antibiotic use in animal care.

Our study reveals the multifaceted nature of factors influencing antibiotic use among livestock farmers in Kenya. The significant influence of advice from family members or own indicates the importance of social networks and personal experiences in shaping farmers' decisions on antibiotic use. Farmers may rely on the experiences and practices of family members or themselves, which can impact their antibiotic use behaviour. This discovery aligns with the research conducted by Irungu et al. (2011), Boamah et al. (2016), Farrell et al. (2023), underscoring the impact of both internal and external factors on the antibiotic usage patterns of farmers. The implications of these findings extend to policymakers, extension workers, and other stakeholders, offering valuable insights for the development of evidence-based strategies. Such strategies can aim to encourage judicious antibiotic use, ensuring both the well-being of animals and the preservation of public health and environmental safety.

Conclusions and recommendations

Our survey on antibiotics use in Kenyan livestock farming highlights critical patterns and challenges on the state of antibiotic practices, awareness on antimicrobial resistance (AMR), and factors influencing farmers' decisions. A majority (80%) of farmers use antibiotics in their

Table 8 Factors influencing the use of antibiotics

Test variable	Coefficient	Standard error
Number of cows	0.001***	0.000
Number of goats	0.000***	0.000
Number of sheep	0.000***	0.000
Number of poultry	0.000***	0.000
Gender (1 = male)	– 0.002*	0.007
Who administered antibiotics	0.330	0.003
Knowledge about AMR (1 = yes)	0.000***	0.002
Knowledge about antibiotic safe use (1 = yes)	– 0.003	0.002
Education	0.001***	0.003
Source antibiotics	0.326	0.004
Age category below 35 years	0.013*	0.020
Age category between 36 and 60 years	– 0.069	0.074
Trained Vet administering antibiotic	– 0.033	0.025
Non-trained administering antibiotics	– 0.024	0.019
Formal source of antibiotics	– 0.018	0.058
Informal source of antibiotics	0.094	0.071
Income < KES10,000 (100USD)	– 0.015	0.038
Income between KES10,001 and KES40,000 (101–400USD)	– 0.009**	0.041
Income > KES40,000 (base) (400USD)	0.009**	0.040
Area of residence (rural = 1, urban = 0)	0.011	0.014
Livestock advice by government extension (1 = yes)	0.007**	1.180
Livestock advice by private extension (1 = yes)	0.034	-0.410
Livestock advice by agro-dealer (1 = yes)	0.017	0.010
Livestock advice by family member or own knowledge (1 = yes)	0.011**	1.380
Livestock advice by a plant doctor (1 = yes)	– 0.007**	0.018
Constant	0.355	0.041

KES = Kenya Shillings (KES140 = USD1)

***, **, * means coefficients are significant at 1%, 5% and 10% respectively

livestock production, with a notable reliance on over-the-counter options (95%). This prevalent use, often for non-therapeutic purposes like growth promotion and disease prevention, raises concerns about the emergence of AMR due to continuous sublethal exposure. Furthermore, farmers demonstrated a high degree of non-adherence to recommended withdrawal periods, posing risks of antibiotic residues in animal products and compromising food safety.

Regional variations in antibiotics use were evident, suggesting that local farming practices, prevalent livestock diseases, and regional agricultural systems significantly influence farmers' choices of antibiotics. Farmers' antibiotic use practices were influenced by factors such as livestock numbers, knowledge on antibiotics resistance, education level, and location. While a considerable awareness of the causes and effects of AMR was observed among farmers, there is a need for targeted education to address specific knowledge gaps and misconceptions about antibiotic use and AMR. However, it was also clear that knowledge alone is not enough to create change. Further research into farmers' perceptions and decision-making processes, as well as systems' factors preventing farmers from adopting safer practices, will yield insights into the drivers behind risky practices and required solutions.

Recommendations derived from the findings include tailoring interventions to regional and gendered variations, and implementing targeted educational and awareness interventions. Public awareness campaigns, using various channels, should target not only farmers but also stakeholders and the general public, highlighting the consequences of antibiotic misuse in animal production to its impact on human health, food safety, animal welfare, and environmental sustainability. Strengthening regulatory mechanisms is crucial to ensure proper antibiotic control and monitoring in the industry. Stricter enforcement will discourage the availability of antibiotics over-the-counter and promote adherence to prescription-only practices, ensuring that antibiotics are used only under professional guidance. Promoting research and development into antibiotic alternatives, such as probiotics, vaccines, and improved hygiene practices, is essential to reduce the reliance on antibiotics in animal production.

In conclusion, addressing the complex interplay of factors influencing antibiotic use in Kenyan livestock farming requires a multifaceted approach involving education, regulatory measures, and targeted interventions. By implementing these recommendations, stakeholders can contribute to the sustainable and responsible use of antibiotics, safeguarding both animal, human and environmental health in the long run.

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Author contributions
HR: data analysis and writing. DS: literature review, writing and review. KKM: data analysis, review and proof reading. MI: Data collection, data analysis and review. MF: review and proof reading. ID, WB, BM and HK: study design, review and proof reading. KD: review. CD: data collection and review.

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Availability of data and materials
The data that support the findings of this study are available on request from the corresponding author [Harrison Rware]. The data are not publicly available due to [state restrictions e.g. "them containing information that could compromise research participant privacy/consent"].

Declarations

Ethics approval and consent to participate
This paper is generated using data from an ongoing project on Antibiotics Use in Kenya. We assessed awareness levels on the antibiotic's resistance and use. We also examined the factors that lead to inappropriate use or appropriate use of antibiotics. We have also presented some of the lessons from the research as approved by the project committee. Monica Kansiime: m.kansiime@cabi.org is the project manager.

Consent for publication
Before collecting the data used in this paper, the identified respondents, (farmers), were asked give their consent of participating in the survey before they were interviewed. They were explained about the survey, purpose and objectives and then a question was paused to them, if they would want to take part and they answered Yes/No.

Competing interests
The authors declare that they have no competing interests.

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References

Akande-Sholabi W, Oyesiji E. Antimicrobial stewardship: knowledge, perceptions, and factors associated with antibiotics misuse among consumer's visiting the community pharmacies in a Nigeria Southwestern State. J Pharm Policy Pract. 2023;16:120. https://doi.org/10.1186/s40545-023-00629-x.

Anika TT, Al Noman Z, Ferdous MRA, Khan SH, Mukta MA, Islam MS, Hossain MT, Rafiq K. Time dependent screening of antibiotic residues in milk of antibiotics treated cows. J Adv Vet Anim Res. 2019;6(4):516–20. https://doi.org/10.5455/javar.2019.f376.

Ayukekbong JA, Ntemgwa M, Atabe AN. The threat of antimicrobial resistance in developing countries: causes and control strategies. Antimicrob Resist Infect Control. 2017;6:47. https://doi.org/10.1186/s13756-017-0208-x.

Boamah VE, Agyare C, Odoi H, Dalsgaard A. Practices and factors influencing the use of antibiotics in selected poultry farms in Ghana. J Antimicrob Agents. 2016;2:120. https://doi.org/10.4172/2472-1212.1000120.

Caudell MA, Quinlan MB, Subbiah M, Call DR, Roulette CJ, Roulette JW, Roth A, Matthews L, Quinlan RJ. Antimicrobial use and veterinary care among agro-pastoralists in northern Tanzania. PLoS ONE. 2017;12(1): e0170328. https://doi.org/10.1371/journal.pone.0170328.

Caudell MA, Dorado-Garcia A, Eckford S, Creese C, Byarugaba DK, Afakye K, Chansa-Kabali T, Fasina FO, Kabali E, Kiambi S, Kimani T, Mainda G, Mangesho PE, Chimpangu F, Dube K, Kikimoto BB, Koka E, Mugara T, Rubegwa B, Swiswa S. Towards a bottom-up understanding of antimicrobial use and resistance on the farm: a knowledge, attitudes, and practices survey across livestock systems in five African countries. PLoS ONE. 2020;15(1): e0220274. https://doi.org/10.1371/journal.pone.0220274.PMID:31978098; PMCID:PMC6980545.

De Bruyne B, Fearon WF, Pijls NH, Barbato E, Tonino P, Piroth Z, Jagic N, Mobius-Winckler S, Rioufol G, Witt N, Kala P, MacCarthy P, Engström T, Oldroyd K, Mavromatis K, Manoharan G, Verlee P, Frobert O, Curzen N, Johnson JB, Limacher A, Nüesch E, Jüni P, FAME 2 Trial Investigators. Fractional flow reserve-guided PCI for stable coronary artery disease. N Engl J Med. 2014;371(13):1208–17. https://doi.org/10.1056/NEJMoa1408758. (**Epub 2014 Sep 1. Erratum in: N Engl J Med. 2014;371(15):1465**).

Durso LM, Cook KL. Impacts of antibiotic use in agriculture: what are the benefits and risks? Curr Opin Microbiol. 2014;2014(19):37–44. https://doi.org/10.1016/j.mib.2014.05.019. (**Epub 2014 Jul 2**).

EMA. Categorisation of antibiotics used in animals promotes responsible use to protect public and animal health. European Medicines Agency, The Netherlands. EMA/688114/2020. 2020.

Emes E, Wieland B, Magnusson U, Dione M. How farm practices and antibiotic use drive disease incidence in smallholder livestock farms: evidence from a survey in Uganda. One Health. 2023;14(17): 100627. https://doi.org/10.1016/j.onehlt.2023.100627.

Erdaw MM. Contribution, prospects and trends of livestock production in sub-Saharan Africa: a review. Int J Agric Sustain. 2023;21:1.

FAO. Livestock for Health in Kenya. Contributing to the prevention of acute malnutrition among children in pastoral households through nutrition-sensitive livestock programming in Marsabit County. Rome: Food and Agriculture Organisation of the United Nations; 2023.

Farrell S, Benson T, McKernan C, Regan Á, Burrell AM, Dean M. Factors influencing dairy farmers' antibiotic use: an application of the COM-B model. J Dairy Sci. 2023;106(6):4059–71. https://doi.org/10.3168/jds.2022-22263.

Gilbert W, Rushton J. Tropical livestock units: re-evaluating a methodology. Front Vet Sci. 2020;7: 556788. https://doi.org/10.3389/fvets.2020.556788.

Hassan BAR. HPLC uses and importance in the pharmaceutical analysis and industrial field. Pharm Anal Acta. 2012. https://doi.org/10.4172/2153-2435.1000e133.

Hossain MT, Rafiq K, Islam MZ, Chowdhury S, Islam P, Haque Z, Samad MA, Sani AA, Ara Ferdous MR, Islam MR, Ahmed N, Hossen MI, Khasruzzman AKM, Jaman Bhuiyan MK. A survey on knowledge, attitude, and practices of large-animal farmers towards antimicrobial use, resistance, and residues in Mymensingh Division of Bangladesh. Antibiotics. 2022;11(4):442. https://doi.org/10.3390/antibiotics11040442.

Hughes A, Roe E, Wambiya E, Brown JA, Munthali A, Ziraba A. The challenges of implementing antibiotic stewardship in diverse poultry value chains in Kenya. Agric Hum Values. 2023. https://doi.org/10.1007/s10460-023-10518-3.
Irungu P, Kariuki S, Winters CJ. A pilot survey of farmers' motivations of antibiotics use in livestock production in Kenya; 2011.
Kariuki S, Onsare R, Mwituria J, Ng'etich R, Nafula C, Karimi K, Karimi P, Njeruh F, Irungu P, Mitema E. Improving food safety in meat value chains in Kenya. Food Prot Trends. 2013;5:172–9.
Kariuki S, Kering K, Wairimu C, Onsare R, Mbae C. Antimicrobial resistance rates and surveillance in sub-Saharan Africa: where are we now? Infect Drug Resist. 2022;15:3589–609. https://doi.org/10.2147/IDR.S342753.
Kariuki JW, Jacobs J, Ngogang MP, Howland O. Antibiotic use by poultry farmers in Kiambu County, Kenya: exploring practices and drivers of potential overuse. Antimicrob Resist Infect Control. 2023;12:3. https://doi.org/10.1186/s13756-022-01202-y.
Kemp SA, Pinchbeck GL, Fèvre EM, Williams NJ. A cross-sectional survey of the knowledge, attitudes, and practices of antimicrobial users and providers in an area of high-density livestock-human population in western Kenya. Front Vet Sci. 2021. https://doi.org/10.3389/fvets.2021.727365/full.
Kiambi S, Mwanza R, Sirma A, Czerniak C, Kimani T, Kabali E, Dorado-Garcia A, Eckford S, Price C, Gikonyo S, et al. Understanding antimicrobial use contexts in the poultry sector: challenges for small-scale layer farms in Kenya. Antibiotics. 2021;2021(10):106.
Kisoo L, Muloi DM, Oguta W, Ronoh D, Kirwa L, Akoko J, Fèvre EM, Moodley A, Wambua L. Practices and drivers for antibiotic use in cattle production systems in Kenya. One Health. 2023;17: 100646. https://doi.org/10.1016/j.onehlt.2023.100646.
KVA. Advocacy and policy Kenya Veterinary Association, Nairobi, Kenya; 2016.
Livermore DM. Has the era of untreatable infections arrived? J Antimicrob Chemother. 2009;64:29–36.
Muriuki FK, Ogara WO, Njeruh FM, Mitema ES. Tetracycline residue levels in cattle meat from Nairobi salughter house in Kenya. J Vet Sci. 2001;2(2):97–101.
Murray CJ, Ikuta KS, Sharara F, Swetschinski L, Aguilar GR, Gray A, et al. Global burden of bacterial antimicrobial resistance in a systematic analysis. Lancet. 2022;399(10325):629–55.
Mutua F, Kiarie G, Mbatha M, Onono J, Boqvist S, Kilonzi E, Mugisha L, Moodley A, Sternberg-Lewerin S. Antimicrobial use by peri-urban poultry smallholders of Kajiado and Machakos Counties in Kenya. Antibiotics. 2023;12:905. https://doi.org/10.3390/antibiotics12050905.
O'Neill J. Antimicrobial resistance: tackling a crisis for the health and wealth of nations. 2014. https://www.who.int/news/item/29-04-2019-new-report-calls-for-urgent-action-to-avert-antimicrobial-resistance-crisis.
Oluwasile BB, Agbaje M, Ojo OE, Dipeolu MA. Antibiotic usage pattern in selected poultry farms in Ogun state. Sok J Vet Sci. 2014;12:45–50.
Omolo JO, Omani R, Caudell MA, Kimani T, Kiambi S, Fasina FO. Knowledge, attitudes, practices, and perceptions of livestock stakeholders on antimicrobial use in Kenya. Preprints. 2023. https://doi.org/10.20944/preprints202307.0547.v1.
Omulo S, Thumbi SM, Lockwood S, Verani JR, Bigogo G, Masyongo G, Call DR. Evidence of superficial knowledge regarding antibiotics and their use: results of two cross-sectional surveys in an urban informal settlement in Kenya. PLoS ONE. 2017;12(10): e0185827. https://doi.org/10.1371/journal.pone.0185827.
Samuel M, Fredrick Wabwire T, Tumwine G, Waiswa P. Antimicrobial usage by small-scale commercial poultry farmers in mid-western district of Masindi Uganda: patterns, public health implications, and antimicrobial resistance of *E. coli*. Vet Med Int. 2023. https://doi.org/10.1155/2023/6644271.
Singh M. Sampling techniques & determination of sample size in applied statistics research: an overview. International Journal of Economics, Commerce and Management United Kingdom. 2014;II(11). https://ijecm.co.uk/ ISSN 2348 0386.
Tang KL, Caffrey NP, Nóbrega DB, Cork SC, Ronksley PE, Barkema HW, Polachek AJ, Ganshorn H, Sharma N, Kellner JD, Ghali WA. Restricting the use of antibiotics in food-producing animals and its associations with antibiotic resistance in food-producing animals and human beings: a systematic review and meta-analysis. Lancet Planet Health. 2017;1(8):e316–27. https://doi.org/10.1016/S2542-5196(17)30141-9. (**Erratum in: Lancet Planet Health. 2017;1(9):e359**).
Van Boeckel TP, Brower C, Gilbert M, Grenfell BT, Levin SA, Robinson TP, Teillant A, Laxminarayan R. Global trends in antimicrobial use in food animals. Proc Natl Acad Sci. 2015;112(18):5649–54. https://doi.org/10.1073/pnas.1503141112.
Van TTH, Yidana Z, Smooker PM, Coloe PJ. Antibiotic use in food animals worldwide, with a focus on Africa: pluses and minuses. J Glob Antimicrob Resist. 2020;20:170–7. https://doi.org/10.1016/j.jgar.2019.07.031. (**Epub 2019 Aug 8**).
WHO. Kenya national action plan on antimicrobial resistance: review of progress in the human health sector. Geneva: World Health Organization (Antimicrobial resistance policy information and action brief series). Licence: CC BY-NC-SA 3.0 IGO. 2022.

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