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Analysis of antibiotic use and access to drugs among poultry farmers in Kenya

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ABSTRACT

Understanding access to and use of antibiotics in livestock production systems is critical for guiding antimicrobial stewardship programmes and animal health services. We analysed antibiotic use practices among smallholder-intensive poultry farms in Kenya and characterised access to veterinary supply chains by calculating travel time to drug stores.

Data were collected from 766 poultry farms across 15 Kenyan counties, representing all production types, between May 2021 and February 2022. We also collected antibiotic sales and geolocation data from 321 veterinary drug stores in Nakuru and Kilifi counties, representing areas with high and low-intensity poultry production, respectively. Using a machine learning framework, we predicted farm-level antibiotic use based on collected demographic and production traits. We also built geospatial models to characterise farmer travel time to drug stores with motorised transport.

Half of farms used antibiotics at least once in the last two months, mostly for self-administered therapeutic reasons. Random forest analysis predicted that farms using disinfectants in cleaning, keeping other poultry species, with rodents in the chicken house and vaccinating their birds had the highest likelihood of antibiotic use. 95.4 % of farmers lived within one hour of a veterinary drug store, with 40 % residing within 15 min.

Antibiotic use is integrated in smallholder poultry production, emphasising the need for prioritizing biosecurity, regulatory and socio-behavioural interventions, and economic incentives to enhance stewardship. Spatial maps suggests both risks and opportunities for antibiotic access and veterinary care.

1. Introduction

Globally, antibiotic use is increasing in livestock in low- and middle-income countries (LMICs) where food production systems, especially fast-growing pig and poultry systems, are intensifying [1]. For example, according to FAOSTAT, poultry production in Africa grew by 97 % between 2000 and 2022, largely driven by the increasing demand for meat and eggs, especially in rapidly urbanising populations. Across most LMIC settings antibiotics are easily accessible to farmers, thus providing a cost-effective alternative to more expensive veterinary health interventions [2]. This widespread overuse has prompted urgent calls for responsible antibiotic use in farming, with a recognition of the need for investments in antibiotic stewardship initiatives and adoption of improved husbandry practices [3]. In 2017, Kenya launched a National

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Action Plan on antimicrobial resistance (AMR) which emphasises the prudent use of antibiotics and investments in AMR and antimicrobial use (AMU) surveillance initiatives [4].

Approximately 80 % of the rural and peri-urban households in Kenya rely on poultry production for their livelihoods, nutrition, and food security with the subsector contributing about 30 % of the agricultural gross domestic product (GDP) and 8 % to the national GDP [5]. Kenya's commercial poultry production system is fragmented, consisting of a small number of large, vertically integrated farms (>5000 birds), a sizeable mid-tier production sector (501–5000 birds), and a large, diffuse population of small-scale producers (50–500 birds). At each of these production levels, antibiotics are commonly used for the treatment and prevention of poultry disease, despite most of the diseases presenting non-specific symptoms and often of viral origin [6]. The high levels of consumption of antimicrobials in poultry systems raise concerns about the development of AMR in poultry production translating as a downstream public and ecosystem health risk. Thus, efforts are required to understand antibiotic use in different production systems and to assess the scale and motivation for use and the implications on the wider risk of resistance development. Indeed, the collection of antibiotic use data is a key pillar of a plethora of internationally funded programmes designed to contextualise AMR surveillance globally. AMU surveillance is important in both human and animal populations, but the decentralised, largely private sector-driven market for veterinary pharmaceuticals [7] complicates matters in the agricultural sector in Africa. Existing studies on AMU surveillance in Kenya have focused on specific geographical locations or production systems, mostly broilers, and do not capture the entirety of a subsector like poultry [6,8]. Those studies have demonstrated that antibiotics are commonly used, without expert veterinary input, or indeed without diagnostic support and are often administered by farmers themselves.

Access to veterinary care remains severely limited in most LMICs, with a recent study highlighting a critical shortage in Africa: just 2 veterinarians per 100,000 people on average [9]. The per capita number of veterinarians in Kenya is not known. As a result, community veterinary drug stores serve as crucial sources of inputs, including antibiotics, veterinary services, and animal health information [10]. In human health, characterising travel times by patients to healthcare facilities, including pharmacies, has provided policymakers with valuable tools to improve service provision whilst supporting the investigation of socio-economic and geographic inequalities in access [11,12]. Studies in Vietnam [13], the USA [14], and Brazil [15] have revealed significant geographic variations in pharmacy coverage and accessibility among different population groups. Such data are currently lacking in animal health but could greatly inform antibiotic use practices and animal health service delivery. Existing studies primarily focus on knowledge and prescription practices related to antibiotics in drug stores, rather than on accessibility [11,12].

In this study, we report the results of a national cross-sectional survey in smallholder poultry farms and veterinary drug stores in Kenya to investigate on-farm antibiotic usage patterns and practices and characterising travel time to veterinary drug stores by farmers.

2. Materials and methods

2.1. Study area and population

A cross-sectional study targeting commercial poultry farms in 15 Kenyan counties was carried out from May 2021 to December 2022 as part of a national AMR surveillance programme [16]. The study design is described in detail in the Supplementary Methods. In brief, we selected six Veterinary Investigation Laboratories (VILs), which function as national veterinary service laboratories. Given Kenya's devolved administrative structure, we chose three counties within the catchment area of each VIL. These counties represent the range of agro-ecological zones in which poultry production takes place in the country. Our target sample consisted of 800 farms, based on an assumed 50 % prevalence of AMR in *Escherichia coli* for broiler, layer, and indigenous chicken production systems. Allocations were made proportionally to the number of farms with varying production intensities in the 15 counties (Supplementary Methods).

2.2. Farm selection and data collection

To establish our sampling frame, we mapped all farms within a 60-km radius of each VIL – considered a practical distance for microbiological sampling – due to the absence of a central farm registry. A total of 1676 farms were identified. From this frame, we randomly selected 800 farms that met specific inclusion criteria: were commercial operations (production is focused on sale and profit rather than home consumption), expressed willingness to participate, and were accessible for sample collection. Questionnaires detailing livestock parameters, farm management practices and antimicrobial use patterns were administered at each farm using the Kenya Animal Bio-surveillance System mobile application [17]. Additionally, we mapped all veterinary drug stores in two counties – Nakuru and Kilifi – representing areas with high and low-intensity poultry production, respectively. We collected data on store location (latitude/longitude), the number and qualifications of workers, product inventory, and antibiotic sales. The distribution of sampled farms and veterinary drug stores is shown in Supplementary Fig. 1.

2.3. Analysis of farm-level drivers of antibiotic use

Of the surveyed 800 farms, 34 were excluded from the analysis due to missing data on the outcome of interest and most of the predictors, resulting in a final sample of 766 farms. We analysed the association between antibiotic use in poultry farms (defined as any self-reported antibiotic use by farmers within the last two months) and potential predictor variables. Selection of explanatory variables was guided by a directed acyclic graph, which included factors such as the use of disinfectants in cleaning, feeding chickens with household waste, practising all-in-all-out production, keeping other poultry species, having a footbath at the farm entrance, and farmer-reported presence of rodents and wild birds in the chicken house as well as vaccination history, receipt of veterinary extension, and bird confinement status (Supplementary Fig. 2 and Supplementary Table 1). Missing data in some predictors were imputed using the R package 'missForest' [18]. To enhance model accuracy and predictive power, we employed the Boruta algorithm [19] implemented in the Boruta package to identify key variables that describe variation in antibiotic use. Four important variables were identified and used in the subsequent analysis.

We the used a random forest approach– a machine learning non-parametric algorithm that optimizes model performance through an ensemble of individual decision trees [20,21]. Random forest analysis was performed using the R package randomForest [22]. First, the data set was randomly divided into a training set (75 %) for model fitting and a testing set (25 %) for evaluating model performance. Next, we generated 200 alternative data splits, building a random forest model for each split consisting of 5000 trees, with each tree constructed using a bootstrapped sample of the training data and a randomly selected subset of predictors. Given that random forest models do not provide parametric predictor effect sizes (e.g., odds ratios) and direction, we evaluated potential factors influencing antibiotic use through partial dependence analysis. This method describes the marginal effects of individual variables while averaging across the influence of other predictors in the model. We calculated partial dependence using the pdp package [23], interpreting results as the mean relative change in log-odds for predicting antibiotic use, converted to predicted probabilities for each risk factor. Receiver operating characteristic (ROC) curve in R package pROC [24] was used for assessing the random forest model prediction performance.

2.4. Geospatial analysis of veterinary drug store access

We modelled travel time to veterinary drug stores, locally known as 'agrovets' in Nakuru and Kilifi counties. We obtained location data for these stores from our mapping exercise, which involved traversing all major roads and urban centres in both counties. For the purposes of this analysis, we assumed all stores could stock antibiotics suitable for all species, thus including all in the analysis. Household datasets for the two sites were obtained from the Google Open Building dataset [25] which uses machine learning from high-resolution satellite imagery, proving valuable for mapping in rural areas where limited data are available. We randomly selected target households based on a conservative threshold of 60 % livestock ownership. Livestock ownership typically varies between rural (92.5 % [26]) and urban (32 % [27]) areas, and both counties contain both populations, thus our threshold is intended to account for this variation.

In rural communities, access to veterinary stores typically relies on road networks which are usually situated in trading centres at road junctions. Consequently, we considered road data layers as critical inputs for our models. We obtained the road network dataset from OpenStreetMap (OSM) [28], the largest available source of global road-based transport networks. We downloaded the OSM roads data in May 2024 in a vector format prioritizing overlapping roads based on speed to ensure the fastest routes were analysed.

To calculate travel time from each mapped household to the nearest veterinary drug store via the shortest route, we used a least-cost-path algorithm implemented in the qGIS Network Analysis Toolbox 3 (QNEAT3). We modelled travel time assuming motorised transportation (public buses, motorcycles, or a combination) with an average speed of 35 km/h [12,29]. We classified access as the percentage of livestock keeping households within 15, 30, 45 and 60 min of a veterinary drug store, measured by one-way travel time by road.

3. Results

3.1. Characteristics of the study population

A total of 766 farms were included in the analysis, comprising farms with local indigenous breeds (50.5 %, $n = 387$), layers (31.6 %, $n = 242$), and broilers (17.9 %, $n = 137$). Two-thirds of the farmers (62.7 %, $n = 480$) were older than 40 years, and 56.7 % ($n = 411$) were female. Most farms (74.6 %, $n = 572$) had poultry flocks containing <500 birds, with a median farm size of one acre. Hatcheries were the most common source of day-old chicks for 78.6 % of the farmers, with chicks purchased directly or through a distributor. The remaining 21.4 % of farms hatched their chicks. Biosecurity measures varied across farms; for example, only 28.6 % had a footbath, 56 % practised all-in/all-out production systems, 74.3 % reported rodent presence, and 91.8 % vaccinated their birds for at least one vaccine preventable infection (Supplementary Table 1).

We mapped a total of 435 veterinary drug stores, 340 of which were located in Nakuru and 95 in Kilifi. Female (47.6, $n = 207$) and male (52.4 %, $n = 228$) pharmacy staff were roughly equally represented. The stores averaged 2.2 staff (median 2, range 1–18). Animal health training varied among stores: 32.6 % (142/435) of stores, did not have any staff with animal health training, while only 17.9 % (78/435) had all staff trained. The remaining stores had a mix of trained and untrained staff. At the time of the survey, only 74.9 % ($n = 326$) of mapped stores had poultry antibiotics in stock, and poultry vaccines were available in 29.2 % ($n = 127$) of stores. In addition to antibiotics, the stores stocked other products: crop inputs (in 90 % of all 435 stores), animal feeds (78 %) and other animal drugs (79 %). Notably, 5.7 % ($n = 25$) of stores also stocked antibiotics for human use.

3.2. Antibiotic use and access practices

More than half of the surveyed farms (54.7 %, $n = 419$) reported having used antibiotics at least once in the last two months, with 73.3 % used for apparent therapeutic reasons, 21.2 % for prophylactic reasons, and 5.5 % for both purposes. The four most frequently reported antibiotics were tylosin (24.6 %), doxycycline (19.6 %), oxytetracycline (18.7 %), and trimethoprim (16.2 %) (Fig. 1A). Veterinary drug stores served as the most common source of antibiotics and animal health advice for nearly all farmers (97.4 %, $n = 408/419$), with the remainder sourcing from animal health service providers. Additionally,10.7 % ($n = 45/419$) of farmers reported using human antibiotics for their birds.

Drug store surveys revealed a total of 81 unique antibiotic brands, with each store averaging 6.7 brands (range: 1–26). These brands represented 18 distinct active antibiotic ingredients, and 43.2 % contained more than one antibiotic ingredient (average 1.5/brand, range 1–4 antibiotics), also known as fixed-dose combinations (FDCs). Likewise, 38.3 % ($n = 31/81$) of the brands were available as combination of antibiotics and vitamins. Oxytetracycline, trimethoprim, sulfamethoxazole, and tylosin were the four most sold antibiotic types in 40.9 %, 25.6 %, 24.9 %, and 20.9 % of 326 stores respectively (Fig. 1B). Across drug stores and farms, we found considerable overlap in the types of antibiotics sold and used (Supplementary Fig. 3), with variations in the proportions available at both levels (Supplementary Fig. 4). Farmers were the most frequent customers of antibiotics in 94.5 % ($n = 412$) of drug stores, while animal health professionals made up the remaining 5.5 %.

3.3. Predictors of farm level antibiotic use

The Boruta algorithm identified four variables as important predictors of on-farm antibiotic use: presence of other poultry species on the farm, the use of disinfectants to clean, vaccination history, and the presence of rodents in the chicken house (Fig. 2).

We quantified the effects of the four most informative risk factors using averaged partial dependence. We show that farms using disinfectants in cleaning, keeping other poultry species, with the presence of rodents in the chicken house and vaccinating their birds had the highest likelihood of antibiotic use (Fig. 3). The ability of the modelling to predict antibiotic use status reported an area under the curve, receiver operating characteristics (AUCROC) of 0.66 (95 % CI: (0.59 0.74) (Supplementary Fig. 5).

3.4. Travel time mapping to veterinary drug stores with access to motorised transport

Overall, with access to motorised transportation, 94.3 % and 95.2 % of the farming population in Nakuru and Kilifi, respectively areas lived within one hour of a veterinary drug store. Additionally, 40 % and 38.1 % of these populations in Nakuru and Kilifi, respectively, resided within 15 min of a store when using motorised transport (Fig. 4).

4. Discussion

These data represent the most comprehensive collection of information on antibiotic use patterns, practices, and access within Kenyan poultry systems to date. Our findings underscore the significance of a nationally representative sample and the necessity for robust national-level surveillance of antibiotic use. We demonstrate that antibiotics are frequently purchased and used by farmers as integral components of a broader array of farm inputs, including vaccines and disinfectants. Previous studies in Kenya [8,30,31] and similar low-resource settings [32,33] have shown comparable patterns of frequent self-medication, in contrast to high-resource settings where antibiotic access is more regulated. This finding suggests that farmers who actively engage in the acquisition of agricultural inputs are predisposed to incorporate antibiotics as one of these inputs, with the specific choice of antibiotic and its recommended indication for use potentially considered secondary. Our random forest analysis supports this finding, indicating that the use of disinfectants or vaccines is positively correlated with increased

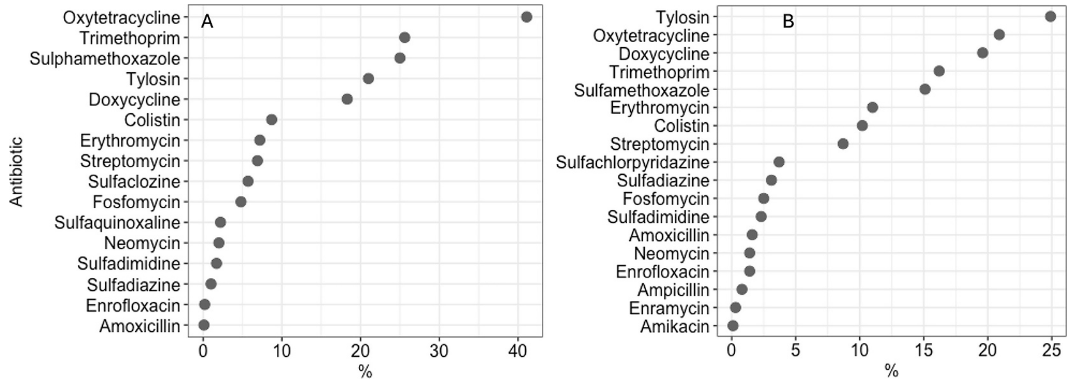

Fig. 1. A) The distribution of antibiotics used by farmers (n = 419) and B) sold in veterinary drug stores (n = 326). Data arranged in order of the average proportion of antibiotics for each group.

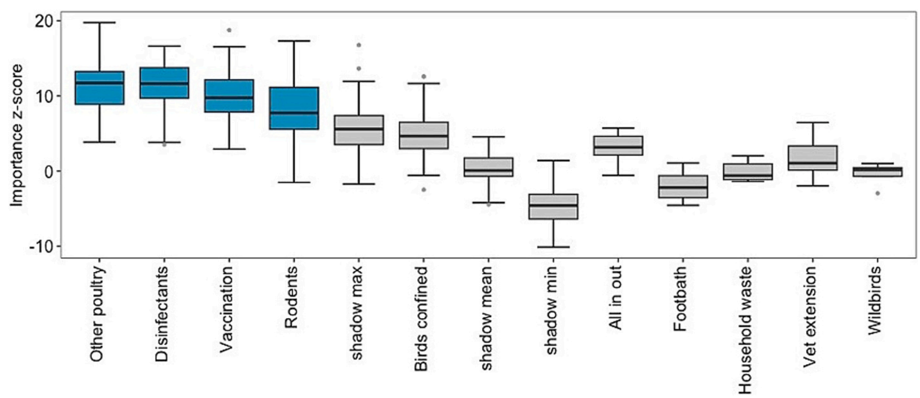

Fig. 2. Variables predicting antibiotic use in random forest model (blue colour) using the Boruta feature selection algorithm. Shadow max, shadow min and shadow mean are paremeters produced by the algorithm and serve as an external reference to decide whether the importance of a test variable. Boxplots: lower, middle and upper bounds correspond to the 25th, 50th and 75th percentiles. Upper and lower whiskers extend to largest and smallest value no further than 1.5 × interquartile range (IQR) from respective percentiles. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

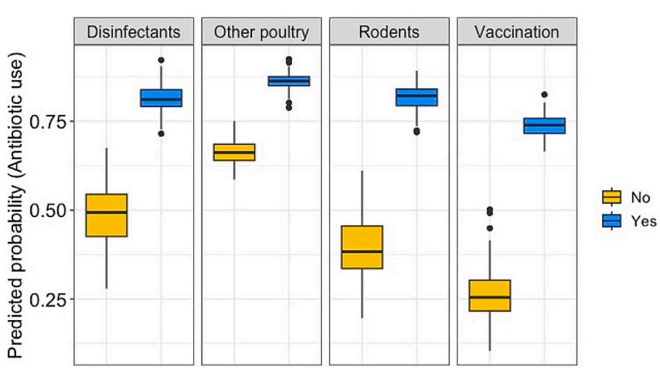

Fig. 3. Partial dependence from random forest models in predicting on farm antibiotic use. Y axis denotes the predicted probability of antibiotic use for each risk factor in random forest models. Boxes show distribution of probabilities across 200 random forest models with alternative training/test partitions, with lines showing median probability.

antibiotic use, in contrast to the anticipated decline in usage due to lower infection rate. We hypothesise that, to a farmer, an antibiotic, vaccine, or disinfectant is simply another farm input, akin to animal feed and water, and in the absence of stringent regulations governing access or antimicrobial 'guardians' and 'gatekeepers' [34] at community drug stores, this unrestricted access becomes commonplace. These inputs, including antibiotics, are often dispensed without a prescription, with pricing or customer preferences serving as predominant determinants in product selection [10,35]. The motivations for purchasing this 'farm input' bundle likely stems from farmers' exigent needs for solutions to mitigate the risk of infections (or simply their fear of infections) and to sustain productivity of their flocks; however, our study did not directly address these underlying issues. This pattern mirrors antibiotic use practices observed in community pharmacies in Nairobi during the COVID-19 pandemic, where antibiotics were sold for human use as a unit alongside analgesics, vitamins, anti-inflammatory agents, or antihistamines for the prevention or treatment of active SARS-CoV-2 infections [36].

Our study identified a wide array of antibiotic brands (n = 81) within the Kenyan market, the majority of which contain similar antibiotic substances or target similar clinical indications. This finding mirrors observations in other LMIC settings where consumers can freely select and purchase antibiotics over the counter, lacking regulatory oversight concerning permitted active ingredients, labelling, marketing, distribution, and pricing [33,37,38]. Understanding how these farmers navigate decision-making processes and procure antibiotics within this dynamic, market-driven ecosystem remains a critical area for future research. Notably, we found that half of the brands available in drug stores were fixed-dose combinations (FDCs), some containing as many as four active ingredients, effectively creating antibiotic "cocktails" that significantly heighten the risk of selecting for multidrug resistance in a single step [39]. These findings align with previously reported results in Kenya [40], Malawi[33]and Nigeria [41]; partly reflecting the heavy reliance of different countries on a few common suppliers dominating the global antibiotic supply chain [42]. FDCs are popular in LMICs for both animal and human health [43], due to their lower costs and broad-

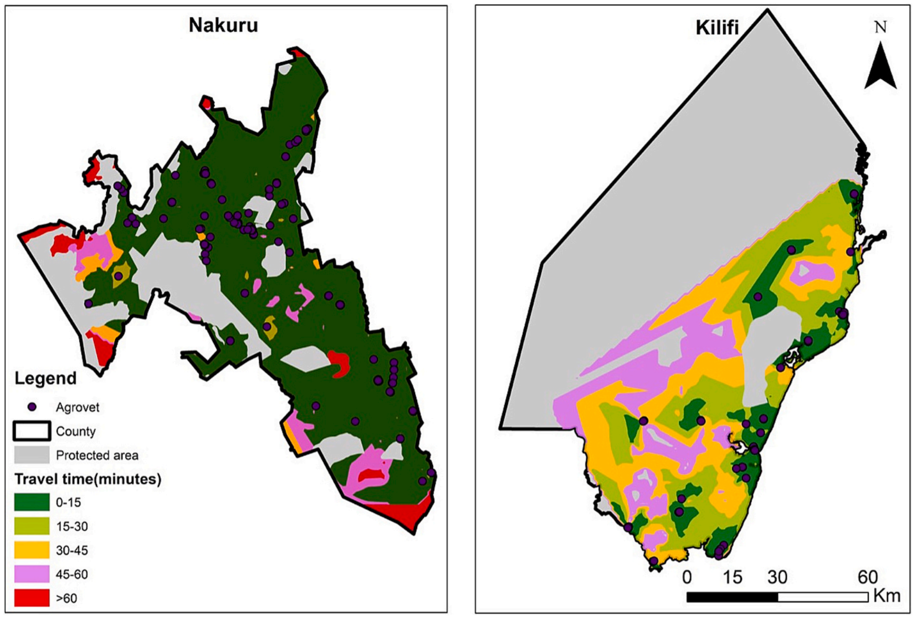

Fig. 4. Travel time (in minutes) to the nearest veterinary drug store assuming motorised transport. Green highlights areas with better access, while red indicates areas with the least access. Protected areas are national reserves with no human or livestock population. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

spectrum efficacy in the absence of diagnostic support. While some FDCs, such as those containing sulphonamides/trimethoprim, are clinically justified, others confer no additional clinical benefit. For instance, a prevalent FDC in our study combined erythromycin, oxytetracycline, streptomycin, and colistin. In human health, FDC antibiotics have been a subject of global discussion, with some countries banning them [44], however, there is limited traction for such restriction in animal health systems particularly outside high-income countries. This underscores a critical policy gap that necessitates urgent attention. Furthermore, the existence of brands that combine antibiotics and vitamins raises pertinent questions: do farmers primarily perceive these products primarily as vitamins, antibiotics, or both? This ambiguity warrants a policy focus on regulating the marketing and sale of combination antibiotic products, potentially including a ban on antibiotic-vitamin combinations.

The observed variability in the adoption of biosecurity measures, in line with previous studies [45,46], reflects the heterogenous needs and investment capacities of smallholder poultry farms, necessitating a tiered approach to developing potential solutions [47]. For example, further contextualization of the existing national biosecurity guidelines within the poultry sector could yield specific recommendations tailored to varying production scales. Our findings reveal a contrasting pattern: while most biosecurity measures do not appear to correlate with increased antibiotic use, farms with mixed poultry production systems and rodent infestations had higher antibiotic use. The tools employed to gather biosecurity data in our study and others are not specifically contextualised for smallholder farming contexts [48], therefore it is possible that the directs effects of biosecurity on antibiotic use were not adequately captured in this investigation. Future research should prioritise the development of bespoke tools for measuring biosecurity and crucially quantifying antibiotic use within smallholder poultry systems [49].

We demonstrate that over 94 % of the farming population in the two contrasting livestock production zones resides within one hour of a veterinary drug store, given access to motorised transportation. This finding presents a dichotomy. On the one hand, the spatial distribution of veterinary drug stores, a common source of animal health services in Kenya [10,30] and similar settings [32,50,51], is commendably robust in these regions for farmers. This high level of accessibility presents opportunities for enhanced veterinary care, particularly in rural locales, which could extend beyond mere dispensing of medication to include increased provision of vaccinations, point-of-care diagnostics, and herd/flock health management. By contrast, the ease of access to drug stores, predominantly staffed by unqualified personnel (32.6 % of stores in our study), may correlate with high/imprudent antibiotic use and/or AMR. We did not explore these hypotheses. Untangling the relationship between travel time to veterinary drug stores and the quantity or practices of antibiotic use or rates of AMR carriage will be a critical next step. For example, a recent study in Thailand demonstrated a positive association between shorter distances to veterinary drug providers and increased antibiotic use and AMR prevalence in small-scale pig farms [51].

In our observational study, where much of the data were self-reported, including the outcome variable of interest – antibiotic use on farms– our findings are susceptible to a certain degree of social desirability bias. The performance of our random forest model is contingent upon the context of the dataset used. Incorporating additional variables, such as biosecurity and economic attributes, would enhance the robustness of our models. This analysis would benefit from quantifying antibiotic use and deeper socio-economic contextualisation, to disentangle the human-related drivers of antibiotic use, such as attitudinal factors. We modelled travel time to the nearest geolocated veterinary drug store, assuming that people used a motorised transportation at an optimal speed. In reality, factors such as income and access to motorised transport likely influence individuals' decisions regarding travel modes to veterinary drug stores. For instance, individuals may prefer more affordable options, such as walking or a combination of walking and motorised transport.

5. Conclusion

This study provides critical insights into antibiotic use patterns within Kenyan poultry systems, revealing that a significant proportion of farmers integrate antibiotics into their production practices. The widespread availability of fixed-dose combinations raises concerns about multidrug resistance, posing risks to both animal and human health. Effective stewardship initiatives must prioritise investments in biosecurity, socio-behavioural nudges, and economic incentives for farmers. Managing antibiotic use is thus a much broader issue than that of emphasising the preservation of active compounds – it is a broad cultural issue of product use in the face of uncertain risks. Addressing this issue will require strategies beyond just biomedical intervention necessitating collaboration with social science practitioners. Furthermore, our spatial analysis of veterinary drug stores highlights potential risks for inappropriate antibiotic supply and AMR emergence, while also presenting opportunities to improve access to veterinary care, ultimately safeguarding public health and promoting sustainable agricultural practices.

Ethics approval and consent to participate

This study was part of a national government-led surveillance activity on antibiotic resistance and use across Kenya. Animal health surveillance is considered a quality improvement activity within the mandate of the Directorate of Veterinary Services, Ministry of Agriculture, Livestock and Fisheries, Kenya. As the investigation did not involve any changes to veterinary care and did not collect farmer-level identifiers, institutional review board approval was not required. Verbal informed consent was obtained from all participating farmers.

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CRediT authorship contribution statement

Dishon M. Muloi: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mitchelle R. Kasudi:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis. **Maurice K. Murungi:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Eugine Lusanji Ibayi:** Project administration, Methodology, Investigation. **Samuel Kahariri:** Writing – review & editing, Software, Investigation. **Charity Karimi:** Writing – review & editing, Methodology, Investigation. **Max Korir:** Writing – review & editing, Software, Formal analysis. **Bridgit Muasa:** Writing – review & editing, Methodology, Investigation. **Damaris Mwololo:** Writing – review & editing, Methodology, Investigation. **Romona Ndanyi:** Writing – review & editing, Project administration, Methodology, Investigation, Conceptualization. **Robert Ndungi:** Writing – review & editing, Methodology, Investigation. **Jane Njiru:** Writing – review & editing, Project administration, Methodology, Investigation. **Ruth Omani:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Rose Owada:** Writing – review & editing, Methodology, Investigation. **Sylvia Omulo:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Allan Azegele:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Eric M. Fèvre:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.onehlt.2025.100987.

Data availability

Data will be made available on request.

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