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Antimicrobial resistance in an emerging economy

The occurrence and drivers on Vietnamese small- and medium-scale chicken farms

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Cover: Small-scale chicken farming in Vo Nhai district, Thai Nguyen province, Vietnam (photo: Ms. Luu Thi Hai Yen/NIVR)

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Antimicrobial resistance in an emerging economy. The occurrence and drivers on Vietnamese small- and medium-scale chicken farms

Abstract

Due to overuse and misuse of antibiotics, antimicrobial resistance (AMR) has become a severe threat to animal and human health worldwide, as well as to people's livelihoods and food security, especially in low- and middle-income countries. Vietnam has had a tremendous economic development the past decades, and the poultry sector has grown. Heavy antibiotic use and high AMR rates have been reported from the sector, resulting in the implementation of a regulatory framework to handle the issue. However, regulation enforcement is insufficient, which calls for other AMR-mitigating actions. Hence, the aim of this thesis was to understand more about AMR, and its drivers, on Vietnamese small- and medium-scale poultry farms.

Firstly, 305 farmers were interviewed to investigate their access to animal health services and veterinary drugs, as well as their AMR-related knowledge and practices. Over 95% had access to veterinary drugs over the counter, but only 32% had access to animal health services. A majority used antibiotics prophylactically, while several desirable disease prevention practices could be improved. Disease treatment was often based on experience, or advice from a veterinary drug shop. Several knowledge gaps regarding antibiotics and AMR were identified. Knowledge and practice levels were associated with numerous farm(er) variables. Secondly, AMR in 764 commensal *E. coli* isolates from poultry was assessed. Resistance rates were high, including multi-drug resistance. Higher levels of farmers' practices and knowledge were not associated with lower AMR. Thirdly, 50 veterinary drug shop workers were interviewed to investigate their AMR-related knowledge, and routines when selling antibiotics. The workers were often highly educated and knowledgeable about AMR. However, several undesirable sales routines were identified. Also, their ability to contribute to improved antibiotic use on farms was limited for several reasons. The research shows that AMR is still an urgent issue in Vietnamese poultry, and that there is a need to look beyond the farm level to understand its drivers. The findings may be used as guidance when developing AMR-mitigating interventions.

Keywords: AMR, antibiotics, poultry, Vietnam, microdilution, KAP, One Health

Antibiotikaresistens i en tillväxtekonomi. Förekomst och drivkrafter på små- och medelstora kycklinggårdar i Vietnam

Abstract

Överanvändning av antibiotika har gjort antimikrobiell resistens (AMR) till ett allvarligt hot mot djurs och människors hälsa globalt, samt mot människors försörjning och livsmedelssäkerhet, särskilt i låg- och medelinkomstländer. Vietnam har haft en stark ekonomisk utveckling de senaste årtiondena och fjäderfäsektorn har vuxit. Omfattande antibiotikaanvändning och höga AMR-nivåer har rapporterats från sektorn, vilket föranlett implementeringen av ett regulatoriskt ramverk för att hantera frågan. Dock är införlivandet av regleringarna fortfarande bristfälligt vilket innebär att det finns ett behov av ytterligare AMR-reducerande åtgärder. Mot denna bakgrund var målet med denna avhandling att öka förståelsen om AMR, och dess drivkrafter, på små och medelstora kycklinggårdar i Vietnam.

Först intervjuades 305 kycklinguppfödare om tillgång till djurhälsotjänster och veterinära läkemedel, samt AMR-relaterad kunskap och praktik. Över 95% hade tillgång till veterinära läkemedel utan recept men endast 32% hade tillgång till djurhälsotjänster. Två tredjedelar gav antibiotika profylaktiskt och det sjukdomsförebyggande arbetet var ofta bristfälligt. Sjukdomsbehandling baserades ofta på erfarenhet eller på råd från en veterinär läkemedelsbutik. Flera kunskapsluckor relaterade till AMR identifierades. Kunskaps- och praktiknivåerna var associerade till flera gårdsvariabler. Därefter utvärderades AMR i 764 isolat av kommensala *E. coli* från fjäderfä på ovannämnda gårdar. Resistensnivåerna var höga, inklusive multiresistens. Bättre AMR-relaterad kunskap och praktik hos uppfödarna var inte associerad med lägre AMR. Slutligen intervjuades 50 försäljare i veterinära läkemedelsbutiker om rutiner vid antibiotikaförsäljning samt AMR-relaterad kunskap. Försäljarna var ofta välutbildade och kunniga, men flera icke önskvärda försäljningsrutiner identifierades. Möjligheten att bidra till förbättrad antibiotikaanvändning var begränsad av flera anledningar. Den presenterade forskningen visar att AMR fortsatt är ett allvarligt problem i vietnamesisk fjäderfäuppfödning och behovet av att söka efter dess drivkrafter bortom gårdsnivå. Resultaten kan vara vägledande när AMR-reducerande interventioner ska utvecklas.

Keywords: AMR, antibiotika, fjäderfä, Vietnam, mikrodilution, KAP, One Health

Dedication

Till Tilde, Claudia och Tuva

A little consideration, a little thought for others, makes all the difference.
— Eeyore

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. Nohrborg, S., Nguyen-Thi, T., Xuan, H.N., Lindahl, J., Boqvist, S., Järhult, J.D. & Magnusson, U. (2024). Understanding Vietnamese chicken farmers' knowledge and practices related to antimicrobial resistance using an item response theory approach. *Frontiers in Veterinary Science*, 11, 1319933. https://doi.org/10.3389/fvets.2024.1319933

II. Nohrborg, S., Xuan, H.N., Nguyen-Thi, T., Lindahl, J., Boqvist, S., Järhult, J.D. & Magnusson, U. Antimicrobial resistance on Vietnamese small- and medium-scale poultry farms – lack of associations with farmers' antibiotic-related knowledge and practices (submitted to *PLOS One*)

III. Nohrborg, S., Nguyen-Thi, T., Xuan, H.N., Hai, Y.L.T., Lindahl, J., Boqvist, S., Järhult, J.D. & Magnusson, U. (2024). Understanding veterinary drug shop workers' knowledge and practices to identify drivers of antibiotic use in Vietnamese livestock farms. *Veterinary Medicine and Science,* 10(4), e1502. https://doi.org/10.1002/vms3.1502

All published papers are published open access.

The contribution of Sandra Nohrborg to the papers included in this thesis was as follows:

I. Took part in the planning and organisation of the study. Constructed the questionnaire with input from supervisors and Vietnamese colleagues. Assisted the data collection process from a distance (field work took place during the COVID-19 pandemic). Performed statistical analyses and interpreted results together with supervisors. Wrote the manuscript and revised after feedback from co-authors.

II. Took part in the planning and organisation of the study. Performed parts of the laboratory work (AST analyses). Performed statistical analyses and interpreted results with assistance from supervisors. Wrote the manuscript and revised after feedback from co-authors. Responsible for journal submission and contact.

III. Took part in the planning and organisation of the study. Constructed the questionnaire with input from supervisors and Vietnamese colleagues. Took part in the data collection. Analysed and interpreted results with input from supervisors. Wrote the manuscript and revised after feedback from co-authors. Responsible for journal submission and contact.

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Abbreviations

ABU	Antibiotic use
AIDS	Acquired immunodeficiency syndrome
AmpC	Overexpressed cephalosporinases
AMR	Antimicrobial resistance
AMU	Antimicrobial use
APEC	Avian pathogenic *Escherichia coli*
ARG	Antibiotic resistance gene
ASF	African swine fever
AST	Antibiotic susceptibility testing
CIA	Critically important antimicrobial
DALY	Disability-adjusted life-year
E. coli	*Escherichia coli*
EHEC	Enterohemorrhagic *Escherichia coli*
ESBL	Extended-spectrum beta-lactamase
ExPEC	Extraintestinal pathogenic *Escherichia coli*
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
GAP	Global action plan
GDP	Gross domestic product
GP	Growth promoter
HIA	Highly important antimicrobial
HIC	High-income country
HIV	Human immunodeficiency virus
HPAI	Highly pathogenic avian influenza

HPCIA	Highest priority critically important antimicrobial
IA	Important antimicrobial
ILRI	International Livestock Research Institute
IPEC	Intestinal pathogenic *Escherichia coli*
IRT	Item response theory
KAP	Knowledge, attitudes, and practices
LMIC	Low- and middle-income country
LA-MRSA	Livestock-associated methicillin-resistant *Staphylococcus aureus*
MDR	Multi-drug resistant
MRSA	Methicillin-resistant *Staphylococcus aureus*
MRSP	Methicillin-resistant *Staphylococcus pseudintermedius*
NAP	National action plan
NIVR	National Institute of Veterinary Research, Hanoi
OTC	Over the counter
SEA	Southeast Asia
Sub-DAH	Sub-Department of Animal Health
WHO	World Health Organization of the United Nations
WOAH	World Organisation for Animal Health

1. Introduction

1.1 Antimicrobial resistance – a One Health issue

1.1.1 Impact of antimicrobial resistance

Antimicrobial resistance (AMR), the mechanism in microbes to survive drug treatment, has become one of the largest threats to the health and wellbeing of humans and animals worldwide, and is often referred to as a silent pandemic (Bengtsson & Greko 2014; Holmes et al. 2016; World Bank 2017). However, the silence is about to be broken. If not mitigated, AMR threatens to bring societies back to the pre-antibiotic age, substantially altering the possibilities to manage infectious disease.

Although the term AMR covers resistance to all kinds of antimicrobials in microbes, including antibiotics, antivirals, antiparasitics, and antifungals, it refers specifically to antibiotic resistance in bacteria in this thesis.

Impact on animal health

In livestock, AMR naturally causes increased distress for individual animals, as resistant infections are more difficult to treat. The negative impact on animal welfare may also be accompanied by decreased productivity due to disease which can have serious effects on farmers' economy (Vaarten 2012). Further, as resistant infections take longer, or are impossible to treat, the risk of large-scale disease outbreaks and zoonotic transmission to humans increases.

The overall impact of AMR on livestock health on a global scale is difficult to estimate due to scarcity of data (Robinson et al. 2016). However, non-treatable or difficult-to-treat infections due to AMR have been widely documented in both livestock and companion animals, such as infections with methicillin-resistant *Staphylococcus aureus* (MRSA) and *pseudintermedius* (MRSP), as well as *Escherichia coli* (*E. coli*) that produce extended-spectrum β-lactamases (ESBL) (van Duijkeren et al. 2011; Bengtsson & Greko 2014; Silva et al. 2023a; Kuan et al. 2024; Mandujano-Hernández et al. 2024; Barua et al. 2025).

In poultry, multi-drug resistant (MDR) infections with avian pathogenic *E. coli* (APEC), known as colibacillosis, have been reported globally (Nhung et al. 2017; Kathayat et al. 2021). Other examples are infections with resistant *Avibacterium paragallinarum* (causing infectious coryza), *Salmonella* Pullorum/Gallinarum (causing pullorum disease and fowl typhoid), and *Pasteurella multocida* (causing fowl cholera) (Nhung et al. 2017; WOAH 2018a). All of the above-mentioned poultry infections are already major causes of disease worldwide, especially in low- and middle-income countries (LMICs) (Nhung et al. 2017; WOAH 2018a; Kathayat et al. 2021). A situation which increasing AMR could further aggravate.

Impact on human health

It has been estimated that in 2021, 1.1 million human deaths were directly attributable to drug-resistant bacterial infections, while a further 4.7 million were associated with AMR (Antimicrobial Resistance Collaborators 2024). Comparing to other causes of death, AMR caused more deaths than HIV/AIDS, malaria, and tuberculosis that year (Causes of Death Collaborators 2024). It should also be noted that the highest AMR burden was observed in LMICs (Antimicrobial Resistance Collaborators 2024). These attributable deaths corresponded to >42.5 million disability-adjusted life-years (DALYs), a measure that accounts for years of life lost due to premature death or lived with disability. On a global scale, it is projected that the number of human deaths attributable to, and associated with, resistant infections will increase to 1.9 and 8.2 million, respectively, in 2050, with LMICs remaining the most severely affected.

Besides the direct health effects of resistant infections, several treatments and procedures in modern medicine that rely on antibiotics to be safely performed may be jeopardized due to AMR, such as organ transplants, joint replacements, and cancer therapy (World Bank 2017).

Impact on livelihoods and food security from a low- and middle-income country perspective

In 2019, 857 million people worldwide were employed within agriculture, of which 67% resided in Asia (Davis et al. 2023). However, since small-scale and household farmers are in majority in most LMICs, and thereby not always visible in employment statistics, the number of people who actually depend on agriculture for their livelihoods is probably even larger (HLPE 2013; Lowder et al. 2016). It has been estimated that smallholder farms provide livelihoods to 2 billion people worldwide, and produce 80% of the food consumed in Asia and sub-Saharan Africa (HLPE 2013).

As of 2024, 2.3 billion people were moderately or severely food insecure in the world (FAO/IFAD/UNICEF/WFP/WHO 2025). In Southeast Asia (SEA), 14% of the total population, and 17% of the rural population, faced such food insecurity. Especially in LMICs, a large share of farmers, mainly smallholders, keep livestock for both livelihood and household consumption purposes (HLPE 2013). Needless to say, widespread AMR, causing increased morbidity (illness) and mortality (death) in livestock, as well as lowered productivity, may have severe negative impacts on people's livelihoods and food security, particularly in those resource-limited settings (Adamie et al. 2024). Not only do treatment costs go up when additional antibiotics or other medicines are needed to treat resistant infections, but also, when productivity goes down, the income from sales of animal-source products is reduced.

It has been estimated that the current AMR situation, compared to a low-resistance scenario, already results in a global loss of >2% chicken meat, equivalent to the consumption need of 129 million people, and the loss is expected to increase (Adamie et al. 2024). Comparing the present situation to a worsened situation, with increased antibiotic use (ABU) and AMR, losses in the poultry sector are estimated to equal the consumption need of 550 million people. In a future with high impacts on human and animal health from AMR, another projection state that livestock production in LMICs could decrease by 7–10% to 2050, a substantially larger decrease than what is projected for high-income countries (HICs) (World Bank 2017).

Impact on the global economy

Agriculture, including livestock production, is an important contributor to the gross domestic product (GDP) in many countries, especially in LMICs (World Bank 2017; Adamie et al. 2024). Therefore, AMR may have severe consequences not only for individual farmers, but also for the economies of countries with large livestock production. The reduced productivity that results from increased AMR also means lower access to animal-source foods for the general population, and thereby increased market prices, affecting both economy and food security (World Bank 2017).

Looking at the human health sector, AMR comes with high direct and indirect costs. Direct costs result from, for example, longer or more expensive treatments and hospitalizations, while indirect costs are the costs for societies that come from reduced work capacity in the population due to increased morbidity and mortality (World Bank 2017). In a future where

AMR impacts on human and animal health are high, it is estimated that the global economic output will drop by >3% in 2030 compared to 2017, corresponding to losses of ~3.5 trillion US dollars annually from 2030 (World Bank 2017). Further, the economic consequences are projected to be more severe in LMICs than in HICs.

1.1.2 One Health aspects of antimicrobial resistance

One Health is a well-established concept to describe the interconnections between human health, animal health, and the environment. Since resistant bacteria are not confined to a specific host or geographic location, AMR qualifies as a true One Health issue (Holmes et al. 2016; Robinson et al. 2016). Resistant bacteria or drug residues may migrate between species through various routes. An overview of the complex One Health nature of AMR is illustrated in Figure 1. Thus, AMR in animals is not solely relevant for animal health, but also in extension for human health, and vice versa. Globalisation, with increased travel and trade of livestock and agricultural products, further complicates the situation as it facilitates AMR spread outside of the geographic area where it first emerged. This makes AMR not only a One Health issue but also a One World issue, which calls for global and cross-sectorial efforts to mitigate AMR development in the human, animal, and environmental sectors.

Antimicrobial resistance spread from animals to humans

Resistant bacteria can spread from animals to humans through direct contact, or indirectly, for example through surface-contaminated animal-source foods, or via the environment through manure or contaminated water sources (Marshall & Levy 2011). These bacteria can be either pathogens, causing difficult-to-treat infections, or commensal (non-pathogenic), such as gut *E. coli*. If the bacteria colonize the gut of the human host, the antibiotic resistance genes (ARGs) that they carry may then be transferred to other gut bacteria. People working in close contact with animals, such as farmers, veterinarians, and slaughterhouse workers, are at greatest risk of direct transmission. However, people who acquire resistant bacteria through direct contact with livestock can potentially pass them on to their family members and communities. In LMICs, where close contact between people and livestock is more common than in HICs, direct transmission of resistant bacteria is more likely, and may therefore contribute more to the overall burden of AMR within communities (Nadimpalli et al. 2023).

Nonetheless, it should be noted that a direct impact of AMR in livestock on the human AMR situation can be difficult to prove (Atterby et al. 2017; Muloi et al. 2018; Wee et al. 2020; Emes et al. 2022; ECDC/EFSA/EMA 2024). At population level, significant associations between aminopenicillin resistance in livestock and human *E. coli* have been shown in the European Union (EU) (ECDC/EFSA/EMA 2024). However, for several other antibiotics, including fluoroquinolones and third-generation cephalosporins, such associations have not been demonstrated.

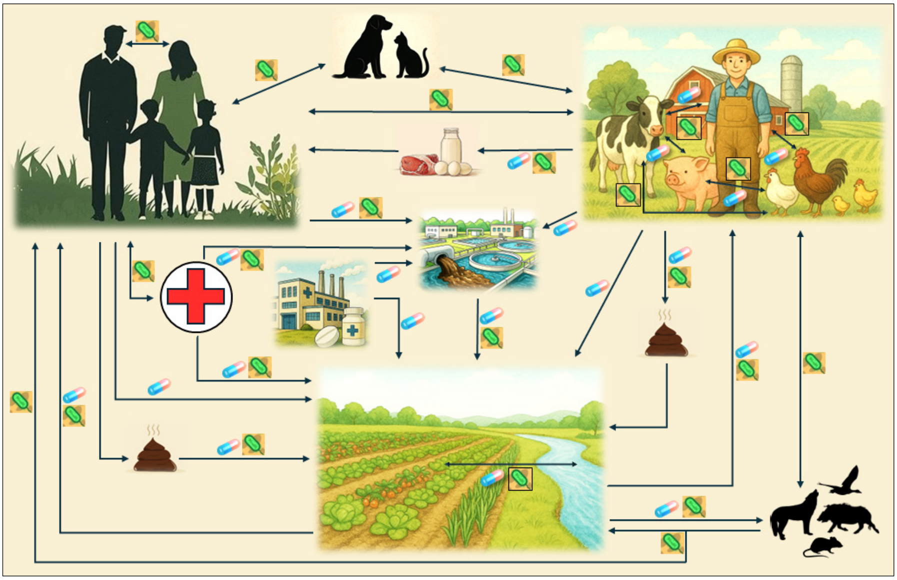

Figure 1. Antimicrobial resistance in a One Health perspective. Arrows indicate direction of spread of antibiotics and antibiotic residues (💊), or resistant bacteria (🦠). Picture sources: Pixabay, Canva, ChatGPT. Figure design: Author.

Yet, several individual studies have shown evidence of overlap between resistant *E. coli* and ARGs in humans and animals, although the direction of the suggested transmission has not always been determined (Marshall & Levy 2011; Muloi et al. 2018). For example, it has been shown multiple times that farm workers and their animals harbour *E. coli* with the same AMR profile, implying transfer between them (van den Bogaard 2001; Marshall & Levy 2011; Nakano et al. 2021). Another example is the detection of livestock-associated methicillin-resistant *Staphylococcus aureus* (LA-MRSA) in humans in both HIC and LMIC settings, showing an animal-to-human transmission (van Loo et al. 2007; Declercq et al. 2008; Catry et al. 2010; Crespo-Piazuelo & Lawlor 2021). Taken together, current evidence indicates spillover of AMR from livestock to humans, but to which extent is still unclear and is likely to vary across production systems and geographical regions.

Antimicrobial resistance spread from humans to animals

Since bacteria generally are not confined to a specific species, spread from humans to animals is also possible. As stated above, several studies have shown overlap between resistant bacterial strains in humans and animals, without being able to state the direction of transmission (Muloi et al. 2018).

However, there are suggested cases of spread of resistant *E. coli* from humans to animals, for instance when AMR to the β-lactam antibiotic meropenem has been detected in livestock and companion animals. Since this antibiotic is solely used in human medicine, the detection of such resistance in *E. coli* from animals might indicate a human-to-animal transmission, although co-resistance due to high use of other β-lactam antibiotics in animals cannot be excluded (Poirel et al. 2018).

Antimicrobial resistance spread via the environment

The environment has shown to be an excellent reservoir for resistant bacteria and ARGs. In a livestock context, antibiotic residues and resistant bacteria may enter the environment through the use of untreated manure as crop fertilizer, or via runoff water contaminated with manure or improperly disposed antibiotics (Samreen et al. 2021; Marutescu et al. 2022; Ishwarya et al. 2025). Subsequently, the environment may function as a carrier of AMR bacteria and ARGs that potentially can be transferred to humans either through crops or commonly used water sources.

In addition, high contamination with antibiotic residues of water sources has been documented in close proximity of pharmaceutical production sites and hospitals, as well as in wastewater plants, putting substantial selective pressure on environmental bacteria to develop AMR (Holmes et al. 2016; Samreen et al. 2021; Hanna et al. 2023). For example, in India, effluent from a wastewater treatment plant that treats wastewater from pharmaceutical manufacturers has shown to contain higher concentrations of the fluoroquinolone antibiotic ciprofloxacin than the blood of a ciprofloxacin-treated patient (Larsson et al. 2007). This effluent, that was later released into a nearby water stream, naturally cause concerning environmental contamination with antibiotics. Furthermore, the high contamination with both antibiotics and bacteria from various sources, as seen in sewage, makes wastewater environments unpleasant melting pots for ARG transfer (Berglund et al. 2023). Such ARG transfer between bacteria, that also may occur in other environmental compartments, further drives AMR development, possibly generating new MDR bacterial strains that can be transferred to humans or animals (Samreen et al. 2021).

1.1.3 Antimicrobial resistance development

Antimicrobial resistance is a naturally occurring mechanism in bacteria to survive exposure to antibiotics of either natural or synthetic origin. The phenomenon, however, predates the use of antibiotics in modern medicine, which followed upon the discovery of penicillin by Alexander Fleming in 1928 (Fleming 1929; Hutchings et al. 2019). For example, ARGs coding for AMR to the antibiotic classes β-lactams, tetracyclines, and glycopeptides have been extracted from 30,000-year-old permafrost sediments in Canada (D'Costa et al. 2011). This ancient ability in soil bacteria to develop AMR is thought to have emerged to enable co-existence, and competition for resources, with antibiotic-producing organisms in the same environmental niche (Wright 2007; Hutchings et al. 2019).

Intrinsic resistance

Bacteria may harbour resistance traits that are universal for the bacterial species they belong to, and that cannot be passed on to other bacteria by ARG transfer (Cox & Wright 2013). For example, gram-negative bacteria, such as *E. coli*, have an outer membrane which makes it difficult for certain antibiotic molecules to enter the bacterial cell, as well as active efflux pumps that facilitate reduction of the intracellular drug concentration. Thus, this kind of intrinsic resistance is not affected by ABU and is therefore not a subject for regular AMR-mitigating efforts that aim to reduce such use. However, intrinsic resistance needs to be considered in the AMR context to avoid inaccurate ABU, and thereby unnecessary AMR development in other bacteria.

Acquired resistance

Although AMR is an ancient phenomenon, there is a common understanding that ABU, especially excessive use, accelerates AMR development (Holmes et al. 2016). When antibiotics are used, they put selective pressure on bacteria, whether commensal or pathogenic, that use their natural ability to develop AMR as a defence mechanism, a process referred to as acquired resistance (Levy & Marshall 2004; Wright 2007; Holmes et al. 2016). This induces a "survival-of-the-fittest" scenario, where the resistant bacteria are the ones that survive. Acquired resistance may also be obtained through horizontal transfer of ARGs between bacteria of the same or different species.

However, acquired resistance is not as easily understood as using one antibiotic causes AMR to that, and only that, antibiotic in a bacterium. Other forms of acquired resistance include co- and cross-resistance, when AMR to other antibiotics than the one exerting the selective pressure develops (Levy & Marshall 2004). This may occur if the same AMR mechanism is effective against several antibiotics, or if ARGs that code for AMR mechanisms against different antibiotics are located close to each other in the bacterial genome (Cantón & Ruiz-Garbajosa 2011; Poirel et al. 2018).

When AMR has emerged, a vicious cycle starts in which first-line antibiotics are no longer effective, leading to the use of more broad-spectrum or last-resort antibiotics which further accelerates AMR development (Barbosa & Levy 2000). When a bacterium has developed AMR to three or more antibiotic classes, it is defined as MDR. If this downward spiral is not broken, the pool of effective antibiotics will eventually be depleted, and doctors, veterinary practitioners, and farmers are left with alternative non-antibiotic treatment options, if such are available.

1.1.4 *Escherichia coli* as an antimicrobial resistance indicator

The occurrence and role of Escherichia coli in the gut

E. coli are gram-negative bacteria that are commonly present in the gut of all vertebrates, including humans. The bacterium was discovered in the late 1800s and is today one of the most popular to study in various research fields, including AMR (Foster-Nyarko & Pallen 2022). Most often these *E. coli* bacteria are commensal, meaning that they do not cause disease in the host. On the contrary, they are part of a healthy gut microbiome, which is essential for the host's digestion and immune system. However, some *E. coli* strains are pathogenic and may cause diarrheal disease (IPEC), such as enterohemorrhagic *E. coli* infection (EHEC) in humans, or disease outside of the gut (ExPEC), such as avian colibacillosis (APEC) in poultry. In severe cases, *E. coli* infection may lead to sepsis (Narasinakuppe Krishnegowda et al. 2022; Holmes et al. 2025). In 2019, pathogenic *E. coli* caused the most deaths attributable to, and associated with, AMR in humans (Antimicrobial Resistance Collaborators 2022). Both commensal and pathogenic *E. coli* may also be present in environments outside of a human or animal host for example in water, soil, and food products (Foster-Nyarko & Pallen 2022; Silva et al. 2023b).

Commensal Escherichia coli as an antimicrobial resistance reservoir

E. coli bacteria have an excellent ability to acquire and harbour ARGs from other bacteria, which they in turn may transfer to other bacteria as well, whether pathogenic or non-pathogenic (Poirel et al. 2018). Most commonly, such gene acquisition and transfer occur through horizontal gene transfer via bacterial plasmids, which are mobile genetic elements. Further, *E. coli* may acquire ARGs through mutations in their DNA due to selective pressure imposed by ABU (Levy & Marshall 2004). One of the most well-known AMR traits in *E. coli* is AMR to narrow- and broad-spectrum β-lactam antibiotics (penicillins and cephalosporins), facilitated by the production of different enzymes; ESBLs or overexpressed cephalosporinases (AmpCs) (Poirel et al. 2018). The majority of ARGs coding for ESBL production are located on plasmids and are often co-located with ARGs coding for AMR to other antibiotics, such as tetracyclines, aminoglycosides, fluoroquinolones, and phenicols. Such co-location enables rapid acquisition of AMR to several antibiotics. Naturally, both pathogenic and commensal *E. coli* may carry and transfer ARGs. However, since commensal *E. coli* bacteria do not cause disease in the host, they are continuously present in the gut, making it possible for them to acquire more ARGs and turning them into unpleasant silent AMR reservoirs.

1.1.5 Antimicrobial resistance in Vietnamese poultry

In Vietnam, the analysis of the AMR situation in poultry is based on the interpretation of individual research findings, since no structured surveillance program is yet in place. However, a pilot surveillance program was conducted in 2017–2019 which showed alarmingly high AMR rates in commensal gut *E. coli* from chickens sold in wet markets (Tuat et al. 2021). For example, AMR to the antibiotic classes tetracyclines, penicillins, phenicols, sulfonamides, and aminoglycosides was present in ≥80% of *E. coli* isolates, and 95% of isolates were MDR. Besides aminoglycosides, AMR to other antibiotics that are also classified as critically important to human medicine (WHO 2024a), such as fluoroquinolones, macrolides, and third-generation cephalosporins, was also quite frequently present. Other studies have also presented high AMR rates in *E. coli*, including MDR, from Vietnamese chicken farms of different production scales, as well as from slaughterhouses (Usui et al. 2014; Nhung et al. 2015; Nguyen et al. 2015; Nguyen et al. 2016; Vounba et al. 2019).

Other countries in SEA are also facing challenging AMR situations, such as Thailand, where the intensification of the poultry sector has come further than in Vietnam, but also countries like Cambodia and Laos which, like Vietnam, have poultry sectors still dominated by small-scale farmers (Nhung et al. 2016; Trongjit et al. 2016; Ström et al. 2018; Birhanu et al. 2021a; Chansamouth et al. 2021; Lao Statistics Bureau 2021; Inthavong et al. 2022). However, making comparisons between countries is difficult due to the lack or resolution of data, and the use of different methodologies.

Although comparisons should be made with caution, AMR rates in poultry *E. coli* are reportedly higher (for some antibiotics substantially) in Vietnam than in the EU, where a structured surveillance program is in place (EFSA & ECDC 2025). Resistance rates to four selected antibiotics in commensal poultry *E. coli* isolates from Sweden, the EU, and Vietnam have been reported as follows: ampicillin ~20% / ~40% / ~90%; chloramphenicol 0% / ~10% / ~90%; tetracycline ~7% / ~30% / ~90%; and sulfamethoxazole ~10% / ~30% / ~95% (Tuat et al. 2021; EFSA & ECDC 2025). Further, MDR rates have been reported at ~8%, ~35%, and 95% in Sweden, the EU, and Vietnam, respectively.

1.2 Vietnam – an agricultural nation

Vietnam is a middle-income country in SEA, bordering to China, Laos and Cambodia (Figure 2). As of 2025, the country had a human population of approximately 100 million people (United Nations Population Fund n.d.). Similar to many emerging economies, urbanization is ongoing. Nonetheless,

Figure 2. The continent of Asia, Vietnam marked in purple. Created with MapChart: https://www.mapchart.net License: https://creativecommons.org/licenses/by-sa/4.0/

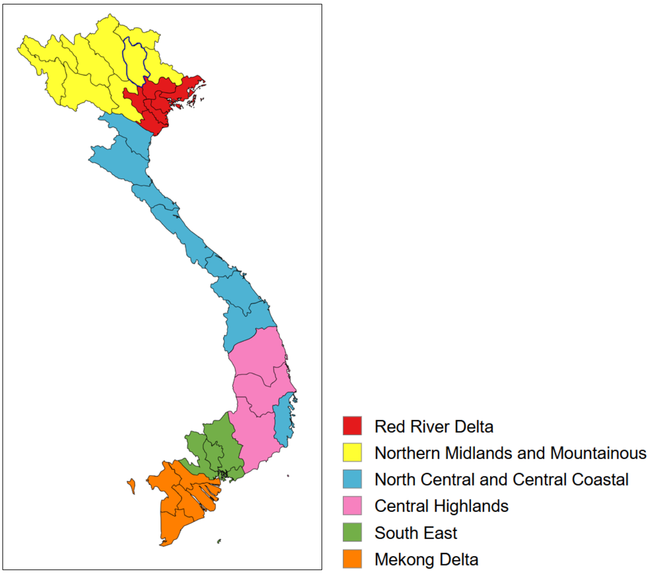

Figure 3. Map of Vietnam highlighting the six country regions. Province of Thai Nguyen (study area of the thesis) marked with thicker dark blue border (Northern Midlands and Mountainous region). Created with MapChart: https://www.mapchart.net License: https://creativecommons.org/licenses/by-sa/4.0/

most people still reside in rural areas, and in 2020, there were more than eight million agricultural households in the country (National Statistics Office 2021a).

Vietnam has a strong agricultural tradition, producing a wide range of agricultural products, both animal-source foods and a variety of crops (National Statistics Office 2024). The livestock sector is dominated by pig, poultry, and aquaculture production, which is still mainly intended for domestic consumption. However, there are governmental ambitions to move towards a larger export of animal-source foods (Decision No. 1520/2020/QD-TTg). In 2023, the export of food, foodstuffs, and live animals was valued at 44 million US dollars, constituting 12% of the total export. Some of the main agricultural products exported were fishery products, vegetables and fruit, cashew nuts, rice, coffee, and tea (National Statistics Office 2024).

1.3 Poultry production in Vietnam

1.3.1 Poultry population

Vietnam has a long history of poultry keeping, with archaeological findings supporting the theory that poultry were kept in the northern parts of the country already 3,000 years ago (FAO 2008). In 2023, the total poultry population was estimated to 560 million heads (National Statistics Office 2024). In only five years, the number of poultry had increased with >25% to that year. Poultry rearing is spread across the country; however, as of 2019, >85% of the poultry population was concentrated in four regions: Red River Delta, Northern Midlands and Mountainous, North Central and Central Coastal, and Mekong River Delta (Birhanu et al. 2021b). Country regions are displayed in Figure 3.

Different indigenous breeds make up 80% of the country's poultry population (Birhanu et al. 2021b). The most popular breed in small-scale chicken production in northern Vietnam is the Ri breed (Figure 4), which is often crossbred with other local breeds (FAO 2008; Birhanu et al. 2021b). The breed is slow-growing and lighter compared to exotic breeds used in intensive systems, such as Ross and Hubbard.

Although chicken keeping dominates the Vietnamese poultry sector, keeping of other poultry species, such as ducks and Muscovy ducks, is also common (CIRAD & CIRRD 2008; FAO 2008). Many small- and medium-scale poultry farmers keep several animal species on their farms, including different poultry species, but also other kinds of livestock and pets (Nguyen et al. 2015; Delabouglise et al. 2019).

Figure 4. Ri chicken on a chicken farm in Dong Hy district, Thai Nguyen province, Vietnam. Photo credit: Ms. Luu Thi Hai Yen/NIVR.

1.3.2 Reasons for poultry keeping

Food security and nutrition

As poultry is the second largest meat source in the country, keeping the production up is important for the overall food security and nutrition of the Vietnamese population (National Statistics Office 2021a). Small-scale poultry farmers often raise chickens for their own household consumption; hence, poultry keeping is directly contributing to their food security and nutrition (Birhanu et al. 2021b). The small- and medium-scale poultry producers also make an important contribution to the food security and nutrition of their communities, as they mainly sell their products directly from their farms or via local markets. Many Vietnamese people prefer to buy fresh still-warm chicken meat from newly slaughtered chickens, and hence, the local production is essential for food security, especially in rural communities (Birhanu et al. 2021b; Thi Dien et al. 2023).

Livelihoods

Despite most farms being small-scale, raising poultry makes an important contribution to the livelihoods of many households through sales of live poultry, chicken meat, and eggs. For smallholders, keeping poultry may also serve as an economic safety net, allowing them to generate income from sales when needed to cover service costs, such as school fees, or urgent expenses, like medical treatments (FAO 2008; Birhanu et al. 2021b).

Cultural

Several local chicken breeds are of strong cultural importance in Vietnam (FAO 2008). For example, the Ac breed may be used as traditional medicine for pregnant women, children, and elderly. Poultry and eggs are also commonly offered as gifts to neighbours, friends, and family at different occasions. During certain periods of the year, such as during wedding season (August–January) and Tết celebrations (January–February), consumer demand for poultry meat and eggs is especially high (Thi Dien et al. 2023). The longstanding tradition of poultry keeping in Vietnam is also reflected in traditional cultural works, such as paintings and poetry (ILRI n.d.; FAO 2008).

1.3.3 Development of the poultry sector the past decades

Due to the massive economic growth Vietnam has experienced over the past decades, poultry production has increased in response to a greater demand for animal-source foods (Birhanu et al. 2021b). Such correlations between consumption of animal products and country GDP, often linked to urbanization rate, have been shown in several LMICs previously (FAO 2017; IFAD 2021). Still, the Vietnamese poultry sector is dominated by small-scale farmers, where 94% of the chicken-keeping households keep less than 100 chickens/hens (National Statistics Office 2021a). However, a trend towards more large-scale farms has been identified over the last years (Birhanu et al. 2021b). Such development started in Thailand in the 1980s, which today has a poultry sector dominated by industrialized large-scale farms contracted by companies that produce poultry products for the domestic market, as well as for export (FAO 2004). These Thai large-scale farms operate side by side with the many smallholders that still produce poultry for household consumption and local markets (FAO 2004; Charoensook et al. 2021; Hinjoy et al. 2024).

Moving towards larger, more industrialized farms brings new possibilities, such as higher incomes for farmers and export opportunities. Export of Vietnamese chicken meat is still small, but as poultry production systems become more modern and intensified, the Vietnamese government aims for increased export in the future (Decision No. 1520/2020/QD-TTg). However, intensification of livestock production also comes with challenges. As farms become larger, keeping birds healthy becomes increasingly difficult due to higher disease pressure, if proper disease prevention measures are not applied (Jones et al. 2013; Adamie et al. 2024). This in turn might impede export possibilities and also accelerate AMR development, as increased disease frequencies mostly result in higher ABU. Inadequate disease prevention measures on Vietnamese small- and medium-scale poultry farms are well documented and contribute to the high disease burden they face (FAO 2008; Carrique-Mas et al. 2019; Delabouglise et al. 2019; Birhanu et al. 2021b; Auplish et al. 2024). In addition, an intensification of the poultry sector may result in that smallholders who cannot, or choose not to, increase their production are left behind and outcompeted by larger farms, especially if limited market access and infrastructure prevent them from competing effectively (FAO 2018; Chaiban et al. 2020).

1.3.4 Impact of specific disease outbreaks on the poultry sector

In late 2003, Vietnam faced a large countrywide outbreak of highly pathogenic avian influenza (HPAI), H5N1, which had severe consequences for the poultry sector, as 40 million poultry died or were culled (FAO 2008). The poultry loss during the first months of 2004 corresponded to approximately 15% of the poultry population (Figué & Desvaux 2015). In addition, 32 human cases, including 23 deaths, were reported from the start of the outbreak to the end of 2004 (WHO 2025). Although the initial outbreak was controlled in 2004, several waves of smaller outbreaks have followed, and the disease is currently circulating in the Vietnamese poultry population (FAO 2008; Nguyen et al. 2020; Nguyen et al. 2023; Dao et al. 2024). Large-scale vaccinations of poultry have been used as a strategy to control the disease (Figué & Desvaux 2015).

In early 2019, the first case of the high-mortality pig disease African swine fever (ASF) was reported in one of Vietnam's northern provinces (Chuong et al. 2025). This case marked the starting point of a large ASF outbreak, affecting swine herds across the country. By the end of 2019, almost 6 million pigs had died or been culled, equivalent to approximately 20% of the country's pig population (Nguyen-Thi et al. 2021). The disease is currently considered endemic in the country (Nguyen et al. 2022a). African swine fever has had a detrimental impact on the swine industry, forcing many farmers to switch from pig farming to other livestock, especially poultry (USDA 2020; Nguyen-Thi et al. 2021). Such a shift has also been promoted to farmers by authorities. Hence, the indirect effects of ASF on Vietnamese poultry production have been a boost of the sector, but also a decline in prices due to the sudden large (over)supply of poultry products on the market (Phu et al. 2020; USDA 2020).

The COVID-19 pandemic in 2020–2023 negatively impacted Vietnamese poultry production as it caused supply-chain disruptions, resulting in increased prices for feed and other farm inputs (Tran Cong et al. 2021; Hammond et al. 2022). It also lowered the consumer demand for poultry due to social isolation and closing of markets. Many farmers could not afford to continue their production, or had to switch from commercial production to keeping poultry for household consumption only (National Statistics Office 2021b; Personal communications). From an AMR perspective, this strenuous economic situation for farmers and fluctuations in poultry-product prices could make farmers reluctant to change their ABU practices, as providing antibiotics was seen as an easy way to secure production in uncertain times (Bâtie et al. 2023).

1.3.5 Common diseases in Vietnamese poultry farming

Vietnamese small- and medium-scale poultry producers are challenged by several poultry diseases that negatively impact animal welfare and production, and lead to economic losses for farmers. Since disease prevention is often lacking in these smaller farming systems, they are especially susceptible to disease introduction, and circulation within flocks.

Multiple viral, bacterial, and parasitic diseases are circulating in the Vietnamese poultry population (WAHIS n.d.; Schou et al. 2007; FAO 2008; Tu et al. 2015; Lettini et al. 2016; Delabouglise et al. 2019; Le et al. 2019; Van et al. 2020a; Van et al. 2020b; Nguyen et al. 2021a; Nguyen et al. 2021b;

Viet Thu et al. 2022), and some are endemic despite vaccines being available in the Vietnamese market.

Several of the circulating diseases may cause similar disease signs which makes diagnosing difficult without laboratory diagnostics. For example, the viral diseases avian influenza, infectious bronchitis, and Newcastle disease, as well as the bacterial diseases infectious coryza, avian mycoplasmosis, ornitobacteriosis, and fowl cholera, may all cause respiratory symptoms (Alexander 2000; WOAH 2018b, 2021a, 2021b; Barbosa et al. 2019; MSD 2024a, 2024b). Similarly, the viral diseases avian influenza, Gumboro disease, and Newcastle disease, the bacterial diseases avian salmonellosis, and fowl cholera, as well as infections with gastrointestinal parasites, may all cause symptoms from the digestive tract (Alexander 2000; WOAH 2021a, 2024; MSD 2024b, 2024c, 2025a, 2025b).

1.4 Access to veterinary drugs and animal health services in Vietnam

1.4.1 The antibiotic supply chain

Large-scale commercial farmers most commonly access antibiotics directly from drug companies. However, small- and medium-scale farmers mostly buy them from a veterinary drug shop, or occasionally from a veterinarian (Bâtie et al. 2022). Veterinary drug shops are run as private businesses that often also provide other goods than veterinary drugs, such as feed and other products related to animal husbandry (Phu et al. 2019). It is not uncommon for these shops to be run as family businesses, and, in those cases, the shop may also offer completely different kinds of goods or services.

As in several countries in SEA, veterinary drugs, including antibiotics, are available over the counter (OTC), meaning that a prescription is not needed to purchase them (Zellweger et al. 2017; Pham-Duc et al. 2019; Ha et al. 2021; Malijan et al. 2022). This practice is common in many LMICs. A report from the European Commission in 2018 on AMR policies in 77 non-EU countries showed that in 90% of low-income countries, 80% of lower middle-income countries, and 52% of upper middle-income countries, a prescription was never or only sometimes used in connection with veterinary drug sales (European Commission 2018). In 2024, ~80% of countries globally, and in the Asia and the Pacific region (including

Vietnam), reported having legislation in place demanding a prescription for sales of antibiotics for terrestrial animal use, but OTC sales are still widespread (TrACSS 2024).

1.4.2 Animal health services

According to official sources, as of 2020, governmental veterinary services were available in 90% of the 4854 communes in the country, with coverage varying by region, ranging from ~80% in the North Central and Central Coastal region to 99% in the Red River Delta (National Statistics Office 2021a). In addition, private veterinary services were available in ~60% of communes, with coverage again varying by region, ranging from ~40% in the Northern Midlands and Mountainous region (the study area of this thesis) to ~75% in the South East. However, other evidence suggests limited availability of veterinary services in rural areas (FAO 2008; Truong et al. 2019; Auplish et al. 2024).

As a substitute to veterinary services, veterinary drug shops have become sources not only for veterinary drugs, but also for treatment advice (Carrique-Mas et al. 2015; Truong et al. 2019; Pham-Duc et al. 2019; Phu et al. 2019; Luu et al. 2021). Some veterinary drug shop workers also offer basic diagnostic services. Hence, it is likely that veterinary drug shop workers may influence farmers' ABU practices in different directions depending on their knowledge and experience, as well as their rationales for antibiotic sales. However, despite their key role in the supply chain of antibiotics to farmers, these aspects were largely understudied before the research in this thesis.

1.5 Antibiotic use in Vietnamese livestock

Asia and the Pacific had the highest use of antimicrobials per kg animal biomass in 2022 (WOAH 2025a). Adjusted for animal biomass coverage, the use was 147 mg/kg, which is almost four times higher than the use in Europe, and 1.5 times higher than the global average. For terrestrial animals, the most used antibiotics per kg biomass on a global scale belonged to the antibiotic classes tetracyclines, penicillins, macrolides, amphenicols, and aminoglycosides. Both macrolides and aminoglycosides are considered critically important antimicrobials (CIA) for human medicine by the World Health Organization (WHO) (WHO 2024a).

Table 1. Common antibiotic classes and substances classified according to their importance for human medicine.

Importance for human medicine category	Examples of antibiotic classes within category	Examples of antibiotic substances within class
Important (IA)	Aminocyclitols[A]	Spectinomycin
	Cyclic polypeptides[B]	Bacitracin
	Pleuromutilins[B]	Tiamulin
Highly important (HIA)	Amphenicols[A]	Chloramphenicol* Florfenicol
	1st and 2nd generation cephalosporins[B] (β-lactams)	Cefalexin Cefalotin
	Lincosamides[B]	Clindamycin Lincomycin
	Penicillins[A] (β-lactams)	Amoxicillin Ampicillin* Benzylpenicillin
	Sulfonamides[A] (folate pathway inhibitors)	Sulfamethoxazole* Trimethoprim*
	Tetracyclines[A]	Doxycycline Oxytetracycline Tetracycline*
Critically important (CIA)	Aminoglycosides[A]	Amikacin* Gentamicin* Streptomycin
	Macrolides[A]	Azithromycin* Erythromycin Tylosin
Highest priority critically important (HPCIA)	3rd and 4th generation cephalosporins[A] (β-lactams)	Cefotaxime* Ceftazidime* Ceftiofur
	Quinolones[A,B]	Ciprofloxacin* Enrofloxacin Nalidixic acid*
	Polymyxins[B]	Colistin* Polymyxin B

Importance for human medicine category	Examples of antibiotic classes within category	Examples of antibiotic substances within class
Human use only	Carbapenems (β-lactams)	Meropenem*
	5th generation cephalosporins (β-lactams)	Ceftaroline
	Glycopeptides	Vancomycin
	Glycylcyclines	Tigecycline*

Coloured cells = classification of importance for human medicine according to the World Health Organization (WHO 2024a). A = veterinary critically important antimicrobial agent, B = veterinary highly important antimicrobial agent, according to the World Organisation for Animal Health (WOAH 2025b). * = included in antibiotic susceptibility testing presented in Paper II.

Some common antibiotics are listed in Table 1 according to their WHO classification.

Looking at Vietnam, it has been estimated that in 2015 approximately 70% of the antibiotics used in the country were used in livestock production (Carrique-Mas et al. 2020). Further, it is projected that the consumption will increase by 157% to 2030 compared to 2010 (Van Boeckel et al. 2015). On a global scale, this increase is "only" projected to be 67%. A more recent estimation predicts a global increase of 8% between 2020 and 2030 (Mulchandani et al. 2023). The Red River Delta in northern Vietnam has been categorized as a hotspot for both ABU and AMR in livestock (Van Boeckel et al. 2015; Van Boeckel et al. 2019; Mulchandani et al. 2023).

The largest ABU in Vietnam takes place within pig production, followed by poultry. However, when ABU is calculated per kg animal biomass and excluding antibiotics as growth promoters (GPs) in feed (which have been banned in the country since 2018), the use in poultry is the highest, estimated to 188 mg/kg, compared to 46 mg/kg in pigs (Circular No. 06/2016/TT-BNNPTNT; Law No. 32/2018/QH14; Carrique-Mas et al. 2020). Several studies on Vietnamese poultry farms have reported frequent and/or medically irrational ABU (Carrique-Mas et al. 2015; Nguyen et al. 2016; Pham-Duc et al. 2019; Truong et al. 2019; Luu et al. 2021; Bâtie et al. 2022). Rational ABU is defined by Magnusson et al. (2019) as making correct diagnoses and using the right kind of good quality drugs in adequate doses. Examples of medically irrational ABU on Vietnamese farms include ABU for disease-preventive (prophylactic) purposes, and for treatment of viral disease. More vague reasons for ABU have also been presented, like weather or seasonal changes (Pham-Duc et al. 2019; Truong et al. 2019).

1.6 Purposes of antibiotic use in poultry

1.6.1 Disease treatment

The intended use of antibiotics for humans and animals overall is to treat bacterial disease (therapeutic use). As mentioned above, several bacterial diseases circulate on Vietnamese poultry farms, resulting in a need and/or demand for antibiotics among poultry farmers. Antibiotics for poultry-disease treatment are most commonly and effectively distributed to the whole flock via the drinking water, but other distribution routes are sometimes used (Carrique-Mas et al. 2015; Gray et al. 2021; Islam et al. 2024).

To reduce the risk of unnecessary AMR development, an antibiotic with as narrow a spectrum as possible should be selected for treatment; in other words, an antibiotic that targets few bacterial species, such as penicillins (Magnusson et al. 2019; Gray et al. 2021). The opposite is using a broad-spectrum antibiotic, which is effective against several kinds of bacteria, such as fluoroquinolones. The use of broad-spectrum antibiotics has shown to contribute to AMR more severely than narrow-spectrum ones (Barbosa & Levy 2000; Modi et al. 2014; Spaulding et al. 2018). However, to be able to provide targeted antibiotic treatment with the correct narrow-spectrum antibiotic, suitable diagnostics need to be available, which is not always the case in LMICs (Paul & Varghese 2020; Hobbs et al. 2021).

1.6.2 Disease prevention

Use of antibiotics for disease prevention (prophylactic use) is widespread in the livestock sector, not only in poultry (Marshall & Levy 2011; FAO 2016). Due to the risk of AMR development associated with such long-term or recurring ABU, this practice is no longer permitted within the EU (other than in exceptional cases), and similar legislation is currently being implemented in Vietnam (Regulation (EU) 2019/6; Decree No. 13/2020/ND-CP). However, prophylactic ABU is still common practice in many countries, including LMICs dominated by small-scale farming (Malijan et al. 2022).

There are several rationales for using antibiotics prophylactically, for example: to compensate for poor disease prevention practices, to protect animals from infections during especially sensitive life stages, or in case of disease outbreaks in proximity to the farm. However, with good animal husbandry, biosecurity measures, and vaccination schemes, this kind of ABU is often not needed and creates unnecessary selection pressure for AMR in gut bacteria (Magnusson et al. 2019).

1.6.3 Growth promotion

In the 1940s it was discovered that providing livestock with a low dose of antibiotics in the feed would make them grow faster. After this discovery, the use of antibiotics such as tetracyclines, lincosamides, macrolides, and penicillins as GPs became common in livestock production worldwide, with the United States becoming the first country, in 1951, to approve such use without a veterinary prescription (Witte 2000; Dibner & Richards 2005; Castanon 2007). Such continuous use of subtherapeutic doses of antibiotics creates an ongoing selective pressure on gut bacteria, which facilitates AMR development (Marshall & Levy 2011). As the threat of AMR has come into the spotlight and consumer pressure against antibiotics in animal-source foods has increased, several countries have banned this practice, with Sweden being the first in 1986 (SFS 1985:295; SOU 1997:132). In the EU, such a ban came into place 20 years later, and several other countries have followed since then (Regulation (EC) No. 1831/2003; Law No. 32/2018/QH14; TrACSS 2024).

However, in many LMICs, the use of antibiotics as GPs is still commonly occurring, where some countries lack legislation prohibiting such use, while others have the legislation in place but lack the capacity to enforce it. The latest report from the World Organisation for Animal Health (WOAH) states that, as of 2023, almost 25% of its member countries still used GPs in livestock (WOAH 2025a). For the Asia and Pacific region, this share was ~40%, even though ~75% of countries in the region reported having legislation prohibiting GP use (TrACSS 2024; WOAH 2025a). In Vietnam, the use of GPs has been banned since 2018 (Circular No. 06/2016/TT-BNNPTNT; Law No. 32/2018/QH14).

1.7 Policies on antibiotic use in livestock

1.7.1 Vietnamese regulations on antibiotic use and sales

Vietnam has among the most comprehensive AMR-related regulatory frameworks in SEA, to a large extent in line with what is implemented in the EU and Canada (Regulation (EC) No. 1831/2003; Regulation (EU) 2019/6; Carrique-Mas et al. 2023). Restrictions regarding ABU and sales are incorporated in several legislative documents listed in Table 2. Some of the major regulations are the ban on ABU for growth promotion and prophylaxis (Circular No. 06/2016/TT-BNNPTNT; Law No. 32/2018/QH14; Decree No. 13/2020/ND-CP). The latter is under implementation in a stepwise manner based on the WHO list of medically important antimicrobials for human medicine (WHO 2024a). A complete ban on prophylactic ABU is to take effect on 1 January 2026. A stepwise implementation of legislation concerning the requirement of a prescription prior to use of veterinary drugs, based on farm size, was finalized on 1 January 2025 (Circular No. 12/2020/TT-BNNPTNT). Further, veterinary drug shops need to be officially registered, and salespersons need to have a certificate of veterinary practice to prove that they are qualified (Law No. 79/2015/QH13; Ha et al. 2021). Veterinary drug shop workers are also obliged to keep records of their drug sales.

1.7.2 Action plans against antimicrobial resistance

Global action plan

In 2015, the World Health Assembly of the WHO adopted the global action plan against AMR (GAP-AMR) which outlines strategies to combat AMR using a One Health approach (WHO 2015). The action plan was developed by the WHO, with consultation from the Food and Agriculture Organization (FAO), WOAH, and other relevant stakeholders. The GAP-AMR includes five specific objectives to mitigate AMR development that concern the following areas: awareness and understanding; surveillance and research; disease prevention; optimized ABU; and sustainable investment.

The GAP-AMR is also intended to serve as a guideline for countries when they develop their own national action plans (NAPs). A process to update the GAP-AMR is currently ongoing.

Table 2. Important Vietnamese regulations concerning the use and sales of antibiotics intended for livestock.

Regulatory document	Important points	Specifications/Comments
Law No. 79/2015/QH13 on Veterinary Medicine **Took effect: 2016**	Required certificates for sales of veterinary drugs	• Certificate of Business/Enterprise registration • Veterinary practice certificate for salespersons • Certificate of eligibility for trading in veterinary drugs
	Requirement of keeping a logbook of veterinary drug sales	
Law No. 32/2018/QH14 on Animal Husbandry **Took effect: 2020**	Ban on antibiotics as growth promoters	Took effect in 2018, as stated by Circular No. 06/2016/TT-BNNPTNT
	Antibiotics in feed only allowed after prescription for preventing disease in young animals or to treat disease	Took effect in 2017, as stated by Decree No. 39/2017/ND-CP
Decree No. 13/2020/ND-CP on elaboration of the Law on Animal Husbandry **Took effect: 2020**	Ban on antibiotics for disease prevention to mature terrestrial animals	Poultry: Antibiotics for disease prevention in feed only allowed for animals 0–21 days of age
	Roadmap towards complete ban of antibiotics for disease prevention	• HPCIA/CIAs: banned from 1 January 2021 • HIAs: banned from 1 January 2022 • IAs: banned from 1 January 2023 • Other: banned from 1 January 2026

Regulatory document	Important points	Specifications/Comments
Circular No. 12/2020/TT-BNNPTNT Providing for Management of Veterinary Drugs Containing Narcotic Substances and Precursors; Veterinary Prescribing **Took effect: 2020**	All veterinary drugs must be prescribed, and prescriptions must be based on examination, diagnosis, or testing result	Exceptions: • Anticoccidials • Drugs containing antiseptics/disinfectants • Vaccines • Drugs that strengthen resistance/supports treatment • Herbal medicines
	Regulations on allowed prescribers	• Veterinarians • People with bachelor's degree in veterinary medicine/animal husbandry • Holders of a veterinary practice certificate
	Regulations on archiving of prescriptions	Prescribers must archive prescriptions for two years
	Responsibilities of users of veterinary drugs	• Use veterinary drugs according to prescription • Document the use of antibiotic-containing drugs • Archive prescriptions
	Roadmap for implementation of prescription regulations based on farm size	• Large-scale: 9 November 2020 • Medium-scale: 1 January 2022 • Small-scale: 1 January 2023 • Family farming: 1 January 2025

HPCIA = highest priority critically important, CIA = critically important, HIA = highly important, IA = important, antimicrobials for human medicine according to the World Health Organization (WHO 2024a).

National action plans

Almost all countries have developed their own AMR NAPs (TrACSS 2024). As the first country in the WHO Western Pacific region, Vietnam adopted its first NAP already in 2013, which was mainly focused on human health (Ministry of Health 2013; Thomas et al. 2024). In addition, a NAP specifically addressing AMR in livestock and aquaculture was released in 2017 (Ministry of Agriculture and Rural Development 2017). The 2017 NAP includes specific objectives targeting the following areas: AMR policy and governance; awareness-raising; good treatment and production practices; AMR and AMU monitoring; and inter-sectoral collaboration.

1.7.3 Classification of antibiotics according to importance for human medicine and animal health

The emergence of AMR has rendered some antibiotics especially important to preserve, as they in some cases may be the only or among the very few antibiotics effective against an infection caused by resistant bacteria. Further, in livestock, where the options are often more limited than in human medicine, some antibiotics are crucial to preserve from an animal welfare perspective. Therefore, the WHO and WOAH have individually developed lists where antibiotics are classified according to their importance for human medicine and animal health (WHO 2024a; WOAH 2025b). These documents may be used as guidance for countries when issuing treatment recommendations, developing AMR/AMU surveillance systems, performing AMR/AMU risk assessments, and ensuring access to important human and veterinary medicines. As mentioned above, in Vietnam, the stepwise phasing out of ABU for prophylaxis is based on the WHO list (Tables 1 and 2) (Decree No. 13/2020/ND-CP).

1.7.4 Implementation of policies

Although country policies may be officially similar, the capacity to implement and enforce them differ between countries. In HICs, there are often sufficient infrastructure and systems in place to facilitate such implementation and enforcement, including governmental funding. This is not the case in many LMICs (Pham-Duc et al. 2019; Caudell et al. 2020; Malijan et al. 2022; Thomas et al. 2024; WHO 2024b). According to the WHO, as of 2023, only 25% of member countries had a NAP that was actively implemented and funded, and only 11% had funding from national budgets. There may also be a lack of structure for the coordination between the human, animal, and environmental sectors to secure the One Health approach in AMR-mitigating strategies. Hence, even though the ambitions to tackle AMR through different kinds of policies may be high at the governmental and authority level, there is a risk that lack of capacity leaves those policies on paper, instead of transforming them into practices on the ground.

1.8 Alternative approaches for change

When regulation enforcement is lacking, the need for bottom-up approaches to complement the regulations arise, including interventions to achieve a change of practices at the farm or community level. However, to make such interventions effective and efficient, they need to be based on an understanding of what actually drives the behaviours targeted for change, such as ABU practices. To investigate such drivers, knowledge, attitudes, and practices (KAP) studies have become increasingly common in AMR research, both in HICs and LMICs (Sadiq et al. 2018; Pham-Duc et al. 2019; Rayner et al. 2019; Ström et al. 2019; Caudell et al. 2020; Gemeda et al. 2020; Thi Huong-Anh et al. 2020; Borelli et al. 2023). However, KAP studies seldom evaluate the relationship between farmer KAP and AMR occurrence, highlighting that there is a knowledge gap to be bridged regarding the actual impact of farm(er) characteristics on the AMR situation on farms.

2. Aims of the thesis

The overall aim was to identify possible areas for interventions that may lower the incidence of antimicrobial resistance (AMR) in the livestock sector globally by providing new, cross-disciplinary data from Vietnamese poultry farms.

The specific objectives were to:

- Describe farm characteristics and management routines on Vietnamese small- and medium-scale chicken farms, as well as farmers' access to veterinary drugs and animal health services.

- Investigate, and evaluate, Vietnamese small- and medium-scale chicken farmers' knowledge and practices related to antibiotics and AMR, including disease prevention.

- Evaluate which farmer demographics and farm characteristics that are associated with chicken farmers' AMR-related knowledge and practice levels.

- Assess AMR in commensal *E. coli* from healthy poultry on Vietnamese small- and medium-scale chicken farms.

- Explore possible associations between farmers' AMR-related knowledge and practices and AMR in commensal *E. coli* on their farms.

- Understand, and evaluate, veterinary drug shop workers' knowledge regarding antibiotics and AMR, as well as their routines when selling antibiotics to farmers.

3. Considerations on materials and methods

3.1 Study area (Papers I–III)

Vietnam is an interesting study site for AMR development within poultry production due to the ongoing expansion of the poultry sector in the country, in combination with the reportedly high access to, and use of, antibiotics. Thus, the situation in Vietnam may serve as a representative for other emerging economies.

The research was conducted in Thai Nguyen province, located in the Northern Midlands and Mountainous region, north of the capital of Hanoi (Figure 3). As of 2023, the province had a human population of 1.4 million, and as of 2016, the number of chicken-keeping households was 173 thousand, corresponding to approximately 2% of the chicken-keeping households in the country (National Statistics Office 2018; National Statistics Office 2024). The province was selected based on its large poultry population and the diverse urban/rural profiles of districts within the province. It was also a suitable choice for logistic reasons, being located close to the laboratory facilities at the National Institute of Veterinary Research (NIVR), Hanoi. Three districts with different urban/rural profiles, Thai Nguyen City, Dong Hy, and Vo Nhai, were selected to serve as proxies for the province as a whole.

3.2 Study population (Papers I–III)

3.2.1 Poultry farms (Papers I and II)

Farms of two size categories were included, small-scale farms defined as having 20–49 chickens/hens, and medium-scale farms defined as having 100–499 chickens/hens (examples in Figures 5 and 6). Large-scale farms are still rare in Vietnam and were not included since their production system often differs considerably from the smaller farms'. The combination of the continued dominance of small farms in the poultry sector, and the observed trend of intensification, makes the included farming systems especially important to study from an AMR-mitigating perspective. A shift towards

Figure 5. Free-range poultry on a small-scale chicken farm in Dong Hy district, Thai Nguyen province. Photo credit: Ms. Luu Thi Hai Yen/NIVR.

Figure 6. Medium-scale chicken farm in Thai Nguyen City district, Thai Nguyen province. Photo credit: Mr. Tran Viet Dung Kien/NIVR.

larger flock sizes together with insufficient biosecurity increases the likelihood for additional disease pressure, extensive ABU, and subsequent AMR development. To avoid such a scenario, it is imperative to understand the antibiotic-related practices on these farms before they begin, or come further on, their intensification journey.

The choice of including farms from groups distinctively different in size, instead of including all farms within the 20–499 bird range, was based on the initial ambition to compare AMR occurrence and AMR-related farmer knowledge and practices between size groups. The sample size from each district was stratified according to the total number of farms in the different districts in order for the total sample to be representative for the province. Included farms were randomly selected from official lists of farms from each size category provided by the sub-Department of Animal Health (sub-DAH) in Thai Nguyen province. When field work was initiated, the field work team became aware that farms often did not keep the number of poultry stated in the official records. Therefore, the initial idea of comparing farm-size groups was abandoned, and the two samples were merged into one.

The inclusion criterion for the respondent (farmer) was that they should be the person with the primary responsibility of poultry keeping on the farm.

3.2.2 Veterinary drug shops (Paper III)

The veterinary drug shop study was conducted in the same province and districts as the two farm studies in order to be able to interpret results from all studies together in a reliable way. Veterinary drug shops were randomly selected from official lists provided by the sub-DAH in Thai Nguyen province. As for the farm studies, the number of shops selected from each district was stratified according to the districts' total number of shops.

3.2.3 Replacement considerations (Papers I–III)

For the farm studies (Papers I and II), a replacement list with randomly selected farms was created prior to the start of the field work. However, as the number of farms that needed to be replaced was larger than anticipated, the strategy had to be changed to choosing another farm that met the inclusion criteria and that was located in proximity to the originally selected farm. For the veterinary drug shop study (Paper III), the number of shops was limited; hence, all shops that were not selected in the randomization process were included in the replacement list. When necessary, the shop from the replacement list located closest to the originally selected shop was chosen for substitution.

3.3 Ethical considerations

3.3.1 Ethical approval (Papers I–III)

All studies were conducted according to guidelines of the declaration of Helsinki, and ethical approvals were collected from the Institutional Ethical Review Board of the Hanoi University of Public Health (HUPH), reference numbers 021-356/DD-YTCC (Papers I and II) and 022–457/DD-YTCC (Paper III).

3.3.2 Respondents (Papers I and III)

Voluntary participation

Before initializing the interviews on both farms and in shops, informed consent was collected from all respondents. The digital questionnaires used could not be opened until consent was collected. The consent statements clearly informed respondents that participation was voluntary and that they could retract their consent at any time.

Anonymity and pseudonymisation

The consent statement informed respondents that the collected data would be anonymised and that results could not be traced back to them. Names of respondents were not collected in the questionnaires. However, geographical data (village names and coordinates) were collected, which hypothetically could be used to find respondents if made public. Therefore, these geographical data were not included in the datasets that were made available by the time of journal publication of research articles. The published datasets included ID numbers that through a code key (separately stored) could be linked to the coordinate and village data, and therefore datasets were made available with restricted access.

3.3.3 Animal ethics (Paper II)

The field work was planned by the Swedish and Vietnamese research team partners together. During the preparatory work, animal ethics were discussed in order for the Swedish team (who could not participate in the field work due to the COVID-19 pandemic) and the Vietnamese team to be in agreement on how animals would be handled and sampled. It was decided that the field work would be conducted by enumerators employed by the research partner NIVR in Hanoi, who all had previous experience with the sampling technique. In addition, the enumerator team participated in a one-day training to assure harmonization within the group regarding questionnaire use and sampling procedures. The training was facilitated by staff from the International Livestock Research Institute (ILRI), the second Vietnamese research partner of the project, who also participated during the first days of field work.

3.4 Questionnaire development and considerations (Papers I and III)

3.4.1 Questionnaire structure

Question categories

The distributed questionnaires started with general sections including demographic and farm/shop characteristic questions to be able to understand and describe the contexts of visited farms (Paper I) and drug shops (Paper III). The demographic and farm-characteristic variables were also important in order to perform the statistical analyses presented in Papers I and II. For a broader understanding of farm circumstances, information about poultry-disease issues, as well as access to animal health services and veterinary drugs, was also collected in the farmer questionnaire. Further, the purpose of including questions regarding access to animal health services and veterinary drugs was also to enable comparisons to the findings in the drug shop study.

The main focus of both questionnaires was on practices and knowledge directly, or indirectly, connected to AMR development and spread. Indirectly connected farm practices were, for example, practices concerning disease prevention, housing, feeding, sales of animals or animal-source foods, manure handling, and slaughter. To capture nuances in AMR knowledge, different aspects of AMR were covered by the knowledge questions, such as working mechanisms of antibiotics, AMR development and its consequences, as well as AMR spread, including the One Health perspective. For comparative purposes, the knowledge questions for farmers and veterinary drug shop workers were almost the same. However, in order to reduce the interview time for veterinary drug shop workers, who participated during their drug shop opening hours, the number of questions in the drug shop questionnaire was fewer compared to the farmer questionnaire.

Item response theory considerations for the questionnaire (Paper I)

The farmer questionnaire was developed with the aim of using the collected data for a certain statistical method for test evaluation, item response theory (IRT). In this case the evaluated tests were sets of AMR-related knowledge and practice questions. To maximize the chances of being able to apply IRT to the collected data, the questionnaire needed to be designed appropriately. For example, a large number of knowledge and practice questions needed to be included, since the IRT workflow most often involves excluding questions in the process. Further, responses to knowledge questions needed to be coded into correct/incorrect, and for practice questions into desirable/undesirable (from an AMR-mitigation perspective). This was considered already in the questionnaire development process, so that each possible answer was clearly categorized beforehand. Since the IRT method considers question difficulty when generating respondent test scores, questions of varying difficulties were included (subjectively assessed by the author).

3.5 Interview and data-handling considerations (Papers I and III)

3.5.1 Interview methods

Face-to-face interviews in Vietnamese (Papers I and III)

To help respondents understand the phrasing of questions and to reduce desirability bias, interviews for both the farmer and drug shop studies were conducted in Vietnamese, face-to-face, and on a one-on-one basis. Questionnaires were developed in English and then translated into Vietnamese. Re-translation back to English by a native Vietnamese speaker outside of the research team was also performed for the farmer study.

Guidance on antibiotic substances (Paper III)

When asking veterinary drug shop workers about the most commonly sold antibiotics in their shops, they were provided a printed list of the different antibiotic classes they could choose from, as well as examples of substances within each class. A printed-out version was chosen to make it easier for respondents to get an overview of the many options and examples given in order to decrease the risk of respondent fatigue.

No possibility to skip questions (Papers I and III)

A setting in the questionnaire software was applied that did not allow respondents to move to the next question without providing an answer to the one currently displayed. Since especially the farmer questionnaire was extensive, the risk of respondent fatigue when choosing this method was considered. However, some questions in the questionnaires would only appear if a certain answer had been provided for a previous question. Hence, the majority of respondents did not need to answer all questions in the questionnaire despite the "no-skipping" setting. After consultation with Vietnamese partners experienced in similar field work, the risk of respondent fatigue was believed to be low compared to the benefit of avoiding missing data when applying the described approach.

3.6 Antibiotic susceptibility testing considerations (Paper II)

3.6.1 Choice of indicator bacteria

Commensal gut *E. coli* were chosen as the indicator bacteria for AMR due to their widespread presence in the gut of vertebrate species (Foster-Nyarko & Pallen 2022). This makes *E. coli* easy to retrieve and enables comparisons between species. Further, *E. coli* are suitable for AMR screening purposes due to their ability to harbour ARGs and thereby function as AMR reservoirs (Poirel et al. 2018). For these reasons, analysing AMR in commensal gut *E. coli* is common in both AMR research and in established AMR surveillance programs, for example the one applied within the EU (EFSA & ECDC 2025). Choosing *E. coli* was therefore suitable to facilitate comparisons of the findings in Paper II with previous studies. When performing AMR screening in low-resource settings, analysing *E. coli* is also preferable due to their high survival rate after sample collection, and because they are easy to culture with basic laboratory equipment. As the study area of this thesis included remote areas, this reasoning was applied in the decision-making process.

Compared to using pathogens, using commensal bacteria for screening purposes is beneficial since the number of animals that are possible to sample is larger compared to sampling sick animals only. Not having to rely on disease occurrence also means that surveillance can be more easily planned and regularly performed. Further, test results are not as likely to be influenced by ongoing disease and/or disease treatment as if pathogens were to be used for surveillance. In addition, working with commensal bacteria rather than human pathogens reduces the health risks for field workers and laboratory staff.

3.6.2 Sampling considerations

The aim of the sampling was to get an overview of the AMR situation among chickens/hens on the visited farms. Chickens/hens on the same farm were assumed to have relatively homogenous bacterial populations in their gut because of their shared environment, and therefore sampling of three chickens/hens per farm was considered sufficient (Kers et al. 2018). The sampled chickens/hens were randomly selected if all chickens/hens on the farm were of the same age category. However, if several age categories were present, birds from the oldest age category were sampled, since they were assumed to have gathered more AMR in their gut than younger birds. Since keeping multiple animal species is common on Vietnamese small- and medium-scale farms, cloacal swabbing was chosen as the sampling method to ensure that the tested *E. coli* originated from chickens/hens rather than other farm sources (Figure 7).

In addition to the cloacal swabs, one pooled faecal sample from each farm was collected for the purpose of selective culturing for specific resistances (third-generation cephalosporins, colistin and carbapenems). Unfortunately, time did not allow for the isolates from these samples to be fully analysed, and they are therefore not included in the results of this thesis. The selectively cultured *E. coli* isolates are, however, stored in a −80 °C freezer at the Swedish University of Agricultural Sciences (SLU) for future analyses (see Future perspectives).

3.6.3 Bacterial culturing considerations

Upon arrival at the laboratory at NIVR, Hanoi, non-selective culturing of commensal *E. coli* from the collected cloacal swabs was performed. Culturing non-selectively results in a randomly selected *E. coli* colony being used for antibiotic susceptibility testing (AST), which is useful when aiming to investigate how commonly occurring different resistances are. In other words, the more common a resistance is, the higher the probability of finding it in a randomly selected *E. coli*. As the aim was to get an overview of the AMR situation on the visited farms, this was therefore the preferred method. However, the method also poses a risk of underrepresentation of the occurrence of rare resistances at farm level. To decrease this risk, three samples were collected from each farm.

Figure 7. Cloacal swabbing of poultry on a chicken farm in Thai Nguyen City district, Thai Nguyen province. Photo credit: Ms. Le Thi Minh Hang/NIVR.

3.6.4 Antibiotic susceptibility testing method

There are two major methods for AST of bacteria, disc diffusion and broth microdilution. Both methods have been used in AMR research and surveillance in livestock previously (Nhung et al. 2016). The disc diffusion method is cheaper and requires less laboratory equipment than the broth microdilution method, why this method might be the necessary choice if there are, for example, financial or capacity constraints. However, broth microdilution is considered the golden standard in AMR surveillance, as it provides more precise results, and was therefore selected for this project (EFSA 2019). Further, even though genotypic AST would provide valuable information regarding which ARGs that circulate on Vietnamese poultry farms, phenotypic AST was considered the most adequate for the overall surveillance purpose of the study presented in Paper II. However*, E. coli* isolates are saved in a −80 °C freezer at SLU for possible future genotypic analyses.

3.6.5 Selection of antibiotic substances

A microdilution plate including 15 antibiotic substances was chosen for the AST procedure according to the considerations listed below. The most suitable plate ended up being the same as the one used for AMR surveillance within the EU (ThermoFisher n.d.; EFSA 2019). Included substances are indicated in Table 1.

Relevance for the Vietnamese setting

To ensure relevance for the Vietnamese setting, information regarding commonly sold antibiotics in the study area was collected and analysed (pictures provided by field work team). In addition, a screening of which antibiotics that had been included in previous research on AMR/ABU in Vietnamese poultry was performed (Carrique-Mas et al. 2015; Nguyen et al. 2016; Luu et al. 2021; Tuat et al. 2021).

One Health relevance

To make findings relevant from a One Health perspective, antibiotics of critical importance for veterinary and human medicine were included. These considerations were based on the categorization of antimicrobials made by the WOAH and WHO (WHO 2019; WOAH 2021c). For some of the antibiotics of critical importance to human medicine, such as aminoglycosides, fluoroquinolones, and macrolides, high AMR rates have been previously described in Vietnamese livestock (Usui et al. 2014; Nhung et al. 2015; Nguyen et al. 2015; Nguyen et al. 2016; Vounba et al. 2019; Tuat et al. 2021; Nguyen et al. 2022b). For others, such as carbapenems, AMR has only been rarely detected (Yen et al. 2022). However, due to the crucial importance of carbapenems to human medicine it is meaningful to track any AMR emergence to them.

3.7 Data analysis considerations (Papers I–III)

3.7.1 Item response theory versus classical test theory (Paper I)

The application of IRT in research is not new, although its entry into veterinary public health research, including AMR, is fairly recent (Gemeda et al. 2020; Dohoo & Emanuelson 2021; Muloi et al. 2023; Sharma et al. 2024). The IRT method was chosen to generate farmer test scores as it holds several advantages over more traditional methods. In traditional classical test theory, all questions in the test are valued equally although they might be of varying difficulty, and the sum of scores is often used as the outcome. Furthermore, it is often unclear what the questions used for that sum of scores actually measure, as there is no defined underlying scale. With IRT, both these shortcomings are addressed. Firstly, questions contribute differently to the score depending on their difficulty and quality, meaning that which score a respondent ends up with depends on which questions they get right (Hobart & Cano 2009). Secondly, the IRT workflow generates a set of questions that all represent the same underlying scale. Taken together, these aspects make results generated through IRT more reliable compared to classical test theory results. However, using IRT puts higher demands on questionnaire development and data processing, making it more time consuming than simpler methods. Because of this, it was decided to focus on measuring the respondents' knowledge and practices only, not including AMR attitudes which is usually done in KAP studies.

3.7.2 Data analysis of antibiotic susceptibility testing results (Paper II)

Besides presenting AST data descriptively, regression analyses were performed between the IRT scores presented in Paper I and certain AST results. The total number of antibiotic substances to which an isolate was resistant, AMR to specific antibiotic substances, and MDR status were included in these analyses. Specific antibiotic substances were selected based on their particular One Health relevance. The WHO list of critically important antimicrobials for human medicine was used as guidance for this selection, and included substances were classified as either highest priority critically important (HPCIA), critically important (CIA), or for “human use only” (WHO 2024a). In addition, to examine AMR combinations within isolates, pairwise correlation analysis was performed.

A basic geographical analysis of AMR distribution was done based on the coordinate data collected through the farmer questionnaire belonging to Paper I. However, since spatial analysis was not a part of the initial research question, and the farm selection was stratified leading to uneven geographical distribution of farms, a more thorough spatial analysis was not performed.

Handling of different number of isolates from farms

Three cloacal swabs were collected on each farm; however, not all swabs resulted in an *E. coli* isolate. Consequently, 84 of the 296 farms (28%) were represented by two isolates, and 20 (7%) by one isolate. This made statistical analyses at the farm level unreliable due to different probabilities of catching AMR depending on the number of isolates from a farm. To handle this, regression analyses between farm(er) variables and AST results were performed at isolate level rather than farm level.

3.7.3 Veterinary drug shop data analysis (Paper III)

Since the sample size in the veterinary drug shop study was limited to 50 due to financial and time constraints, it was decided to present the data descriptively only to avoid unreliable statistical results.

4. Main results and discussion

4.1 Farm characteristics, management routines, and access to veterinary drugs and animal health services

4.1.1 Farm characteristics and management routines

The study presented in Paper I included 305 small- and medium-scale chicken farmers from Thai Nguyen province, northern Vietnam. On average, farmers kept ~91 chickens/hens (median 70, range 2–410). Chickens/hens were mostly kept fenced outdoors, or free-range during the day and housed at night (Figures 5 and 6). In addition, almost all farmers kept other animal species on their farms, mainly pets and other poultry, but ~35% and ~25% kept pigs and cattle, respectively (Figures 8–10). On ~70% of farms, other species reared had access to the chicken/hen keeping areas, again most commonly pets and other poultry. Mixing of species can be problematic from a disease prevention and AMR perspective, as it may facilitate spread of infectious diseases, such as avian influenza, but also resistant bacteria (Henning et al. 2009; Graham et al. 2019; Hedman et al. 2020). A recent study on chicken farms in Thai Nguyen province has also showed an association between simultaneous duck keeping and higher ABU (Kemunto et al. 2025). Further, keeping pets together with livestock may also pose a risk of disease and AMR spread from livestock to humans, due to pets' close contact with their owners.

The farms were run as family farms with the main reason for keeping poultry for the majority of farmers being household consumption. Only ~25% reported commercial purpose as the main reason. However, a majority of farmers still sold live poultry or poultry products, although mainly to family, friends, or neighbours. When disaggregating the data according to farm size, it was found that farmers with ≥100 chickens/hens to a larger extent engaged in commercial activities than the ones with smaller farms. They also more commonly sold live poultry, or poultry products, at local markets. As the data collection took place during the COVID-19 pandemic, it is possible that some farmers had been forced to make a shift from a pre-pandemic commercial purpose rearing to household consumption purpose due to, for example, increased farm input prices and market disruptions

Figure 8. A mix of poultry species on a chicken farm in Thai Nguyen City district, Thai Nguyen province. Photo credit: Ms. Le Thi Minh Hang/NIVR.

Figure 9. Chickens/hens mixing with cattle on a chicken farm in Dong Hy district, Thai Nguyen province. Photo credit: Ms. Luu Thi Hai Yen/NIVR.

Figure 10. Hens mixing with dogs on a chicken farm in Thai Nguyen City district, Thai Nguyen province. Photo credit: Ms. Dang Phuong Anh/NIVR.

(National Statistics Office 2021b; Personal communications). Since poultry keeping was not primarily commercial for most farmers, they relied on other main sources for income, most commonly crop production (80%).

The main feed provided to chickens/hens was grains or crops from the farm or the local community. Although not the most commonly given, ~40% also provided commercial feed to some extent. As antibiotics in feed for growth promotion are no longer allowed in Vietnam, commercial feed should not be considered a risk factor for AMR on these farms, if trusting that feed producers abide by the legislation (Circular No. 06/2016/TT-BNNPTNT; Law No. 32/2018/QH14). During sporadic observations during the data collection for Paper III, no antibiotics were found listed on labels of poultry feed sold in veterinary drug shops. However, almost 20% of farmers said that they themselves added antibiotics to the poultry feed.

4.1.2 Access to veterinary drugs and animal health services

Almost all farmers had access to veterinary drugs in their local community, and ~90% bought them from a veterinary drug shop without a prior prescription. These OTC sales are in line with previous research from Vietnam, other Southeast Asian countries, as well as other LMICs (Zellweger et al. 2017; European Commission 2018; Pham-Duc et al. 2019;

Ha et al. 2021; Malijan et al. 2022). These uncontrolled sales constitute a risk factor for antibiotic overuse and misuse. The findings correspond to the findings in Paper III, where veterinary drug shop workers also stated that farmers almost never brought a prescription when wanting to buy antibiotics.

Only one-third of farmers stated that they had access to animal health services for diagnosing sick animals and for help with disease management and prevention. Such lack of access to affordable veterinary services is a well-known problem in LMICs (Paul & Varghese 2020; Dione et al. 2021; Magnusson et al. 2021). The most commonly available animal health service provider for those with access was a veterinary drug shop worker (63%), followed by a governmental (32%), or private (16%) veterinarian. Vietnamese small-scale poultry producers' reliance on veterinary drug shop workers for animal health services has been described previously (Carrique-Mas et al. 2015; Truong et al. 2019; Phu et al. 2019; Luu et al. 2021). Only ~13% of farmers said that either a private or governmental veterinarian usually would diagnose their chickens/hens when they got sick. In addition, almost none of the visited farms participated in any farmers' association or animal health program that provided health advice or vaccinations. Low access to proper veterinary services in combination with high access to OTC drugs is concerning from an AMR point of view since disease treatment without a prior diagnosis increases the risk of inappropriate ABU.

4.2 Chicken farmers' knowledge and practices related to antibiotics and antimicrobial resistance

4.2.1 Farmers' self-reported practices related to disease prevention, disease handling, and antibiotic use

The most commonly reported disease signs among chickens/hens on the visited farms were from the digestive or respiratory tract. Several infections, both viral and bacterial, presenting with such clinical signs are circulating within Vietnamese poultry production of various scales (WAHIS n.d.; FAO 2008; Tu et al. 2015; Lettini et al. 2016; Delabouglise et al. 2019; Le et al. 2019; Van et al. 2020a). Vaccinations against some of these diseases were used to a varying degree on the visited farms, which is in line with previous studies from Vietnam (Carrique-Mas et al. 2019; Delabouglise et al. 2019). For example, almost half of farmers vaccinated their chickens/hens against

Newcastle disease, but only ~3% and ~10% did so against Marek's disease and avian influenza, respectively. Using vaccinations to prevent disease was overall more common on farms with ≥100 birds than on smaller farms, ~70% versus ~40%.

Since professional diagnoses are rarely made, it is probable that antibiotics are also used for viral disease, putting unnecessary selective pressure on commensal gut bacteria, such as *E. coli*, to develop AMR. Slightly more than 25% of farmers had experienced situations when veterinary drugs did not work when treating sick chickens/hens. Which drugs that did not work was, however, not possible to evaluate since most farmers who had experienced this did not remember which drug they had used.

The evaluation of disease prevention practices showed that several of these could be improved. For example, use of separate footwear when entering animal areas and quarantining newly bought animals before mixing them with the rest of the flock. However, other disease prevention measures were already extensively practiced, such as handwashing after animal contact and isolation of sick chickens/hens. See Table 3 for more examples.

Table 3. Disease prevention measures applied on Vietnamese small- and medium-scale chicken farms. n=305

Disease prevention measure	% (number)
Handwashing after visiting animal areas	92.5 (282)
No mixing of chickens/hens with animals from other farms (rarely/never)	89.2 (272)
Isolation of sick chickens/hens from the rest of the flock	80.0 (244)
Giving prophylactic antibiotics	65.3 (199)
Fencing	63.0 (192)
Quarantining newly bought animals	57.4 (175)
Vaccination (against any disease)	54.1 (165)
Using separate footwear for animal areas	41.3 (126)
Keeping chickens/hens separate from other animals on farm	31.8 (97)
Handwashing before entering animal areas	23.6 (72)
Emptying animal houses/areas between batches (all-in/all-out)	15.1 (46)
Keeping records of chicken/hen disease and mortality	1.0 (3)

The thick central line distinguishes between practices undertaken by more than, or fewer than, 50% of respondents.

The lack of key disease prevention measures obviously increases the risk of disease spread to, and within, a farm. Consequently, a higher disease incidence may increase the need or demand for antibiotics, which in turn may contribute to higher ABU and AMR. If farmers expand their production in line with the national trend towards larger farms, insufficient disease prevention measures may further exacerbate the AMR situation (Jones et al. 2013; Birhanu et al. 2021b; Adamie et al. 2024).

Directly linked to the risk of AMR emergence is the fact that >65% of farmers used antibiotics prophylactically, which is in line with previous research from Vietnam and other countries in SEA (Carrique-Mas et al. 2015; Nguyen et al. 2016; Pham-Duc et al. 2019; Truong et al. 2019; Thi Huong-Anh et al. 2020; Luu et al. 2021; Bâtie et al. 2022; Malijan et al. 2022). Providing chickens/hens with medicines from a veterinary drug shop was also the most common first response to disease (~50%), instead of, for example, consulting a veterinarian (~40%). This practice has been previously described on Vietnamese poultry farms and on small-scale pig farms in Thailand (Hallenberg et al. 2020; Luu et al. 2021). Further, >50% of farmers diagnosed sick chickens/hens themselves, whereas about ~32% consulted a veterinary drug shop worker for this purpose. As discussed above, this lack of a proper diagnosis in most cases is concerning from an AMR perspective since it impedes medically rational ABU. Moreover, about the same number of farmers relied on their own judgment as those who obtained advice from a veterinarian regarding when and how to use antibiotics (~20–25%), whereas about twice as many consulted a veterinary drug shop worker for these purposes (~42–44%).

Treatment length was usually decided by the farmer, with ~50% stating that they would treat animals until they were cured, instead of following treatment instructions. Although the approach for limiting AMR through shorter antibiotic treatment periods based on patient recovery is gaining attention in human medicine, this strategy is more difficult to apply in veterinary medicine, as animals cannot verbally communicate their condition (Borek et al. 2024). Instead, discontinuing antibiotic treatment too soon may lead to recurring infections, as an animal may seem healthy although the infection is not entirely gone. Such a scenario can fuel AMR development as recurring infections often lead to the use of more antibiotics, exerting additional selective pressure on the already antibiotic-exposed gut bacteria (Endale et al. 2023). Taken together, the frequent absence of veterinary advice on antibiotic treatment at the visited farms poses a risk of improper ABU.

Three out of four farmers reported disposing of leftover antibiotics in the trash or latrine. Such practices increase the risk of environmental contamination with antibiotics, putting selective pressure on bacteria in water and soil to develop AMR, that subsequently may spread to the wider community (Samreen et al. 2021; Ishwarya et al. 2025). Further, ~40% of farmers discarded chicken/hen manure into the environment, or either used or sold it untreated as fertilizer. In relation to Paper II, which reported high AMR rates in gut bacteria from chickens/hens on these farms, and Paper I, which documented high ABU, such manure handling poses a risk of environmental dissemination of both AMR bacteria and antibiotic residues (Samreen et al. 2021; Marutescu et al. 2022).

Encouraging from an AMR-mitigation perspective was, however, the seemingly non-existent use of antibiotics for growth promotion, possibly due to the ban on such use implemented in 2018 (Circular No. 06/2016/TT-BNNPTNT; Law No. 32/2018/QH14). This is also in line with other fairly recent studies on Vietnamese farms (Luu et al. 2019; Pham-Duc et al. 2019; Bâtie et al. 2022).

4.2.2 Farmers' knowledge related to antibiotics and antimicrobial resistance

More than two-thirds of farmers knew that antibiotics should be used solely for treating sick animals, and not for disease prevention or growth promotion. This shows a discrepancy with their practices, as almost the same share of farmers provided their poultry with prophylactic antibiotics. However, previous studies have shown that AMR-related knowledge, attitudes, and practices not always correspond to each other (Pham-Duc et al. 2019; Caudell et al. 2020). In addition, findings presented in Paper III showed that >50% of veterinary drug shop workers recommended farmers to use antibiotics prophylactically, possibly influencing farmers to use them even if they know they should not.

A great majority of farmers knew that antibiotics treat bacterial disease, but many also believed them to be effective against viral disease, or all kinds of diseases. Such misconceptions have been described among poultry farmers in LMICs previously, for example in Bangladesh and Cameroon (Moffo et al. 2020; Hassan et al. 2021). Beliefs like this may contribute to antibiotic overuse and unnecessary AMR development, especially when farmers themselves make the decision on when to use antibiotics. Knowledge about AMR as a phenomenon, and its consequences, was generally high. However, the One Health-related aspects of AMR, such as AMR transmission and possible links between ABU in animals and AMR in humans, were less well understood, confirming findings from previous studies in LMICs (Moffo et al. 2020; Thi Huong-Anh et al. 2020). Strengthening the general knowledge about the One Health aspects of AMR might give farmers additional incentives to improve ABU and hygiene routines.

4.3 Farmer demographics and farm characteristics associated with chicken farmers' antimicrobial resistance-related knowledge and practice levels

The farmers' knowledge and practices were evaluated by generating scores through IRT of three underlying scales: two for practices and one for knowledge, where a higher score indicated better practices or knowledge. The scales evaluated were: 1) Ability to perform desirable practices related to disease management and treatment with antibiotics ("Practices 1"), 2) Ability to perform desirable practices regarding disease prevention ("Practices 2"), and 3) Knowledge about AMR development and spread ("Knowledge"). The generated scores were used in regression analyses to search for associations with different farm(er) variables. Significant associations are shown in Table 4.

4.3.1 Practices 1: Ability to perform desirable practices related to disease management and treatment with antibiotics

Three farm(er) variables were associated with the farmer score for disease management and antibiotic treatment. Living in Thai Nguyen City district, the most urban of the three visited, was associated with a higher score compared to living in the other two ($p<0.001$). Since the study design was not constructed to facilitate comparisons between districts, the reason for this difference was not evaluated beyond concluding that there appear to be some regional effects.

Having access to animal health services was associated with a higher score ($p<0.001$), which was expected since several of the questions that made up this scale related to the use of animal health services for disease handling and treatment. Consulting an animal health professional was considered beneficial from an AMR-mitigating perspective; therefore, the responses confirming such consultation were coded as desirable, thereby resulting in higher farmer scores (see section 3.4.1 for IRT considerations, or Paper I for details of the IRT workflow).

Table 4. Associations between farm(er) variables and farmers' practice and knowledge scores on Vietnamese small- and medium-scale chicken farms. n=305

Farm(er) variable	"Practices 1"	"Practices 2"	"Knowledge"
District	X	X	
Respondent's sex		X	
Respondent's age		X	
Livestock-keeping experience (years)	X		
Respondent's education level		X	X
Main reason for chicken/hen keeping		X	X
Farm size		X	X
Access to animal health services	X		X

"Practices 1" = Ability to perform desirable practices related to disease management and treatment with antibiotics
"Practices 2" = Ability to perform desirable practices regarding disease prevention
"Knowledge" = Knowledge about antimicrobial resistance development and spread
X = significant association found ($p<0.05$)

At first glance, it was surprising that having a livestock-keeping experience of 1–10 years was associated with a higher score compared to having 11–20 ($p=0.02$), and 31–40 ($p=0.02$) years of experience. Possibly explaining this is that if you are new in the farming field, you might have a more up-to-date education regarding disease management and ABU, and might also be more prone to seeking professional advice. Education level and respondent's sex were not significantly associated with the score, contrasting findings from previous studies in Vietnam and other countries (Pham-Duc et al. 2019; Moffo et al. 2020; Hassan et al. 2021; Luu et al. 2021). However, those previous studies have only shown associations between antibiotic practices and either gender or education. Additionally, there are several plausible explanations for the diverse findings across studies, such as differences in farm characteristics, socio-economic or geographic contexts, questionnaires, included practice variables, and the statistical methods applied.

4.3.2 Practices 2: Ability to perform desirable practices regarding disease prevention

The picture becomes more complex for the disease prevention scale, with six variables showing significant associations with the farmer score. Again, district being significantly associated indicates some regional effects ($p=0.045$), as for the “Practices 1” scale.

As mentioned above, the variables respondent’s education level and sex have previously been shown to be associated with antibiotic practices, which was not the case here (Pham-Duc et al. 2019; Moffo et al. 2020; Hassan et al. 2021; Luu et al. 2021). However, being female ($p<0.01$) and having higher education ($p<0.001$–0.02) was instead significantly associated with a higher disease prevention score, showing that those variables are still worth considering when planning farm interventions. Further, it was interesting that farmers at an age of >60 years were more likely to have higher scores than farmers between 31–40 ($p=0.04$) and 51–60 ($p=0.03$) years of age, while livestock-keeping experience was not significantly associated with the score. The explanation behind this is unclear.

Having ≥100 chickens/hens was associated with a higher disease prevention score ($p<0.001$), which might be explained by the greater disease pressure that comes with higher animal densities, making disease prevention more important (Jones et al. 2013; Adamie et al. 2024). Such reasoning is further reflected by the more prevalent use of vaccinations on the larger farms, as discussed above. The findings are in line with a recent study in the same study area, where medium- and large-scale chicken farms were found to have better biosecurity than small-scale farms (Kemunto et al. 2025).

In the research presented here, the farmers on the larger farms were also engaged in commercial activities to a higher degree, possibly creating stronger economic incentives for keeping animals healthy. However, the fact that keeping chickens/hens mainly for household consumption was associated with a higher score ($p<0.01$) would contrast this reasoning. Yet, as previously discussed, since data collection took place during the

COVID-19 pandemic, it is possible that some of the household consumption farms had been more commercially oriented before the start of the pandemic (National Statistics Office 2021b; Personal communications).

4.3.3 Knowledge: Knowledge about antimicrobial resistance development and spread

That high education level was associated with a higher knowledge score ($p<0.00–0.001$) was expected since it is both intuitive and in line with previous research in Vietnam and other LMICs (Pham-Duc et al. 2019; Moffo et al. 2020; Hassan et al. 2021). Being more knowledgeable when you have a larger farm ($p<0.01$) is also reasonable, as more animals and a possible commercialization of your farming activity may require higher knowledge about different kinds of treatments. However, again, household consumption purpose of the chicken/hen rearing was associated with a higher score ($p=0.02$). If this association is true, despite COVID-19 pandemic-induced shifts in farming, one might reason that if you are to consume chicken meat/eggs yourself, you may be more prone to learn about possible risks with providing antibiotics to your animals, such as antibiotic residues and AMR. Most surprising was the association between not having access to animal health services and having a higher knowledge score ($p=0.02$). Perhaps if you are without animal health service access you might feel more motivated to increase your own knowledge as a substitute, possibly explaining this relationship.

4.4 Antimicrobial resistance in commensal *Escherichia coli* from healthy poultry on Vietnamese chicken farms

4.4.1 Antimicrobial resistance rates

High rates of AMR were found among the tested *E. coli* isolates from poultry on the visited farms. Figure 11 shows the distribution of AMR to the antibiotic classes included in the AST, as well as MDR, at isolate level (red bars) and farm level (yellow bars, ≥1 isolate resistant). In general, finding high AMR rates was not surprising due to the extensive use of OTC antibiotics for various reasons in Vietnamese poultry production, as found

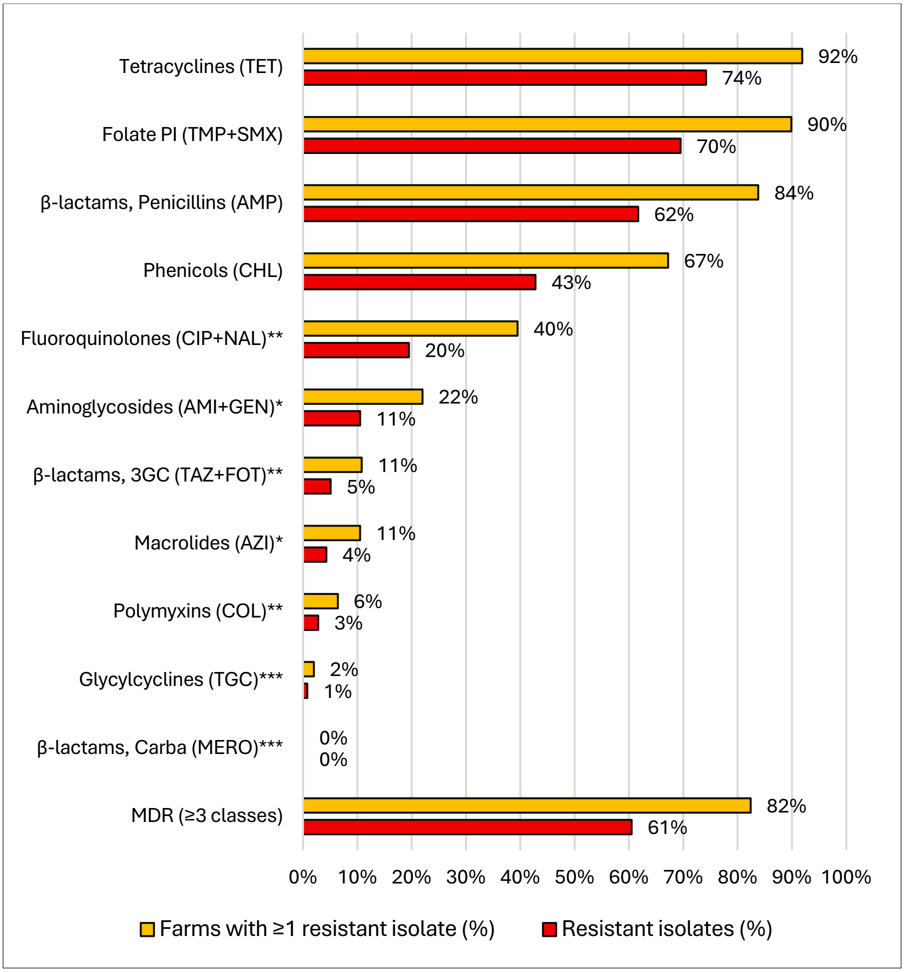

Figure 11. Resistance to antibiotic classes in commensal *E. coli* from poultry on Vietnamese small- and medium-scale chicken farms at isolate level (n=764) and farm level (n=296).

Explanations: 3GC = third-generation cephalosporins, AMI = amikacin, AMP = ampicillin, AZI = azithromycin, Carba = carbapenems, CHL = chloramphenicol, CIP = ciprofloxacin, COL = colistin, FOT = cefotaxime, GEN = gentamicin, MERO = meropenem, NAL = nalidixic acid, PI = pathway inhibitors, SMX = sulfamethoxazole, TAZ = ceftazidime, TET = tetracycline, TGC = tigecycline, TMP = trimethoprim, MDR = multi-drug resistant.

*Critically important antimicrobials for human medicine (CIA) **Highest priority critically important antimicrobials for human medicine (HPCIA) ***Human use only, according to WHO classification (WHO 2024a).

by us and others (Carrique-Mas et al. 2015; Luu et al. 2019; Pham-Duc et al. 2019; Ha et al. 2021; Bâtie et al. 2022). The average number of substances an isolate was resistant to was 3.6 (median 4, range 0–13). Multi-drug resistance was commonly detected, in ~60% of isolates and ~80% of farms. No differences in geographic distribution of resistant isolates were identified.

The most commonly identified AMR was to tetracyclines, folate pathway inhibitors, and penicillins, which is in line with previous research and also expected due to the frequent use of those antibiotics in livestock production (Nguyen et al. 2015; Nhung et al. 2015; Nhung et al. 2016; Tuat et al. 2021; Malijan et al. 2022; Mulchandani et al. 2023). Unfortunately, these antibiotics are also of critical importance for use in animals (WOAH 2025b). The high AMR rates for tetracyclines and penicillins also correspond to the findings presented in Paper III, as those antibiotic classes were the most commonly sold to poultry farmers in veterinary drug shops in the study area. Further, the most common antibiotics from the WHO HPCIA or CIA groups to which AMR was identified were fluoroquinolones and aminoglycosides, also in line with the drug shop study (Paper III) and previous research (Nguyen et al. 2015; Nhung et al. 2016; Tuat et al. 2021). On the other hand, AMR to the polymyxin colistin and the carbapenem meropenem was rarely or never detected. This is obviously beneficial from a public health perspective since both colistin and meropenem commonly are used as last-resort antibiotics for MDR infections in humans (McKenna 2013; Mohapatra et al. 2021). Not finding carbapenem resistance is in line with them not being approved for use in animals. However, co-selection of carbapenem resistance together with resistance to third-generation cephalosporins, which are sometimes used in livestock, has been shown (Bonardi & Pitino 2019). Such co-resistance scenarios might explain why carbapenem resistance has been identified, although very rarely, in Vietnamese livestock previously (Nguyen et al. 2022b; Yen et al. 2022). Alternatively, such findings could possibly indicate a human-to-animal spread due to the higher prevalence of carbapenem resistance in humans (Poirel et al. 2018). Low detection of colistin resistance is in line with a previously conducted pilot surveillance study in Vietnamese poultry, showing a declining trend of such AMR (Tuat et al. 2021).

4.4.2 Antimicrobial resistance combinations

Multiple significant AMR combinations were identified ($p<0.05$), with 23 of them being ≥0.3, and six ≥0.6. Three of the four strongest correlations were between AMR to substances of the same antibiotic class. Although this might seem obvious, it is not necessarily anticipated depending on which antibiotic class the substances belong to (Huovinen 2001; Shariati et al. 2022). Further, the strong correlations found between the resistances that individually were present in a majority of isolates, such as ampicillin, tetracycline, sulfamethoxazole, and trimethoprim, were expected. Additionally, a strong correlation between trimethoprim and sulfamethoxazole resistance is also anticipated since they are often used in combination (Huovinen 2001).

However, different co-resistance scenarios should also be considered when interpreting correlation results. Such scenarios may arise when ARGs coding for AMR to different antibiotics are located close to each other in the bacterial genome. For example, ARGs coding for ESBL production, causing AMR to β-lactams such as third-generation cephalosporins, are often linked to ARGs coding for AMR to aminoglycosides and fluoroquinolones (Carattoli 2011; Poirel et al. 2018). Hence, such co-location could possibly explain the significant correlations found between these resistances here. However, as genomic analyses were not performed, the co-resistances relevant to the presented findings can only be speculated upon. Examples of some of the significant correlations found are displayed in Table 5.

Table 5. Examples of significant correlations ($p<0.05$) between resistance statuses in commensal gut *E. coli* from poultry on Vietnamese small- and medium-scale chicken farms. n=764

Antibiotic substance combinations		**Correlation**
Trimethoprim (FOL)	Sulfamethoxazole (FOL)	0.79
Ciprofloxacin (FLU)	Nalidixic acid (FLU)	0.68
Tetracycline (TET)	Sulfamethoxazole (FOL)	0.61
Tetracycline (TET)	Ampicillin (PEN)	0.58
Gentamicin (AMI)	Cefotaxime (3CG)	0.41
Ciprofloxacin (FLU)	Cefotaxime (3CG)	0.38

3CG = third-generation cephalosporins, AMI = aminoglycosides, FLU = fluoroquinolones, FOL = folate pathway inhibitors, PEN = penicillins, TET = tetracyclines. For full list of significant correlations, see Paper II.

4.5 Associations between farmers' antimicrobial resistance-related knowledge and practices, and antimicrobial resistance in commensal *Escherichia coli*

Regression analyses were performed including the farmer IRT scores presented in Paper I, and the AST results presented in Paper II. Neither the score for disease management and treatment with antibiotics ("Practices 1"), nor the score for knowledge about AMR development and spread ("Knowledge"), showed any significant associations with AMR in *E. coli* isolates. Although this may appear surprising, less than a handful studies on small-scale poultry farms in LMICs have been able to show significant associations between AMR-related practices and actual AMR (Nguyen et al. 2015; Saeed et al. 2023). Also, as previously mentioned, evidence shows that adequate knowledge does not necessarily translate into good practices (Caudell et al. 2020). However, contra-intuitively, a higher score for disease prevention ("Practices 2") was significantly associated with higher odds for an isolate being resistant to more antibiotic substances (p=0.008), and to the individual antibiotic classes fluoroquinolones (p=0.001) and aminoglycosides (p=0.036). Although the reason is unclear, it is possible that farmers who see disease prevention as important may perform several desirable disease prevention practices but also view prophylactic ABU as a part of their disease prevention strategy. This means that a high score for disease prevention could coincide with high ABU and, consequently, more AMR. However, when investigating the relationship between the single variable of ABU for disease prevention and AMR, no significant association was found. Lack of associations between ABU and AMR on poultry farms in LMICs, including Vietnam, have been previously described (Nguyen et al. 2016; Foysal et al. 2024; Mbattide et al. 2024). The presented results imply that there are other factors than the ones studied here that influence AMR occurrence on farms and highlight the need to look beyond the farm level when aiming for successful AMR-mitigating interventions.

For example, environmental routes of AMR spread to farms in these farm-dense communities should be considered, especially due to the heavy use of OTC antibiotics as the results in Papers I and III suggest. Further, the findings presented in Papers I and III revealed that farmers and veterinary drug shop workers most commonly disposed of leftover antibiotics in the trash or latrine, which may contribute to environmental AMR pollution.

Other factors to investigate include the following: possible AMR build-up on farms due to challenges with cleaning and disinfection in small-scale outdoor systems; AMR spillover effects when keeping multiple species on the same farm; and ABU and AMR on chicken-breeding farms from where farmers buy new chickens.

4.6 Veterinary drug shop workers' antibiotic sales routines and their knowledge about antibiotics and antimicrobial resistance

4.6.1 Veterinary drug shop workers' experience and antibiotic sales routines

The visited veterinary drug shops were generally small with a median of two people working in them. The majority of respondents were the owner of the shop (>80%) and they had an average experience of working in a veterinary drug shop of almost 16 years. The most commonly owned livestock species by farmers who visited the shops were chickens/hens followed by pigs.

Drug shop workers described that the farmers visiting them for the purpose of buying antibiotics most often came on their own initiative, and >85% had seldom or never had their animals examined by an animal health professional prior to the visit. This corresponds to the findings presented in Paper I, where a majority of farmers said that they diagnose sick chickens/hens themselves and that they, to a large extent, rely on veterinary drug shop workers for advice on antibiotic use. This situation is also consistent with the low access to professional animal health services perceived by farmers. Further, 86% of drug shop workers said that farmers never or seldom brought a prescription when wanting to buy antibiotics. However, only 50% said that they never or seldom asked for a prescription before selling antibiotics. On the contrary, in the farmer study (Paper I), 85% of farmers said that veterinary drug shop workers did not usually ask for a prescription. Perhaps this reflects desirability bias among drug shop workers or results from different phrasings in questionnaires ("veterinary medicines" in Paper I and "antibiotics" in Paper III). Regardless, these findings again highlight the frequent OTC sales of antibiotics in Vietnam, but this time from the supplier's perspective.

Despite the ongoing implementation of the legislation that prohibits prophylactic ABU (Decree No. 13/2020/ND-CP), >50% of drug shop workers recommended antibiotics for prophylaxis. However, no one reported recommending them for growth promotion, where a ban on such use has been in place for a longer time (Circular No. 06/2016/TT-BNNPTNT; Law No. 32/2018/QH14). Although the sample size was small, it is interesting to note that when disaggregating the data by gender, women seemed more prone to recommending antibiotics for prophylaxis than men, ~65% versus ~40%.

Figure 12 A–B. Two veterinary drug shops in Thai Nguyen province. Photo credit: Author.

The drug shop workers often tried to their best ability to give medically motivated recommendations regarding ABU. The by far most commonly considered factor when giving antibiotic recommendations was treatment recommendations for the specific disease (82%), followed by price (56%), and previous feedback from farmers (46%). Unfortunately, since a professional diagnosis was seldom made, there is still a considerable risk of antibiotic misuse or overuse, as recommendations are based solely on clinical signs, as previously discussed.

None of the drug shop workers considered whether an antibiotic is critically important for human medicine as a main factor in their treatment recommendations. Instead, sales of antibiotics critically important to humans were fairly common, such as aminoglycosides, quinolones, macrolides, and polypeptides (Figure 13). In Paper II, quite high AMR rates for some of these antibiotics were also shown (Figure 11). Regular use of HPCIAs and CIAs on Vietnamese poultry farms has been previously described (Carrique-Mas et al. 2015; Nguyen et al. 2016; Cuong et al. 2019; Ha et al. 2021; Luu et al. 2021). Further, that the antibiotic should have a spectrum as narrow as possible was a factor prioritized by only 20% of drug shop workers. Using narrow-spectrum antibiotics when possible is desirable since the use of broad-spectrum antibiotics has shown to drive AMR to a larger extent (Barbosa & Levy 2000; Modi et al. 2014; Spaulding et al. 2018). However, again, since a proper diagnosis is seldom made, drug shop workers might be prone to choose a broad-spectrum antibiotic to cover multiple possible pathogens.

Figure 13. Over-the-counter sales of fluoroquinolones, aminoglycosides, polymyxins, macrolides, and tetracyclines in a veterinary drug shop in Thai Nguyen province. Photo credit: Author.

Almost all drug shop workers gave advice to farmers on how to use and handle antibiotics. The most commonly given advice concerned administration (100%), dosage (98%), treatment length (96%), preparation of the drug (94%), and withdrawal times (80%). However, off-the-record communication with respondents suggested that farmers' compliance with recommendations was often lacking, which has also been highlighted by veterinary drug shop workers in Cambodia (Heyman 2020). This also corresponds to the farmer study (Paper I), where 20–25% of farmers did not think they needed any advice regarding when and how to use antibiotics, and that 50% based antibiotic treatment length on their own judgment instead of following treatment advice. Naturally, this hampers veterinary drug shop workers' ability to contribute to more prudent ABU on farms.

Another complicating factor, from an AMR point of view, is the possible competition between antibiotic stewardship and economic interests among veterinary drug shop workers, which has been described in LMICs previously (Caudell et al. 2020). As antibiotics were the most commonly sold drugs in the majority of visited shops (58%), these sales obviously make up a substantial part of the drug shop owners' incomes. One may therefore not exclude the possibility that some drug shop workers, due to financial incentives, deviate from best practices to secure their income and to prevent their customers from going to another shop.

4.6.2 Veterinary drug shop workers' knowledge about antibiotics and antimicrobial resistance

In general, the education level among the drug shop workers was high, with 70% having a college/university degree or higher, and the majority within veterinary medicine. A little more than half of respondents had also received specialized training in animal diseases and treatment, as well as in antibiotic mechanisms and antibiotic treatment recommendations. However, fewer (~30%) had received training on the regulatory framework surrounding ABU and sales. This could partly explain why some sales routines that did not align with the current legislation were still extensively practiced, such as recommending antibiotics for prophylaxis, selling antibiotics OTC, and not keeping sales records.

Approximately two-thirds of drug shop workers believed that antibiotics are supposed to be used for both disease treatment and prevention, which is considerably higher than in the farmer study (Paper I) where two-thirds of farmers instead said that antibiotics should be used for disease treatment only. This is surprising given the high level of education among the drug shop workers. It also corresponds to the previously mentioned figure of >50% recommending antibiotics for prophylaxis.

On the other hand, knowledge about antibiotic efficacy and AMR development was generally higher among drug shop workers than among farmers. However, as in the farmer study (Paper I), knowledge about the One Health aspects of AMR was lower than that of the other knowledge areas investigated. For example, ~75% of drug shop workers did not believe that resistant bacteria could spread from animals to humans via animal-source foods. This is in line with research among veterinary drug sellers and practitioners in other LMICs (Heyman et al. 2020; Dione et al. 2021; Chea et al. 2023), and indicates a need for continued education in this domain.

5. Conclusions

By applying a cross-disciplinary approach, this thesis brings new knowledge regarding the complexity of what drives AMR development on small- and medium-scale chicken farms in northern Vietnam. It further highlights the importance of looking beyond the individual farm level when aiming for effective AMR-mitigating interventions. More specifically, results show that:

- Farmers mainly kept chickens for household consumption but still engaged in certain commercial activities. Chickens were often kept together with other animal species. Access to OTC antibiotics was high while access to professional animal health services was limited, a combination which increases the risk of antibiotic overuse and misuse.

- Several farmer practices related to disease prevention and management, including ABU, could be improved to reduce the risk of further AMR emergence. Knowledge about antibiotics and AMR was high in certain areas, while knowledge regarding AMR spread and One Health dimensions was weak. This understanding may provide guidance on which practices and knowledge gaps to target in future farm interventions.

- A wide range of farm(er) characteristics, such as farming experience, education level, and farm size, influenced farmers' AMR-related knowledge and practices. This implies that tailoring AMR-mitigating interventions for Vietnamese small- and medium-scale chicken farmers may be challenging.

- Antimicrobial resistance in commensal chicken *E. coli* was generally high, including to antibiotics critically important for human medicine and animal health. The findings underscore that, despite strict regulations being in place, AMR is still an urgent issue in the Vietnamese livestock sector.

- Higher levels of AMR-related knowledge and practices among farmers were not associated with lower AMR occurrence in commensal chicken *E. coli*. The findings indicate a need to look for other explanations for high AMR rates on farms than the ones directly related to farmers.

- Veterinary drug shop workers were identified as key providers of antibiotics and treatment advice to farmers. However, despite high education and knowledge, drug shop workers' ability to contribute to prudent ABU on farms was limited due to lack of proper diagnostics, poor farmer compliance with advice, and competing economic interests. Several sales routines not aligning with the current Vietnamese legislation regarding ABU and sales were also identified. The findings highlight the need to improve farmer-drug shop worker relationships and to strengthen regulation enforcement.

6. Possible policy implications and practical recommendations

The following section presents possible policy implications of the research and my reflections on how those could be translated into practice. However, it should be emphasized that such activities need to be primarily designed and operated by Vietnamese actors who have the profound understanding of the system where change is intended. As top-down approaches, such as regulations, are not always translated into impact on the ground, there is a need for a mix of policies and policy instruments to achieve behaviour change.

6.1 Improve animal health service availability

Although official sources state that veterinary services are available in most communes in Vietnam (National Statistics Office 2021a), Paper I indicates that small- and medium-scale poultry farmers in northern Vietnam often lack, or perceive a lack of, access to such services. Sometimes the available services are also regarded as non-affordable. This calls for an oversight of the distribution of affordable veterinary services in order to improve availability where needed. Farmers' awareness of how to access available services could also be strengthened through various communication efforts. As Paper III showed that veterinary drug shop workers often were highly educated and also key sources of treatment advice to smallholders, such oversight of veterinary services could be combined with a mapping of veterinary competence in drug shops. Besides providing treatment advice, veterinary drug shop workers with such competence could be encouraged to provide diagnostic services and disease prevention advice to farmers.

As shown in Paper I, many farms could benefit from improving disease prevention practices and vaccination coverage. Yet, practically no farmers participated in any animal health program that provided assistance in those areas. Due to the widespread distribution of these smaller poultry farms, subsidising participation in such programs could bring community-wide benefits by improving the overall health status among poultry in communities, thereby reducing the need for antibiotics and, consequently, AMR emergence.

6.2 Training and education activities

6.2.1 For farmers

Paper I shows that several disease prevention and ABU practices on farms could be improved, and that there are knowledge gaps among farmers regarding antibiotics and AMR, especially related to One Health. Thus, there is room for several local-scale training activities. Different training modules could be offered, for example, one on management routines and disease prevention and another on ABU and handling, including the regulatory framework. Veterinary drug shop workers could assist in promoting participation in such training programs, as improved farmer knowledge could increase farmer compliance with advice. In addition, education materials adapted for farmers on AMR, including the One Health perspective, could be distributed through veterinary drug shops, governmental veterinarians, local markets, and social media. Ideally, training activities and education materials should be adapted to the local community context as far as possible. However, Paper I shows that a wide range of variables may influence farmers' knowledge and practices, emphasizing that local tailoring may be challenging.

6.2.2 For veterinary drug shop workers

As indicated by the findings in Paper III, training activities for veterinary drug shop workers could aim to reduce the sales of antibiotics for prophylaxis and to improve the handling of leftover antibiotics. Further, such activities could be used to raise awareness about the One Health aspects of AMR and provide information on current and upcoming regulations surrounding ABU and sales. In addition, information on poultry diseases circulating in the community, and their clinical signs, could be regularly provided by governmental veterinarians, as diagnostics are seldom used by smallholders (Papers I and III).

6.2.3 For the general public

As shown in Paper I, the majority of farmers had attended primary or secondary school. Including AMR in school education could increase the baseline knowledge in the general population, which obviously includes future poultry farmers as well. If the general public becomes more aware of AMR, it might also create consumer pressure, thereby increasing farmers' social motivation to improve their ABU practices. Awareness-raising activities through information campaigns in media, social media, and via local markets could also be considered for this purpose. Further, as shown in Paper II, AMR on poultry farms may be high despite good farmer knowledge and practices. This indicates that AMR is widespread in farm environments and that reducing it may take time even if farmer practices are improved. This in turn calls for additional measures to reduce the risk of AMR transmission between livestock and the general population, such as public awareness campaigns on food hygiene.

6.3 Facilitate collaboration between actors

As mentioned above, Paper I shows that a majority of farmers perceived a lack of access to veterinary services. As veterinary drug shop workers are often used as a substitute, collaboration between drug shop workers and veterinarians could be encouraged to facilitate re-direction of farmers from drug shops to veterinarians when needed. For example, local authorities could provide lists to veterinary drug shops containing contact information, and areas of expertise, of local veterinarians. However, for this to translate into practice, it would be necessary to investigate which incentives that might motivate drug shop workers to re-direct farmers. Another idea could be to establish a governmental veterinary medical advisory service to which veterinary drug shop workers can turn when uncertain of how to handle particular disease cases.

Further, Papers I and III show that farmers often rely on their own experience when handling disease. Several drug shop workers also mentioned difficulties regarding farmers' compliance with treatment advice and instructions. To improve this situation, certain training activities, for example regarding disease prevention and responsible ABU, could be offered to a mixed target group of both farmers and drug shop workers. Such joint trainings could facilitate increased understanding for each other's situations, knowledge exchange, and in extension better farmer compliance.

6.4 Strengthen systems for regulation enforcement

Papers I and III show that some practices on the visited farms and in drug shops are not in line with the current Vietnamese legislation, such as sales of antibiotics OTC, ABU for prophylaxis, and lack of record keeping of antibiotic sales, indicating a need to enhance regulation enforcement. Since it may be economically and logistically challenging for authorities to physically monitor all shops regularly, an electronic reporting system that drug shop workers can use to record both prescriptions and drug sales could be beneficial. Such a system could provide valuable information for both drug shop owners and monitoring authorities.

7. Future perspectives

7.1 Further analyses of *Escherichia coli* isolates

Completing the AST analyses of the *E. coli* isolates generated from the pooled faecal samples that were selectively cultured for specific resistances (third-generation cephalosporins, colistin and carbapenems) is a natural continuation of the presented work. These analyses would generate additional knowledge about AMR emergence on visited farms as selective culturing enables the detection of the most resistant bacterial clones, which are less likely to be detected when testing random *E. coli*.

In addition, the large collection of *E. coli* isolates could be further analysed with genomic methods. Identifying which ARGs that circulate on farms would give a more comprehensive understanding of the AMR situation and provide valuable information when aiming to investigate possible introduction or transmission routes of AMR in the One Health domain, including the environment, humans, and other animal species.

7.2 Antimicrobial resistance in an environmental and community context

The studies conducted within this project could not show any associations between better antibiotic-related practices and lower AMR occurrence. These findings imply that there are other factors influencing the AMR situation on farms and that there is a need to look beyond the farm level to find them. Future investigations could include looking for introduction of AMR to farms from other sources, such as water, crops, and feed. Another angle would be to take a community-wide approach by searching for associations between AMR on poultry farms and the situation in other nearby farming facilities, such as aquaculture or pig production, where high ABU and AMR have been previously reported in Vietnam (Nhung et al. 2015; Nhinh et al. 2021; Tuat et al. 2021).

7.3 Qualitative studies of farmer attitudes and practices

Extensive questionnaires were used to collect quantitative data from farms and veterinary drug shops. Although valuable information was obtained, the understanding could be deepened further if these quantitative data would be complemented with qualitative data. Such data collection could be done through, for example, focus-group discussions with farmers and veterinary drug shop workers from the same community, either separately or together. These discussions could be based on questions or dilemmas that have risen from the analyses of the quantitative data presented in this thesis. Information gathered could also be valuable when planning AMR-reducing interventions in the study area.

7.4 Intervention studies

The results presented here provide information about areas to target when designing AMR-mitigating interventions, for example, disease prevention, use of animal health services, and routines related to antibiotic treatment and sales. However, the effectiveness of such interventions should be evaluated before implementing them on a large scale. Therefore, intervention studies are a suitable progression of the research, where one group of farmers or drug shop workers takes part in an intervention, and another works as a control group. Such interventions obviously need to be designed in close collaboration with a variety of local partners who have a comprehensive insight into the local socio-economic and geographic contexts.

7.5 Follow-up after regulation implementation

Reportedly, the use of antibiotics for growth promotion on the visited farms, and the recommendation of such use in the veterinary drug shops, were virtually non-existent (Papers I and III). By the time of the data collection, use of GPs had been prohibited by Vietnamese legislation for approximately four years. This is encouraging. However, sales of antibiotics OTC and ABU for prophylaxis were still reported, practices which are both addressed in regulations currently being implemented, the latest one taking full effect on 1 January 2026. Future follow-up on these aspects could provide information about whether these newly adopted legislations result in the same antibiotic-reducing effect that the ban on GPs seemingly had. Such information could be valuable for policymakers to evaluate how regulation enforcement is progressing and also highlight where there is a continuous need for bottom-up approaches to mitigate AMR on Vietnamese farms.

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Popular science summary

Antimicrobial resistance (AMR), the ability in bacteria to resist treatment with antibiotics, is one of the largest threats to human and animal health worldwide. In 2021, >1 million people died from resistant infections, a number which is projected to almost double to 2050. Further, the highest burden of AMR is seen in low- and middle-income countries (LMICs). The health and welfare of animals is also negatively impacted by AMR, as diseases become more difficult or impossible to treat. For livestock, such as cattle, pigs, and poultry, more disease also brings lowered productivity, causing severe effects for the livelihoods and food security of farmers and communities, especially in LMICs. Resistant bacteria can also spread between animals and humans, either through direct contact, or for example via animal-source foods or the environment. Therefore, the AMR that develops in livestock, may impact the human AMR situation and vice versa.

Development of AMR is accelerated when antibiotics are used too much, which is unfortunately common in livestock production globally. Antibiotics have for many years been used not only to treat disease, but also to prevent disease and to promote growth. Although several countries have legislation in place prohibiting antibiotic use for other purposes than disease treatment, enforcement in LMICs is often weak. Further, in many LMICs, antibiotics are frequently sold without a prior prescription from a veterinarian. Consequently, several LMICs, especially in Southeast Asia where livestock production is intense, have become hotspots for antibiotic use and AMR.

Vietnam is a lower middle-income country in Southeast Asia, with most of its 100 million inhabitants living in rural areas, although more and more people are moving into the cities. The country has had a strong economic development the past decades which has led to a rapid growth of the poultry sector to meet the increased demand for animal-source foods. Although small-scale farming is still the most common, farm sizes are increasing. If farms grow bigger without proper disease prevention, animals are more likely to get sick, which can lead to more antibiotic use and AMR.

High AMR levels on Vietnamese chicken farms have been previously reported, but the findings have rarely been connected to farm practices. To increase the chance of tackling AMR, it is necessary to learn which factors that influence antibiotic use and AMR on farms. Therefore, the aim of the research was to describe AMR occurrence on chicken farms in northern

Vietnam, but also to connect those findings to farmers' AMR-related practices and knowledge. In addition, the role of veterinary drug shop workers, the people selling antibiotics to farmers, was investigated to see how they possibly influence antibiotic-related practices on farms. Both farmers and drug shop workers were interviewed using questionnaires, and in addition three chickens from each farm were sampled to test for the presence of AMR in their gut bacteria.

Farmers had high access to antibiotics without a prescription but limited access to veterinary services, a combination which probably increases the risk of incorrect antibiotic use. Further, several farming practices, both regarding disease prevention and management, and antibiotic use and handling, could be improved to reduce the risk of chicken disease and AMR. A wide range of farm(er) factors could be connected to the farmers' level of practices and knowledge, for example, livestock-keeping experience, education, and farm size. The understanding of farming practices, and what affects them, is important to develop effective AMR-reducing interventions. The gut bacteria from chickens on the visited farms showed high levels of AMR, including multi-drug resistance, meaning that a bacterium is resistant to ≥3 antibiotics. These findings show that AMR is still an urgent issue in the Vietnamese livestock sector. However, bacteria from farms where farmers performed better practices or had higher knowledge did not have less AMR. This indicates that AMR is widespread in communities and that there are other factors than the ones directly related to farmers that impact the AMR situation on farms. Veterinary drug shop workers functioned as key providers of both antibiotics and treatment advice to chicken farmers, and they were often highly educated and knowledgeable about AMR. However, they still had limited possibilities to contribute to better antibiotic practices on farms. Some reasons for this were, for example, that a professional diagnosis of sick animals seldom was made before farmers came to the shop for antibiotics, and that farmers often relied on their own experience instead of adhering to treatment advice from the drug shop workers. The results presented in this thesis may serve as guidance for researchers and policymakers who develop interventions or policies to improve disease prevention and antibiotic practices on farms. The findings also highlight the need for further research to investigate how AMR emerges in the Vietnamese poultry sector.

Populärvetenskaplig sammanfattning

Antibiotikaresistens (AMR), bakteriers utvecklade förmåga att överleva antibiotikaexponering, är ett av de största globala hoten mot människors och djurs hälsa. Under 2021 dog >1 miljon människor till följd av AMR, varav den största bördan sågs i låg- och medelinkomstländer. År 2050 förväntas dödssiffran ha fördubblats. Även djur kan drabbas av infektioner med resistenta bakterier, och därmed påverkas även deras hälsa och välfärd negativt av AMR. För produktionsdjur, som nötkreatur, grisar och fjäderfä, innebär också ökad sjuklighet nedsatt produktionsförmåga, vilket kan ha negativa konsekvenser för försörjningen och livsmedelstryggheten för djurhållare och deras samhällen, särskilt i låg- och medelinkomstländer. Resistenta bakterier kan också spridas mellan djur och människor, antingen genom direktkontakt eller via animaliska livsmedel och miljön. Därför kan den AMR som utvecklas hos produktionsdjur även påverka AMR-situationen hos människor, och vice versa.

En av de främsta orsakerna till AMR är att antibiotika används för mycket eller felaktigt, vilket är vanligt inom djurproduktionen globalt. Antibiotika har länge använts inte bara för att behandla sjukdom, utan även för att förebygga sjukdom och främja tillväxt. Flera länder har infört lagar som förbjuder antibiotika för andra syften än behandling, men införlivandet av sådan lagstiftning är ofta svag i låg- och medelinkomstländer. I många av dessa länder är dessutom antibiotikaförsäljning utan recept från veterinär vanligt. Detta har lett till oroväckande hög antibiotikaanvändning och resistens i flera låg- och medelinkomstländer, särskilt i Sydostasien där djurproduktionen är omfattande.

Vietnam är ett lägre medelinkomstland i Sydostasien där majoriteten av de 100 miljoner invånarna bor på landsbygden, även om allt fler flyttar in till städerna. Landet har haft en stark ekonomisk utveckling de senaste decennierna, vilket resulterat i en snabb tillväxt av fjäderfäsektorn för att möta en ökad efterfrågan på animaliska livsmedel. Även om småskalig uppfödning fortfarande dominerar så ses en trend mot större gårdsstorlekar. Om gårdar börjar inhysa fler djur utan tillräckliga sjukdomsförebyggande åtgärder, riskerar sjukligheten bland djuren att öka, vilket också medför högre antibiotikaanvändning och AMR.

Höga AMR-nivåer har rapporterats från vietnamesiska kycklinggårdar tidigare, men de har sällan kopplats ihop med vilka gårdsrutiner som praktiseras. För att öka chanserna att bromsa utvecklingen av AMR är det nödvändigt att förstå vilka faktorer som påverkar antibiotikaanvändning och AMR på gårdsnivå. Därför var målet med den presenterade forskningen att beskriva AMR-förekomsten på kycklinggårdar i norra Vietnam, men också att sammankoppla dessa fynd med djurhållarnas AMR-relaterade rutiner och kunskap. Utöver detta undersöktes rollen som försäljare i veterinära apotek spelar för hur antibiotika används ute på gårdar. Enkätstudier genomfördes med både djurhållare och försäljare, och på varje kycklinggård provtogs tre kycklingar för att undersöka AMR-förekomsten i deras tarmbakterier.

Kycklinguppfödarna hade stor tillgång till receptfria antibiotika till sina djur, men begränsad tillgång till veterinär, en kombination som ökar risken för felaktig antibiotikaanvändning. Vidare sågs att flera rutiner avseende förebyggande och hantering av fjäderfäsjukdom, inklusive användning av antibiotika, skulle kunna förbättras för att minska sjuklighet och AMR-utveckling. Många faktorer kunde kopplas till djurhållarnas nivå av rutiner och kunskap, såsom erfarenhet, utbildningsnivå och gårdsstorlek. Kycklingarnas tarmbakterier visade höga AMR-nivåer, inklusive multiresistens, det vill säga när en bakterie är resistent mot ≥3 antibiotika. Detta visar att AMR fortsatt är en angelägen fråga att hantera i vietnamesisk djurproduktion. Däremot hade bakterierna från kycklingar på de gårdar som drevs av bönder med bättre rutiner och kunskap inte mindre AMR. Det här indikerar att AMR är vida spridd i samhällen i norra Vietnam, och att det sannolikt finns andra faktorer än de som är direkt kopplade till djurhållarna som påverkar AMR-situationen på gårdsnivå. Försäljare i veterinära apotek var en av kycklingproducenternas främsta källor till både antibiotikan i sig, men även till råd kring hur fjäderfäsjukdom skulle hanteras. Vidare var försäljarna ofta välutbildade med hög kunskap om AMR. Av flera anledningar hade de dock begränsade möjligheter att bidra till ansvarsfull antibiotikaanvändning, till exempel då en professionell diagnos nästan aldrig var ställd när djurhållare kom till apoteken för att köpa antibiotika, och att djurhållarna ofta förlitade sig mer på sin egen behandlingserfarenhet än att följa försäljarnas råd. Resultaten presenterade i denna avhandling kan användas som vägledning för forskare och beslutsfattare som ska utveckla åtgärder och policys för att förbättra det sjukdomsförebyggande arbetet och antibiotikaanvändningen inom vietnamesisk kycklingproduktion. Fynden tydliggör också behovet av ytterligare forskning för att vidare utreda hur AMR utvecklas inom den studerade sektorn.

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Understanding Vietnamese chicken farmers' knowledge and practices related to antimicrobial resistance using an item response theory approach

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Introduction: Antimicrobial resistance (AMR) poses a threat to animal and human health, as well as food security and nutrition. Development of AMR is accelerated by over- and misuse of antimicrobials as seen in many livestock systems, including poultry production. In Vietnam, high AMR levels have been reported previously within poultry production, a sector which is dominated by small-scale farming, even though it is intensifying. This study focuses on understanding small- and medium-scale chicken farmers' knowledge and practices related to AMR by applying an item response theory (IRT) approach, which has several advantages over simpler statistical methods.

Methods: Farmers representing 305 farms in Thai Nguyen province were interviewed from November 2021 to January 2022, using a structured questionnaire. Results generated with IRT were used in regression models to find associations between farm characteristics, and knowledge and practice levels.

Results: Descriptive results showed that almost all farmers could buy veterinary drugs without prescription in the local community, that only one third of the farmers received veterinary professional advice or services, and that the majority of farmers gave antibiotics as a disease preventive measure. Regression analysis showed that multiple farm characteristics were significantly associated to farmers' knowledge and practice scores.

Conclusion: The study highlights the complexity when tailoring interventions to move towards more medically rational antibiotic use at farms in a setting with high access to over-the-counter veterinary drugs and low access to veterinary services, since many on-farm factors relevant for the specific context need to be considered.

KEYWORDS

antimicrobial resistance, antimicrobial use, item response theory, chicken farming, poultry, Vietnam, farmers knowledge and practice

1 Introduction

It is widely acknowledged that antimicrobial use (AMU) is closely linked to the development of antimicrobial resistance (AMR), a mechanism in a microbe to survive exposure to an antimicrobial it initially was sensitive to (1, 2). Even though AMR is a naturally occurring phenomenon in bacteria, the development is accelerated by over- and misuse of antibiotics as seen in many livestock production systems and health care facilities. Besides being used, as intended, to treat disease, antibiotics might for example also be used for disease prevention and/or growth promotion (2, 3). The obvious consequence of AMR is treatment failure, which negatively impacts animal welfare, reduces animals' growth and productivity, and increases mortality rates (4). Subsequently, this has serious effects since hundreds of millions of people around the world depend on livestock for their livelihoods, as well as for their food security and nutrition, especially in low- and middle-income countries (LMICs) (5).

Globally, the use of antibiotics in the livestock sector is extensive, estimated to exceed the use in the human sector, and concerning levels of AMR have been documented (6, 7). Further, as resistant bacteria can spread between animals and humans, directly or indirectly, AMU in the livestock sector also poses a threat to public health (8–10). Therefore, serious effort needs to be put into reducing over- and misuse in animal production for the sake of both human and animal health.

Southeast Asia has a rapidly intensifying livestock sector, mainly in the monogastric animal production, i.e., poultry and pig production (11). More animals and higher animal densities in farms, often in combination with insufficient disease preventive measures, lead to higher disease pressure and subsequent increased antibiotic use (ABU), including prophylactic use (6, 12, 13). The connections between intensified animal rearing and increased ABU have contributed to Southeast Asia becoming one of the hotspots for AMR emergence (7, 14). It has further been shown that, since the beginning of the millennium, AMR levels in LMICs have increased the most within poultry and pig production which is consistent with the intensification of those sectors (7).

Apart from increased disease pressure as the livestock sector is intensified, extensive and inappropriate ABU might be further facilitated by weak legislation and guidelines on antibiotic sales and use, and in some settings insufficient enforcement of such regulations (13, 15, 16). For example, in Vietnam, where regulations state that using antibiotics from growth promotion is prohibited (17), over-the-counter sales of antibiotics without prescription are still common, as in many LMICs, which makes implementation of the regulations difficult (13, 18).

As on the global level, the amount of antibiotics used in livestock production in Vietnam exceeds that in humans, with an estimation that >70% of the total amount of antibiotics used in the country in 2015 was used in livestock (19). Further, several studies have reported use of antibiotics critically important to human health, as classified by the World Health Organization (WHO), in Vietnamese farms (12, 20–23).

However, inappropriate use of antibiotics cannot solely be explained by intensified livestock production and weakness in regulatory systems. Different factors at both farmer and community level may affect the use of antibiotics, such as economic incentives, lack of knowledge, and access to animal health services and veterinary drug shops (16, 24). Further, it should be acknowledged that the drivers on different levels might vary across local socio-economic contexts within the same regulatory framework (25). To be able to apply a tailored bottom-up approach to reduce ABU at farm level, there is a need to understand those context-specific drivers among farmers (14, 26). Therefore, questionnaire-based knowledge, attitude and practice studies (KAPs) have become common and valuable research tools (13, 15, 25, 27–30).

Most published farmer KAP studies are based on classical test theory (CTT), which has several limitations, like the equal value of the questions in the test, and difficulties in knowing that the test actually measures the trait of interest due to the lack of an underlying scale. Therefore, another psychometric method called item response theory (IRT) was chosen for this study. In IRT, the foundation is the relationship between a person's unobservable measurement of the underlying trait, e.g., knowledge about AMR, and the probability of different responses to the items in the test. Further, the scores of respondents are measured on a standardized scale and based on the individual difficulty and quality of the questions (or items) in the test. IRT has recently started to transition into the field of veterinary and public health research (29, 31–33). The current study is one of the first to use IRT for evaluating farmers' practice ability and knowledge regarding ABU and AMR development, and to the authors' knowledge, the first in the Southeast Asia region and in poultry production.

The main objectives of the study were to: (1) identify which demographic factors that affect farmers' AMR-related practices and knowledge in small- and medium-scale chicken farms in Vietnam, (2) describe farmers' access to, and use of, veterinary pharmaceuticals and animal health services, and (3) to assess the feasibility of IRT as a method when performing AMR-related KAP studies.

2 Materials and methods

2.1 Study area

Small-scale farming is the most common type of livestock production in Vietnam. However, a trend of increasing farm sizes is seen for several species, including chicken. Even though the number of larger farms is increasing, raising more than 100 chickens is still uncommon, with around 6% of farms being that large in 2020, and 50% of farms had only 20–49 chickens (34).

The study was conducted in Thai Nguyen province which is located in the northern midlands and mountain areas north of the capital of Hanoi (see Figure 1), with a human population of 1.3 million people in 2022 (35). In 2020, 49% of all rural households in the province were engaged in agriculture, forestry or fishery (34), and the number of households that kept chicken in 2016 was approximately 173 thousand, corresponding to about 2% of the chicken raising households in the country (36). The estimated poultry population of the province was around 14 million in 2022, accounting for 2.6% of the number of poultry in the country (35). Thai Nguyen province was selected based on its large chicken population, the distribution of chicken farms between districts within the province, and its proximity to the capital Hanoi.

Farms from three districts in the province were included in the study: Thai Nguyen City, Dong Hy and Vo Nhai, with 360.0, 94.7 and

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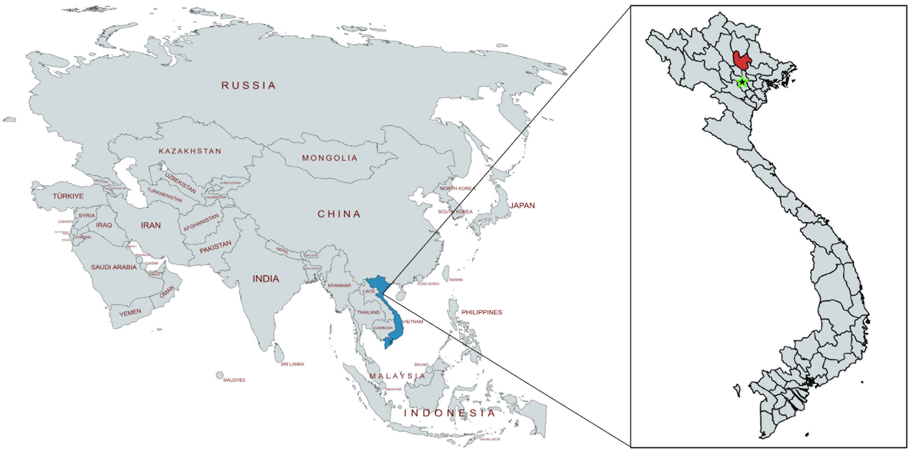

FIGURE 1
Map of the continent of Asia (left) with Vietnam marked in blue, and map of Vietnam (right) with the province Thai Nguyen marked in red. Star marks the capital of Hanoi for reference. Source: https://mapchart.net, accessed September 29, 2023, license: https://creativecommons.org/licenses/by-sa/4.0/.

69.8 thousand inhabitants, respectively, in 2022 (37). Of the three districts, Vo Nhai has the largest land area and Thai Nguyen City the smallest. In Thai Nguyen City, the majority of the population resides in urban areas while in Dong Hy and Vo Nhai, the rural population is in majority (38). The district selection was based on the districts' different chicken population sizes (Thai Nguyen City having the most and Vo Nhai the least) and profiles (Thai Nguyen City being more urban and Dong Hy and Vo Nhai more rural) in order for the districts to be as representative as possible for the province as a whole.

2.2 Study population

The chicken farms in the three selected districts of Thai Nguyen province were categorized as small scale, with 20–49 chickens, and medium scale, with 100–499 chickens. These farm-size categories made up 46.2 and 5.3%, for small- and medium-scale farms respectively, of the total number of chicken farms in the province in 2016 (36).

2.3 Sampling design

A sample size of 300 farms in total was considered sufficient for the purpose of the study, and was distributed evenly between the two farm-size categories. To select farms to be included, lists of all small- and medium-scale chicken-raising households in each district, according to the above-mentioned definitions, were collected from the sub-Department of Animal Health (sub-DAH) in Thai Nguyen province. To avoid an over- or under-representation of a district, the numbers of farms to be included were stratified according to the proportion of farms in each farm size category in each district. After rounding, the number of small- and medium-scale farms from each district were therefore distributed as follows: Thai Nguyen City, 8 and 42; Dong Hy, 24 and 32; and Vo Nhai, 119 and 77, resulting in a sample size of 302 farms.

Two sampling frames, one for each farm-size category, were created from the obtained lists of chicken-raising households for each district. For logistic reasons, villages with less than five households were removed from the sampling frames. According to the stratification, households were then randomly selected via an online randomization tool (39). If one household needed to be replaced for any reason, a nearby farm that met the requirements was included instead. The main reasons for household replacement were: the farmer being busy or not giving consent to participate, or having too many, too few or no chicken at the time of visit. In total, 159 households were replaced (53%).

2.4 Data collection

To investigate the farmers' practices and knowledge regarding antibiotics and AMR, a structured questionnaire of 102 questions was developed and divided into the following sections: (a) General information and farm location, (b) Farm characteristics, general management routines and access to animal health services and veterinary drugs, (c) Chicken disease issues, (d) Disease prevention, disease management and treatment routines, and (e) Knowledge about antibiotic use and AMR (see Supplementary material S1).

The questionnaire was initially developed in English and then translated into Vietnamese. To discover possible misinter pretations, back-translation was performed by a person outside of the research team. The survey was conducted in interview format by five trained enumerators from the National Institute for Veterinary Research (NIVR), Hanoi. Answers were recorded on tablets through the online survey tool platform Netigate (40).

The enumerators participated in a two-day training where they got familiar with the survey tool and the questionnaire. They also got to practice interviewing with each other and to perform pilot interviews in the field, on chicken farms not situated in the study area. Feedback on the questionnaire from the training and field test was taken into account and changes to the questionnaire were made accordingly. The survey was conducted from the 25 November 2021 to the 20 January 2022.

2.5 Statistical methods

2.5.1 Data processing

The questionnaire data was downloaded from Netigate to Microsoft Excel where the dataset was processed. Issues such as duplicate farms, where the same ID number had been erroneously typed for two farms or where the same farm had been entered twice into Netigate, were resolved. The corrected dataset consisted of responses from 305 farms: 51 in Thai Nguyen City, 56 in Dong Hy and 198 in Vo Nhai.

Additional data cleaning was performed, and free text answers were translated from Vietnamese to English and added to the dataset. The dataset was then imported to the statistical software STATA (41) for further data processing and statistical analyses.

Descriptive statistics were compiled for all items (questions) in the questionnaire. Practice and knowledge items were further evaluated according to an IRT workflow (see Section 2.5.2.2.), and items that fit the criteria were included in IRT scales, two for practices (Practice 1, relating to disease management and antibiotic treatment; and Practice 2, relating to disease prevention) and one for knowledge (See Supplementary Table S9). The mean theta values generated through the IRT analyses for groups in different variables of interest (see Section 2.5.2.4.) were compared using one-way ANOVA, and the effects of the variables of interest on theta were evaluated through multilevel mixed-effects linear regression. A 5% significance level was used for all statistical analyses.

2.5.2 Item response theory

2.5.2.1 Concept

When using IRT, the underlying trait of interest, e.g., ability or knowledge, is measured in theta (θ), which is standardized with a mean value of 0 and a standard deviation of 1, i.e., a person with a theta value of 0 has an average level of ability or knowledge. A theta value >0 reflects a higher than average ability or knowledge, and correspondingly, a theta value of <0 reflects a lower than average ability or knowledge.

The IRT model used in this study was a two-parameter logistic (2pl) model. The 2pl model takes into account two parameters of each item in the scale, discrimination and difficulty (42). The discrimination of an item is the measure of how good it can separate people above and below a certain theta level, i.e., how much information the item contributes with to explain a person's ability or knowledge. As for the underlying trait, the difficulty is also measured in theta. A person with the same theta score as the difficulty of the question has a 50% probability of answering the item correctly or desirably.

2.5.2.2 Workflow and scale generation

Binary variables were created from all practice and knowledge questions (38 practice and 18 knowledge questions). Options in practice questions were coded as desirable or undesirable, and knowledge questions as correct or incorrect, from an AMR mitigation, development and spread perspective (see Tables 1, 2). Five practice questions were removed from the scale generation due to too few responses, and one where all respondents answered undesirably, thus not providing any information regarding differences in ability/ practice. As a result, 32 practice questions were left.

The practice and knowledge questions were evaluated on the internal consistency reliability through Cronbach's alpha (CA), a measure of whether the items in the scale consistently measures the same characteristic (43). A value of 0.7 or more for CA was considered sufficient.

In parallel with CA analyses, items were evaluated on other aspects reflecting the reliability and validity of the scales: positive/ negative sign, item-rest correlation and item-total correlation. The average inter-item correlations for each scale were also generated.

Seventeen and five practice questions (for the Practices 1 and Practices 2 scale respectively; Supplementary Table S1), and four knowledge questions with negative signs were removed to make the scale plausible unidimensional (32). Thereafter, questions with an item-rest correlation <0.2 and item-total (sometimes called item-test) correlation <0.4 (42) were removed, seven for each practice scale and four for the knowledge scale. An average inter-item correlation of >0.2 was considered acceptable (44), which was fulfilled for all three scales.

To fit 2pl models, the assumption of unidimensionality needs to be fulfilled, i.e., there is a single underlying trait that accounts for the dependence among observations. Together with above mentioned evaluations, this assumption was tested through exploratory factor analysis and multiple correspondence analysis. These assessments resulted in two items being removed from the Practices 2 scale and three items being removed from the knowledge scale.

As soon as an item was removed in any of the steps described above, the process was iterated until all items in each scale fulfilled the criteria. For the final scales, 98.4, 90.0 and 97.0% of the variance could be explained by the first dimension for the Practices 1, Practices 2 and Knowledge scales, respectively. Together with the ratios between first and second Eigenvalue being 15.1, 11.1 and 11.3, these variance percentages were considered sufficient to assume unidimensionality of the scales (32).

The number of items and the CA for the final scales were: Practices 1—eight and CA 0.8079; Practices 2—nine and CA 0.7200; and Knowledge—seven and CA 0.8206. The final set of items included in each scale are listed in Supplementary Table S9.

Three 2pl models were fitted including the subsets of items generated above. Range in discrimination for the items in each scale were: Practices 1, 0.86–7.55; Practices 2, 0.74–2.02; and Knowledge, 0.68–8.47. The difficulty of the items ranged between: Practices 1, 0.26–1.9; Practices 2, −2.35 to 0.87; and Knowledge, −1.48 to 0.027. Discrimination and difficulty are visualized in the item characteristic curves (ICCs) in Figures 2A–C, where steeper slopes illustrates higher discrimination and difficulty is defined by theta on the X-axis. All discrimination and difficulty values are presented in Supplementary Table S9.

TABLE 1 Antimicrobial resistance (AMR) related practices among small- and medium-scale chicken farmers in Thai Nguyen City, Dong Hy and Vo Nhai districts in Vietnam.

Item	Option category	Option	% (number)
Do other animals at the farm have access to the areas where your chickens/hens are kept?[b] ($n=305$)	Desirable	No, There are no other animal species at my farm	31.8 (97)
	Undesirable	Yes	68.2 (208)
Do your chickens/hens mix with animals from outside your own farm?[b] ($n=305$)	Desirable	Rarely, Never	89.2 (272)
	Undesirable	Yes, often, Yes, sometimes	10.8 (33)
If you slaughter chickens/hens at the farm, do you have a specific area for slaughter that is separated from live animals?[d] ($n=129$)	Desirable	Yes	85.3 (110)
	Undesirable	No	14.7 (19)
How do you usually handle manure from your chickens/hens?[b,c] ($n=305$)	Desirable	Use or sell/give after treatment of the manure, Use or sell/give after at least 1 month of composting, Use for fuel (incl. biogas)	44.6 (136)
	Undesirable	Do nothing, Discard into the environment, Use or sell/give untreated as fertilizer	53.8 (164)
What do you usually do with chickens/hens that die from disease?[b,c] ($n=305$)	Desirable	Burn/destruct, Bury in the ground	78.4 (239)
	Undesirable	Throw in the trash, Use as animal feed, Use for household consumption, Sell at local market, Sell to other farmers as animal feed, Leave on the ground	19.7 (60)
Do you usually empty the animal houses/areas between batches of chickens/hens (all-in/all-out system)? ($n=305$)	Desirable	Yes	15.1 (46)
	Undesirable	No	84.9 (259)
If you use all-in/all-out system, do you remove litter, manure and clean/disinfect animal houses before next batch?[d] ($n=46$)	Desirable	Yes	93.5 (43)
	Undesirable	No	6.5 (3)
If you do not use an all-in/all-out system, how often do you remove litter, manure and clean/disinfect animal houses/areas where the chickens/hens are kept?[b] ($n=259$)	Desirable	Once a week or more often, Every second week, Once a month	65.6 (170)
	Undesirable	More seldom	34.4 (89)
If you have access to buying pharmaceuticals/veterinary drugs, where do you most commonly buy them for your chickens/hens?[a,c] ($n=294$)	Desirable	Via a governmental veterinarian, directly or via prescription, Via a private veterinarian, directly or via prescription	6.5 (19)
	Undesirable	From other farmers, At markets, At veterinary drug shop without prior prescription, From pharmaceutical company, From a feed provider	92.5 (272)
If you have access to animal health services, do you use them for treatment of disease among your chickens/hens and/or advice on disease prevention?[d] ($n=97$)	Desirable	Yes, mostly, Sometimes	87.6 (85)
	Undesirable	No	12.4 (12)
If you use animal health services for treatment and advice, which animal health service provider do you most commonly use?[c,d] ($n=85$)	Desirable	Governmental veterinarian, Private veterinarian	42.4 (36)
	Undesirable	Veterinary drug shop worker (not veterinarian), Staff of drug company	56.5 (48)
If the animal health services include laboratory testing and/or autopsies, do you use these services?[d] ($n=31$)	Desirable	Yes, when needed	58.1 (18)
	Undesirable	Sometimes, Never	41.9 (13)
Do you keep records of disease and mortality among your chickens/hens? ($n=305$)	Desirable	Yes	1.0 (3)
	Undesirable	No	99.0 (302)
To prevent your chickens/hens from becoming sick, do you: Fence them?[b] ($n=305$)	Desirable	Yes	63.0 (192)
	Undesirable	No	37.0 (113)
To prevent your chickens/hens from becoming sick, do you: Usually isolate/quarantine newly bought animals for some time[b] ($n=305$)	Desirable	Yes	57.4 (175)

(Continued)

TABLE 1 (Continued)

Item	Option category	Option	% (number)
	Undesirable	No	42.6 (130)
To prevent your chickens/hens from becoming sick, do you: Give them antibiotics ($n = 305$)	Desirable	No	34.8 (106)
	Undesirable	Yes	65.2 (199)
To prevent your chickens/hens from becoming sick, do you: Give them feed that is supplemented with antibiotics ($n = 305$)	Desirable	No	67.9 (207)
	Undesirable	Yes	32.1 (98)
To prevent your chickens/hens from becoming sick, do you: Vaccinate ($n = 305$)	Desirable	Yes	54.1 (165)
	Undesirable	No	45.9 (140)
Do you: Wash your hands before entering the areas where your animals are kept? ($n = 305$)	Desirable	Yes	23.6 (72)
	Undesirable	No	76.4 (233)
Do you: Wash your hands after visiting the areas where your animals are kept? ($n = 305$)	Desirable	Yes	92.5 (282)
	Undesirable	No	7.5 (23)
Do you: Have separate footwear (e.g., gum boots) or plastic boot covers that you use only in the areas where your chickens/hens are kept?[b] ($n = 305$)	Desirable	Yes	41.3 (126)
	Undesirable	No	58.7 (179)
Do you give your chickens/hens antibiotics to make them grow faster and/or better? ($n = 305$)	Desirable	No	98.0 (299)
	Undesirable	Yes	2.0 (6)
Do you give your hens antibiotics to make them lay more eggs? ($n = 225$)	Desirable	No	98.2 (221)
	Undesirable	Yes	0.9 (2)
Who will usually diagnose disease among the chickens/hens at the farm?[a,c] ($n = 305$)	Desirable	Governmental veterinarian, Private veterinarian	13.4 (41)
	Undesirable	Myself, Veterinary drug shop worker (not veterinarian), Human doctor, Other farmer, Friend/family member	85.9 (262)
What do you usually do first when the chickens/hens at your farm get sick?[a,c] ($n = 305$)	Desirable	Consult a governmental veterinarian, Consult a private veterinarian	40.0 (122)
	Undesirable	Nothing, Give them medicine(s) from a veterinary drug shop/market, Give them traditional medicine/vitamins/herbs, Give them medicine(s) that was left by a veterinarian at a previous visit	55.1 (168)
Do you usually isolate chickens/hens that become sick from the rest of the poultry in the flock?[b] ($n = 305$)	Desirable	Yes	80.0 (244)
	Undesirable	No	20.0 (61)
When you use antibiotics to treat disease among your chickens/hens, which animals do you usually treat?[c] ($n = 305$)	Desirable	Only the chickens/hens that are sick, All chickens/hens that are sick and all animals in contact with the sick chickens/hens	43.0 (131)
	Undesirable	All poultry at the farm, All chickens/hens at the farm, All animals at the farm	51.5 (157)
From where do you usually get advice on when to use antibiotics for your chickens/hens?[a,c] ($n = 305$)	Desirable	From a governmental veterinarian, From a private veterinarian	21.6 (66)
	Undesirable	I do not get advice, I use my own judgment, From other farmers, From veterinary drug shop worker (not veterinarian), From package/label of the medicine, From market sales person, From human doctor, From feed provider, From friends/family	72.8 (222)
When you use antibiotics to treat disease among your chickens/hens, for how long do you usually treat them?[a,c] ($n = 305$)	Desirable	As advised by a governmental veterinarian, As advised by a private veterinarian	29.5 (90)

(Continued)

TABLE 1 (Continued)

Item	Option category	Option	% (number)
	Undesirable	Until animal(s) cured, Until animal(s) begin to recover, As advised by other (e.g., sales person, other farmer, family/friends, human doctor), As instructed on the package/label of the medicine, Until package is empty, One treatment only	64.3 (196)
When treating your chickens/hens with antibiotics, whose instructions do you usually follow on how to use them (dose, treatment length, administration route etc.)?[a,c] ($n = 305$)	Desirable	A governmental veterinarian's, A private veterinarian's	23.9 (73)
	Undesirable	I do not get advice, I use my own judgment, Other farmers', A veterinary drug shop worker's (not veterinarian), The instructions on the package/label of the medicine, A market sales person's, A human doctor's, A feed provider's, Friends'/family's	69.8 (213)
When you use antibiotics to treat disease among chickens/hens, who usually administers the drug?[a,c] ($n = 305$)	Desirable	Myself, after instructions from a governmental veterinarian, Myself, after instructions from a private veterinarian, Governmental veterinarian, Private veterinarian	33.4 (102)
	Undesirable	Myself, by own experience	60.0 (183)
Do you ever give a higher dose of antibiotics than the recommended to your chickens/hens?[c] ($n = 305$)	Desirable	No	75.4 (230)
	Undesirable	Yes	19.3 (59)
Do you ever give a lower dose of antibiotics than the recommended to your chickens/hens?[c] ($n = 305$)	Desirable	No	92.8 (283)
	Undesirable	Yes	1.3 (4)
Do you ever stop giving your chickens/hens antibiotics earlier than recommended if they seem healthy?[c] ($n = 305$)	Desirable	No	79.7 (243)
	Undesirable	Yes	15.1 (46)
Does it happen that you give human medicines to your chickens/hens when they become sick? ($n = 305$)	Desirable	No	64.9 (198)
	Undesirable	Yes, often, Sometimes	35.1 (107)
If the antibiotic treatment of sick chickens/hens is not effective or does not work, what do you usually do?[a,c] ($n = 305$)	Desirable	Contact governmental veterinarian, Contact private veterinarian, Euthanize the sick animal(s)	21.3 (65)
	Undesirable	Increase the dose, Switch to another antibiotic or combine the ongoing treatment with another antibiotic, Switch to other type of medicine, Switch to herbal/traditional medicine, Go back to the veterinary drug shop for advice (from non-veterinarian), Contact other person (not veterinarian) for advice, Slaughter the sick animal(s) for meat, Nothing	66.6 (203)
What do you usually do with expired/leftover veterinary antibiotics?[c] ($n = 305$)	Desirable	Leave to pharmacy/veterinary drug shop	0 (0)
	Undesirable	Throw in the trash/latrine, Keep for later use, Give to other farmer	91.8 (280)
Do you keep records of the use of medicines for the chickens/hens at your farm (e.g., treatment dates, name of medicine, dose)? ($n = 305$)	Desirable	Yes	0.7 (2)
	Undesirable	No	99.3 (303)

Practices 1 = Ability to perform desirable practices related to disease management and treatment with antibiotics, Practices 2 = Ability to perform desirable practices regarding disease prevention.
[a]Item was included in Practices 1 scale.
[b]Item was included in Practices 2 scale.
[c]Item had options that could not be considered desirable or undesirable and these options were coded as missing but are still included in the number of responses.
[d]Item was removed from further analyses due to too few responses (details in Supplementary material S2).

TABLE 2 Knowledge about antibiotics and antimicrobial resistance (AMR) development and spread among small- and medium-scale chicken farmers in Thai Nguyen City, Dong Hy and Vo Nhai districts in Vietnam.

Item	Option category	Option	% (number)
What are antibiotics supposed to be used for? ($n = 305$)	Correct	Treat sick animals	68.9 (210)
	Incorrect	Prevent animals from becoming sick, Make animals grow faster/better, Prevent animals from becoming sick and make animals grow faster/better, Prevent animals from becoming sick and treat sick animals, Treat sick animals and make animals grow faster/better, Prevent animals from becoming sick, treat sick animals and to make animals grow faster/better	31.1 (95)
Antibiotics can treat all kinds of diseases ($n = 305$)	Correct	False	53.8 (164)
	Incorrect	True, Cannot answer	46.2 (141)
Antibiotics can treat diseases caused by viruses ($n = 305$)	Correct	False	50.8 (155)
	Incorrect	True, Cannot answer	49.2 (150)
Antibiotics can treat diseases caused by bacteria ($n = 304$)	Correct	True	87.2 (265)
	Incorrect	False, Cannot answer	12.8 (39)
Antibiotics are the same as anti-inflammatory drugs ($n = 304$)	Correct	False	38.8 (118)
	Incorrect	True, Cannot answer	61.2 (186)
Different types of antibiotics are needed for different diseases ($n = 303$)	Correct	True	80.2 (243)
	Incorrect	False, Cannot answer	19.8 (60)
As a general rule, you should stop treatment with antibiotics when the animal's condition starts to improve ($n = 303$)	Correct	False	50.2 (152)
	Incorrect	True, Cannot answer	49.8 (151)
Using antibiotics too often can make diseases difficult to treat in the future[a] ($n = 304$)	Correct	True	70.4 (214)
	Incorrect	False, Cannot answer	29.6 (90)
Animals can become resistant to antibiotics if antibiotics are used in the wrong way/too often ($n = 304$)	Correct	False	20.7 (63)
	Incorrect	True, Cannot answer	79.3 (241)
Bacteria that cause disease can become resistant to antibiotics if used in the wrong way/too often ($n = 303$)	Correct	True	72.9 (221)
	Incorrect	False, Cannot answer	27.1 (82)
Viruses that cause disease can become resistant to antibiotics if used in the wrong way/too often ($n = 303$)	Correct	False	32.3 (98)
	Incorrect	True, Cannot answer	67.7 (205)
Resistance against antibiotics can make it more difficult to succeed with antibiotic treatment in animals when they get sick[a] ($n = 303$)	Correct	True	76.9 (233)
	Incorrect	False, Cannot answer	23.1 (70)
Bacteria resistant to antibiotics can spread from one animal to another[a] ($n = 304$)	Correct	True	69.4 (211)
	Incorrect	False, Cannot answer	30.6 (93)
Bacteria resistant to antibiotics can spread between animals and humans[a] ($n = 302$)	Correct	True	51.7 (156)
	Incorrect	False, Cannot answer	48.3 (146)
Bacteria resistant to antibiotics can spread from animals to humans through animal source foods, e.g., meat[a] ($n = 302$)	Correct	True	45.0 (136)

(Continued)

TABLE 2 (Continued)

Item	Option category	Option	% (number)
	Incorrect	False, Cannot answer	55.0 (166)
Bacteria resistant to antibiotics can spread through manure from animals[a] ($n = 302$)	Correct	True	52.0 (157)
	Incorrect	False, Cannot answer	48.0 (145)
Using too much antibiotics in animals can make it more difficult to treat some diseases in humans[a] ($n = 302$)	Correct	True	54.3 (164)
	Incorrect	False, Cannot answer	45.7 (138)
Antibiotic resistance in human bacteria is only linked to the use of antibiotics in humans and not in animals ($n = 299$)	Correct	False	24.1 (72)
	Incorrect	True, Cannot answer	75.9 (227)

[a]The question was included in item response theory (IRT) model for knowledge.

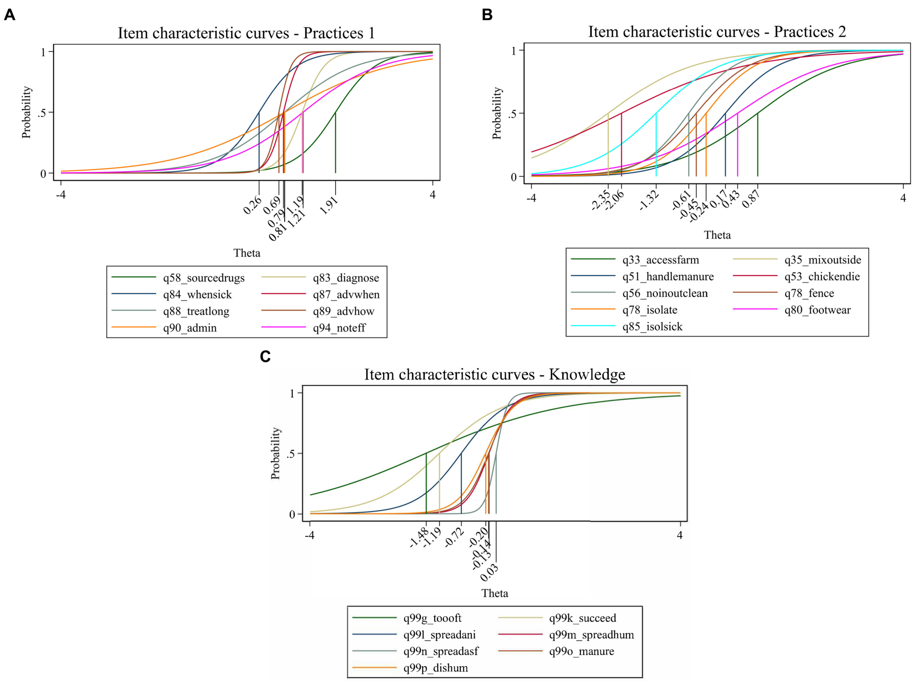

FIGURE 2
(A) Item characteristic curves (ICCs) for Practices 1 scale based on responses in a questionnaire distributed among small- and medium-scale chicken farmers in Thai Nguyen City, Dong Hy and Vo Nhai districts in Vietnam. Practices 1 = Ability to perform desirable practices related to disease management and treatment with antibiotics. Ability and item difficulty is measured in theta (X-axis). See Supplementary Table S9 for full questions. **(B)** Item characteristic curves (ICCs) for Practices 2 scale based on responses in a questionnaire distributed among small- and medium-scale chicken farmers in Thai Nguyen City, Dong Hy and Vo Nhai districts in Vietnam. Practices 2 = Ability to perform desirable practices regarding disease prevention. Ability and item difficulty is measured in theta (X-axis). See Supplementary Table S9 for full questions. **(C)** Item characteristic curves (ICCs) for Knowledge scale based on responses in a questionnaire distributed among small- and medium-scale chicken farmers in Thai Nguyen City, Dong Hy and Vo Nhai districts in Vietnam. Knowledge = Knowledge about antimicrobial resistance (AMR) development and spread. Ability and item difficulty is measured in theta (X-axis). See Supplementary Table S9 for full questions.

TABLE 3 Main demographics and farm characteristics among small- and medium-scale chicken farmers in Thai Nguyen City, Dong Hy and Vo Nhai districts in Vietnam ($n = 305$).

Item	Option	% (number)
Respondent's sex	Female	39.0 (118)
	Male	61.0 (187)
Education level of respondent	Never went to school	1.6 (5)
	Primary school	25.9 (79)
	Secondary school	43.0 (131)
	High school	27.5 (84)
	College/University	2.0 (6)
	Higher education (e.g., master, PhD)	0 (0)
Main source of income for the household	Crop farming	79.7 (243)
	Self-employment other than farming	6.2 (19)
	Salaried employment off farm	5.3 (16)
	Livestock keeping other than poultry	3.6 (11)
	Poultry keeping (layer and/or broiler)	2.3 (7)
	Poultry keeping (other)	2.0 (6)
	Casual labouring	0.3 (1)
Main reason for keeping chickens/hens	Household consumption	72.1 (220)
	Commercial	23.6 (72)
	Other	4.3 (13)
Item		**Number**
Mean age of respondent (years)		51.4
Mean farming experience (years)		21.7
Mean number of chickens/hens (heads)		90.7

2.5.2.3 Scale evaluation

Test information functions (TIFs) were generated (see Supplementary Figures S1A–C) to evaluate where the three scales were the most informative, i.e., how much information the test gives at different thetas. The Practices 1 scale gives the most information around theta 0.7, the Practices 2 scale around theta −0.5 and the Knowledge scale around theta 0.

2.5.2.4 ANOVA and mixed-effects linear regression

After the fitting of the 2pl models, theta values for practice ability and knowledge were generated for each respondent and each scale. Thereafter, mean theta values for different groups of eight selected variables of interest were calculated. The variables for which the effect on theta was evaluated were: district, respondent's sex, respondent's age, respondent's experience in keeping chickens/hens, respondent's education level, main reason for keeping chicken/hens, farm size and access to animal health services. The mean theta values between groups were compared through univariable analysis using one-way ANOVA. The effect of the predictor variables on the response variable theta were then further evaluated using multilevel mixed-effects linear regression.

Before fitting the mixed-effects models, causal diagrams were produced including the variables of interest listed in the section above (45). One diagram was produced for the two practice scales and one for the knowledge scale.

The decision on which variables to include in the models was based on the causal diagrams together with evaluation of coefficient change when removing variables, where a change of >25% resulted in the variable being assumed to be a confounder and thus kept in the model. Commune and village were set as random-effects parameters.

Variables affecting the theta value were determined by evaluating p-values, where a p-value <0.05 was considered significant. All regression models were evaluated with standard visual post estimation methods for residuals, i.e., checks for heteroscedasticity and normality through scatter plots and QQplots.

3 Results

3.1 Descriptive statistics

3.1.1 Demographics and farm characteristics

Out of the 305 respondents, more than half were male. The mean respondent age was around 50 years with a majority of respondents being between 41 and 60 years old. Almost all respondents were either the household head or spouse of the household head. The mean experience in chicken farming was slightly more than 20 years. Regarding education, the most common was to have completed secondary school. Only five respondents never went to school and six had education from university or college. The main demographics and farm characteristics are presented in Table 3 (for more details, see Supplementary material S2).

The most common main income source for the household was crop farming, while almost no respondents stated that poultry farming (layer and/or broiler) served as the main income source. Further, almost three out of four respondents stated that they kept layers or broilers for household consumption and not for commercial purposes. None of the farms had hired workers. Live animals and animal products (eggs and meat) were most commonly sold to neighbours,

TABLE 4 Access to pharmaceuticals among small- and medium-scale chicken farmers in Thai Nguyen City, Dong Hy and Vo Nhai districts in Vietnam.

Question	Option	% (number)
Do you have access to buying pharmaceuticals/veterinary drugs in your local community? ($n=305$)	Yes	96.4 (294)
If you buy veterinary medicines at a veterinary drug shop, do you usually get a prescription from a veterinarian before you buy them? ($n=294$)	No	93.9 (276)
If you buy veterinary medicines at a veterinary drug shop, does the person working there usually ask for a prescription before selling veterinary medicines to you? ($n=294$)	No	85.0 (250)

friends and family. The mean and median number of chickens/hens kept was 90.7 and 70, respectively.

Farms often kept more than one type of poultry. The most commonly kept species was broiler chickens, followed by dual purpose chickens/hens and layer hens. Regarding other animal species, dogs were the most common, followed by cats, other poultry and pigs. At almost all farms, at least one other species than chickens/hens was kept.

3.1.2 Farm management routines

Chickens/hens of all purposes were most commonly kept fenced outdoors and at a majority of the farms, other animal species at the farm had access to the areas where chickens/hens were kept. However, more than four out of five respondents stated that their chickens/hens never mixed with animals from outside the farm. More than four out of five respondents who said that they slaughtered chickens/hens at the farm stated that they had a specific slaughter area separated from live animals. For more details, see Supplementary material S2.

The most common feed used was grains or crops grown at the farm or locally, and at about two out of five farms, pre-mix or commercial feed was used to some extent. One quarter of respondents added medicines to the feed, and of those, a majority said they added antibiotics.

At three out of four farms, the manure from the chickens/hens was used, sold or given away as fertilizer, and about one third did this without prior treatment or composting. The most common practice when handling diseased chickens/hens was to bury them in the ground.

Using an all-in/all-out system was only practiced in a few farms. At farms where all-in/all-out system was not used, it was most common to remove litter and manure and to clean and disinfect once a month or more seldom.

3.1.3 Disease issues

The most common disease issues among the chickens/hens at the farms one year prior to the study were digestive/intestinal and respiratory diseases. These disease types were also the most common in the cases when respondents had experienced that medicines did not work. Almost no respondents stated that they kept records of disease and mortality among their chickens/hens. For more details, see Supplementary material S2.

3.1.4 Access to pharmaceuticals and animal health services

Almost all respondents said they had the possibility to buy pharmaceuticals or veterinary drugs in their local community (see Table 4), and a large majority of those stated that the most common was to buy them over-the-counter in a veterinary drug shop (see Table 1, details in Supplementary material S2). Of the respondents who sometimes used a veterinary drug shop as a drug source, almost none usually obtained a prescription from a veterinarian before buying medicines. Further, more than four out of five said that the person working in the shop usually does not ask for a prescription before selling.

One third of respondents stated that they had access to animal health service providers that give professional advice and help with diagnosis and treatments, and almost no farms belonged to a farmers' association (see Table 5). Further, almost none was a part of any animal health program that provided routine monitoring and advice, or vaccinations. Of the respondents that said they had access to animal health services, the most commonly accessed service was a veterinary drug shop worker who was not a veterinarian, followed by governmental and private veterinarians (see Table 1, details in Supplementary material S2). A majority of the farmers that had access to animal health services said that they mostly, or sometimes, used the services for advice and/or treatment. Out of those, it was most common to use the services of a veterinary drug shop worker who was not a veterinarian. Of the farmers with access to animal health services, one third stated that the service included laboratory testing and/or autopsies.

3.1.5 Disease prevention

A majority of respondents said that they, to prevent their chickens/hens from becoming sick, fenced them, isolated/quarantined newly bought animals, and vaccinated against one or several diseases (see Table 1, details in Supplementary material S2). The most common diseases to vaccinate against were Newcastle disease, pasteurellosis (fowl cholera) and Gumboro disease (see Supplementary material S2 for details). A majority of respondents stated that they gave antibiotics as a disease preventive measure.

Handwashing after visiting the animal areas was performed by almost all respondents, while handwashing before entering animal areas was less common. Two out of five farmers had separate footwear that were only used in the areas where the chickens/hens were kept.

3.1.6 Disease management and antibiotic routines

The most common practice when chickens/hens became sick was to give them medicine(s) from a veterinary drug shop, and second most common was to consult a private veterinarian (see Table 1, details in Supplementary material S2). Four out of five farmers said that they usually isolated chickens/hens that became sick from the rest of the poultry in the flock.

For diagnosing disease among the chickens/hens, it was most common for the farmer to do it him−/herself, while one third had a veterinary drug shop worker, who was not a veterinarian, do it. Consulting a private or governmental veterinarian was far less common.

The most commonly used channel for advice regarding both when, and how, to use antibiotics was a veterinary drug shop worker who was

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TABLE 5 Access to animal health services among small- and medium-scale chicken farmers in Thai Nguyen City, Dong Hy and Vo Nhai districts in Vietnam.

Question	Option	% (number)
Do you have access to animal health service providers that give professional advice on how to handle and prevent diseases among your chickens/hens and help with diagnosis and treatments? ($n = 305$)	Yes	31.8 (97)
If you have access to animal health service providers, which one(s)? (multiple choice) ($n = 97$)	Veterinary drug shop worker (not veterinarian)	62.9 (61)
	Governmental veterinarian	32.0 (31)
	Private veterinarian	15.5 (15)
	Staff of drug company	2.1 (2)
If you have access to animal health services, does the service include laboratory testing and/or autopsies when your chickens/hens are sick? ($n = 97$)	Yes	32.0 (31)
	No	41.2 (40)
	I do not know	26.8 (26)
Is your farm a part of any farmers' association? ($n = 305$)	No	94.8 (289)
Is your farm a part of any animal health program where you get routine monitoring and advice on the health of your chickens/hens? ($n = 305$)	No	99.0 (302)
Is your farm a part of any animal health program that provides vaccinations for your chickens/hens? ($n = 305$)	No	97.7 (298)

not a veterinarian (see Table 1, details in Supplementary material S2). One out of four farmers stated that they used their own judgment for when to use antibiotics, and one out of five that they used their own judgment how to do it. Antibiotic treatment of sick chickens/hens was most commonly provided to sick chickens/hens until they were cured, while about one quarter stated that the treatment length was based on the instructions of a private veterinarian.

It was most common that the farmer him-/herself administered the antibiotics to the animals, either by own experience, or after instructions from a private veterinarian. A majority of respondents said that they never gave a higher or lower dose of antibiotics, or stopped giving antibiotics earlier, than recommended. About one third of respondents said that they often or sometimes gave human medicines to their chickens/hens when they became sick, while giving antibiotics to make the animals grow faster/better or to lay more eggs was almost non-existent practices. Further, almost no farmers kept records of the use of medicines for the chickens/hens.

The most common practices when antibiotic treatment was not effective was to switch to another type of medicine or to go back to the veterinary drug shop for advice from a veterinary drug shop worker, who was not a veterinarian (see Table 1, details in Supplementary material S2). A majority of respondents would handle expired or leftover antibiotics by throwing them into the trash or latrine.

3.1.7 Knowledge about antibiotics and AMR

The results regarding knowledge about antibiotics and AMR are presented in Table 2, with options grouped into correct or incorrect from an AMR development and spread perspective (for details, see Supplementary material S2).

A majority of respondents believed that antibiotics are supposed to be used for treating sick animals, while one third believed that antibiotics are supposed to be used for preventing disease or making animals grow faster/better, solely or in combination with treatment of sick animals. Further, a majority of respondents stated that they thought antibiotics can treat diseases caused by bacteria, and that different antibiotics are needed for different diseases. However, almost half of the respondents did not know that antibiotics cannot be used to treat viral diseases or all kinds of diseases. Further, three out of five did not know that antibiotics are not the same as anti-inflammatory drugs.

A majority of respondents were aware that using antibiotics too often could make diseases difficult to treat in the future and that bacteria could become resistant to antibiotics. However, a majority did not know that the treated animals themselves, and viruses, do not become resistant to antibiotics.

More than half of the respondents knew that resistant bacteria can spread from one animal to another, between humans and animals, and through manure from animals. However, the proportion of respondents that believed resistant bacteria could spread through animal-source foods (ASFs) was lower. While a majority of respondents answered that using too much antibiotics in animals can make it more difficult to treat some diseases in humans, three out of four did not know that antibiotic resistance in human bacteria is not only linked to antibiotic use in humans.

3.2 Item response theory

3.2.1 Univariable analysis

The results from the one-way ANOVA conducted after the generation of the three IRT scales (Practices 1, relating to disease management and antibiotic treatment; Practices 2, relating to disease prevention; and Knowledge) are found in Supplementary Table S10.

3.2.2 Multilevel mixed-effects linear regression

The results from the multilevel mixed-effects linear regression are found in Table 6.

TABLE 6 Multi-level mixed effects regression for Practices 1, Practices 2 and Knowledge scales based on a questionnaire distributed among small- and medium-scale chicken farmers in Thai Nguyen City, Dong Hy and Vo Nhai districts in Vietnam.

Variable	Level	Theta mean Practices 1			Theta mean Practices 2			Theta mean Knowledge		
		Coefficient	p-value	95% CI	Coefficient	p-value	95% CI	Coefficient	p-value	95% CI
Constant		1.084	0.000	0.506–1.661	−0.765	0.032	−1.465 to −0.065	−0.609	0.072	−1.272 to 0.054
Fixed effects										
District	Thai Nguyen City	Ref.			Ref.			Ref.		
	Dong Hy	−0.676	0.000*	−1.042 to −0.310	−0.536	0.047*	−1.066 to −0.007	−0.350	0.152	−0.829 to 0.129
	Vo Nhai	−0.789	0.000*	−1.099 to −0.478	−0.212	0.381	−0.687 to 0.263	−0.215	0.317	−0.638 to 0.207
Respondent's sex	Female	−0.132	0.141	−0.308 to 0.044	0.251	0.007*	0.069–0.432	0.127	0.162	−0.051 to 0.304
	Male	Ref.			Ref.			Ref.		
Age of respondent	21–30	0.484	0.064	−0.028 to 0.996	−0.533	0.069	−1.109 to 0.043	−0.230	0.381	−0.744 to 0.284
	31–40	0.077	0.580	−0.195 to 0.348	−0.380	0.036*	−0.734 to −0.025	−0.045	0.747	−0.315 to 0.226
	41–50	Ref.			−0.073	0.651	−0.388 to 0.242	Ref.		
	51–60	0.028	0.815	−0.205 to 0.260	−0.306	0.026*	−0.576 to −0.036	−0.094	0.432	−0.327 to 0.140
	>60	0.041	0.792	−0.262 to 0.344	Ref.			−0.101	0.522	−0.411 to 0.209
Livestock keeping experience of respondent (years)	1–10	Ref.			Ref.			Ref.		
	11–20	−0.309	0.020*	−0.568 to −0.049	−0.067	0.627	−0.337 to 0.203	−0.086	0.525	−0.350 to 0.178
	21–30	−0.260	0.096	−0.565 to 0.046	−0.013	0.937	−0.331 to 0.306	−0.059	0.714	−0.372 to 0.255
	31–40	−0.430	0.023*	−0.801 to −0.059	−0.075	0.703	−0.461 to 0.311	−0.044	0.822	−0.423 to 0.336
	>40	−0.383	0.205	−0.975 to 0.209	−0.226	0.467	−0.834 to 0.383	0.321	0.292	−0.276 to 0.917
Education level of respondent	Never went to school	−0.324	0.337	−0.985 to 0.338	−0.556	0.098	−1.215 to 0.103	−0.353	0.283	−0.999 to 0.292
	Primary school	−0.088	0.479	−0.332 to 0.156	Ref.			Ref.		
	Secondary school	−0.070	0.492	−0.271 to 0.130	0.287	0.015*	0.057–0.517	0.374	0.001*	0.148–0.601
	High school	Ref.			0.467	0.000*	0.212–0.722	0.557	0.000*	0.306–0.808
	College/University	−0.151	0.631	−0.767 to 0.465	0.752	0.017*	0.133–1.371	1.118	0.000*	0.511–1.726
Main reason for keeping chickens/hens	Commercial	Ref.			Ref.			Ref.		
	Household consumption	0.168	0.142	−0.056 to 0.392	0.322	0.006*	0.091–0.553	0.281	0.015*	0.055–0.508
	Other	0.400	0.084	−0.054 to 0.854	0.033	0.889	−0.434 to 0.501	−0.479	0.041*	−0.937 to −0.021
Farm size	<100	Ref.			Ref.			Ref.		
	≥100	0.049	0.645	−0.158 to 0.255	0.453	0.000*	0.228–0.678	0.306	0.007*	0.083–0.529
Access to animal health services	Yes	0.443	0.000*	0.245–0.641	−0.166	0.119	−0.375 to 0.043	−0.250	0.018*	−0.457 to −0.043
	No	Ref.			Ref.			Ref.		
Random effects		Estimate			Estimate			Estimate		
Commune		<0.001		-	0.040		0.005–0.311	0.019		0.001–0.465
Village		0.063		0.027–0.143	0.123		0.048–0.315	0.149		0.064–0.347

Practices 1 = Ability to perform desirable practices related to disease management and treatment with antibiotics, Practices 2 = Ability to perform desirable practices regarding disease prevention, Knowledge = Knowledge about antimicrobial resistance (AMR) development and spread. *$p < 0.05$.

For the Practices 1 scale, variables significantly associated with a higher ability to perform desirable practices regarding disease management and treatment with antibiotics were: living in Thai Nguyen City, having short livestock keeping experience, and having access to animal health services.

For the Practices 2 scale, variables significantly associated with a higher ability to perform desirable practices related to disease prevention were: living in Thai Nguyen City, being female, being >60 years, having high education, keeping chickens/hens for household consumption, and having ≥100 chickens/hens.

For the Knowledge scale, variables significantly associated with a higher knowledge about effects and spread of AMR were: having a high education, keeping chickens/hens for household consumption, having ≥100 chickens/hens, and not having access to animal health services.

4 Discussion

This study is aimed to increase our understanding of farm level variables associated with small- and medium-scale poultry farmers' AMR-related practices and knowledge, in an emerging Southeast Asian economy. Similar knowledge- and practice-studies have been performed previously in the region. However, applying IRT as an analytic tool allowed us to investigate each individual's unobservable measurement of the underlying trait, the probability of different responses to the items in the test, while standardizing the scores of respondents on a standardized scale based on the individual difficulty and quality of the questions (or items) in the test.

The overall picture of the studied farms is that they were of non-commercial character, not specialized in chicken production, but with highly educated and experienced farmers. Even though the chicken farming was not mainly for commercial purposes for most of the farmers during the time of the study, selling activities were still common, e.g., almost two thirds of the farmers sold live chickens, although mainly to people closest to them (neighbours/friends/family). However, according to personal communications, the proportion of farms keeping chickens for household consumption might have been overestimated since the study was conducted during the Covid-19 pandemic when commercial poultry raising became more difficult. Hence, it is possible that some farms previously had a more commercial character.

Almost all farmers had the possibility to buy pharmaceuticals or veterinary drugs in their local community and, as in many LMICs (18), a prescription was almost never required when buying them. On the other hand, only one third of the respondents stated that they had access to professional animal health services. In addition, other supportive systems like farmers' associations or animal health programs were reportedly either not available or not used. The combination of high access to drugs and low access to animal health services raises concerns about the risk for inappropriate use of antibiotics and subsequent AMR development. These concerns are further strengthened by the fact that almost two thirds of respondents stated that they give antibiotics to prevent their chickens from becoming sick, which is in line with several previous studies in Vietnamese poultry farms (12, 13, 23).

To prevent disease, a majority of farmers implemented both biosecurity measures, such as isolation of newly bought and sick animals, and vaccination strategies. However, the most common disease preventive measure was administration of antibiotics which, as mentioned above, is problematic from an AMR development perspective.

To use antibiotics as growth promoters is a common practice in livestock production, including poultry farming, in many parts of the world (3, 46, 47). However, in the surveyed farms this practice seemed non-existent, which is beneficial from an AMR-mitigation perspective. Similar results have also been presented in another study on Vietnamese poultry farms (13). It is possible that this absence of use of antibiotics as growth promoters is related to the ban of such use according to Vietnamese legislation (17). The common practice of throwing expired or leftover antibiotics into the trash or latrine, is however, concerning, as this imposes a risk for antibiotic contamination of the environment (48).

In cases of disease among the chickens in the visited farms, the most common first response was to give medicines from a veterinary drug shop, in contrast to results from a previous study on chicken farms in northern Vietnam where it was most common to seek advice from a veterinarian (13). However, in that study the farms were larger and more commercially oriented, which might explain this difference.

Diagnosis of sick chickens was most commonly made by the farmers themselves, or less commonly by a veterinary drug shop worker. Similarly, advice on when and how to use antibiotics was most commonly obtained from a veterinary drug shop worker, or from the farmer's own judgment. A high dependence on veterinary drug shop workers for advice regarding antimicrobial use has been shown in previous studies on Vietnamese poultry farms (12, 23, 49), as well as for other farmed species in Asian countries (50–53). Depending on the knowledge and experience of the farmer and drug shop worker, these practices can have implications on the appropriateness and success of each case of antibiotic treatment.

Also, the non-existent use of records for disease, mortality and drug use might further complicate the farmers' ability to handle future disease events appropriately. Record keeping has previously been shown to be associated with higher knowledge about AMR and more favourable AMR-related practices among poultry farmers in Vietnam (13), and in several African countries (15).

In the multi-variable analysis, there were only three variables that showed significant association with the ability to perform desirable practices related to disease management and treatment with antibiotics (Practices 1). As expected, access to animal health services was one of them, since the questions included in this scale to a large extent are connected to the use of animal health services for disease handling and treatment. Geographic district was also significantly associated with the level of practice, indicating some regional effects.

Thirdly, livestock-keeping experience was significantly associated with the Practices 1 score. At first glance, it is surprising that respondents with a livestock-keeping experience of one to ten years had higher scores than respondents with an experience of 11–20, and 31–40 years, respectively. However, a person who is new to farming might have a more up-to-date education on how to handle disease. Being inexperienced, they might also be more prone to seek professional advice. Contrary to findings from a previous study among Vietnamese poultry farmers (23), and several studies from other countries (52, 54), education level was not significantly associated with the level of disease management and antibiotic treatment practices. However, comparisons of studies are generally difficult because of the use of different questionnaires, different variables used for analysis, and variations in statistical methods.

For the second practice scale, evaluating disease prevention ability (Practices 2), the picture is more complex with significant associations for six variables. Of the three scales, this was the only one where gender and age were significantly associated with the score, but the reasons why these variables would affect the level of disease prevention ability are unclear. Previously, an association between ABU-related practices and gender has been shown in Vietnam (13). More expected was the relationship between education and practice level, where people with higher education performed good disease prevention practices to a higher degree.

That having a large farm (>100 birds) was associated with a higher disease prevention score can be explained by the fact that larger numbers of birds often is associated with higher animal density and consequent higher disease pressure, making disease preventive measures important. Owners of large farms are also more likely to sell birds for income, which makes disease prevention important from an economic perspective. However, with that reasoning, it was unexpected that keeping chickens for household consumption was associated with higher scores for this scale. As stated above, it is suspected that some farms in the household consumption group actually kept chickens for commercial purposes before the Covid-19 pandemic. Hence, this relationship should be interpreted with caution.

The results for the two practice scales show that interventions might need tailoring to different target groups depending on which practices that need to be improved. If the focus is on disease management and antibiotic treatment, the target group would appear to be experienced farmers in the more rural areas of Thai Nguyen province, and who have low access to animal health services. On the other hand, if focus is on improving disease preventive practices, young to middle-aged, male, small-scale farmers with low education level should be prioritized. This illustrates the great difficulty in targeting interventions, having to consider multiple variables that might affect different areas of the AMR-related field in different ways.

Four variables were significantly associated with the respondents' knowledge scores (Knowledge scale). Most surprising was the finding that not having access to animal health services was associated with a higher score, contrary to the finding for the practice scale related to disease management and antibiotic treatment practices (Practices 1). One could reason that without access to animal health services, you need to rely on your own knowledge to a larger extent, and therefore have an incitement to learn more about disease handling and treatment, including ABU. Another theory might be that animal health professionals would be hesitant to share their knowledge because they want farmers to rely on their services. However, these are only speculations that need to be investigated further.

That two of the other variables, high education level and large farm size, were significantly associated with higher knowledge scores was more expected. For example, an association between knowledge and education level has previously been shown within poultry production in different LMICs, including in Vietnam (13, 52, 54). Further, it is reasonable that farmers with more animals are closer to commercialization or intensification of their farming methods, making it more important for them to learn about handling disease. If keeping chickens for household consumption is actually a variable to consider here is difficult to evaluate, as for the Practices 2 scale discussed above.

The descriptive results for the knowledge questions reveal that the knowledge level overall is quite high in some areas, but that there are also knowledge gaps to be addressed. On the positive side, more than two thirds of respondents stated that antibiotics are supposed to be used for disease treatment only, and almost 90% understood that antibiotics can treat bacterial disease. On the other hand, almost half of respondents also said that antibiotics can be used to treat all kinds of diseases, including viral diseases. Several questions revealed that a majority knew about AMR, even though an understanding of how AMR spreads was often lacking. These results could possibly be used as guidance if educational interventions are considered in the future. A suggestion would then be to focus on how resistance can spread, both between animals and between animals and humans. The connections between AMR in animals and humans should also be emphasized. Furthermore, results from the regression analysis suggest that there should be a focus on small-scale farmers, and farmers with a low education level in the Thai Nguyen province.

When comparing the three investigated scales, similarities were mainly found between the disease prevention practices scale (Practices 2) and the knowledge scale. It might have been expected to find more similarities between the practice scale related to disease management and antibiotic treatment (Practices 1), and the knowledge scale. Several previous studies among poultry farmers in LMICs have shown a positive correlation between knowledge about antibiotics and AMR and good ABU practices (13, 15, 52, 54). However, it has also been shown that good knowledge does not necessarily translate into desirable practices (15). It is also noteworthy that long experience of keeping livestock showed no significant positive association with the scores for any of the three scales, as has been shown in some other studies (15, 52).

To the authors' knowledge this is the first study to use IRT as a method to evaluate farmers' knowledge and practices related to ABU and AMR. IRT has several advantages over simpler statistical methods, primarily generating more reliable results. In addition, with IRT each question is automatically evaluated regarding its quality and difficulty, providing valuable information for adjusting the questionnaire for future use. However, IRT demands more preparatory work, as well as more time for data processing and statistical analyses, which should be considered in the planning stage. As more studies using IRT are performed within the AMR field, this time can be reduced, hopefully, as sets of questions that are proved to work well, such as the three scales in this study, are generated. Today, IRT is still uncommon within veterinary public health research, so comparisons of results with other studies' are difficult.

The current study has revealed several parameters to consider when planning interventions to reduce AMR in livestock production in LMICs. The wide range of characteristics that may impact farmers' knowledge and practices calls for further work in Vietnam, and other Southeast Asian countries. Further, studies to decide suitable and effective interventions are also required.

The results from this study show the important role of veterinary drug shop workers in the farmers' local communities. Their knowledge and routines regarding ABU and AMR are likely to affect ABU and AMR development at the farm level. Therefore, it is of great interest to investigate the knowledge and practices in the AMR area among these veterinary drug shop workers. Combining the results generated from this study, and similar ones, with a study among veterinary drug shop workers would generate a better understanding for the context in which small- and medium-scale farmers operate.

5 Conclusion

By applying the IRT approach, this study demonstrates the complexity in understanding what drives farmers' behaviour in relation to ABU and AMR in an area with high access to veterinary drugs, low access to veterinary health services and high use of antibiotics for disease prevention. Overall, there were more similarities in significantly associated variables between the disease prevention practices scale and the knowledge scale, than between the disease management and antibiotic treatment practices scale and the knowledge scale. Yet, differences were seen between all three scales. These thorough analyses of variables impacting farmers' practices and knowledge illustrate that perfect targeting of interventions is challenging. When planning for interventions you need to understand the context to decide which variables to focus on in each specific setting, both in terms of access to veterinary drugs and veterinary health services, but also other farm characteristics. This in turn may be one of the reasons why change to better AMR-related practices takes time, there is no one-size-fits-all solution.

5.1 Limitations of the study

In this study, official registers of poultry farms were used as sampling frames. When the field work was initiated, it was noticed that there were over-coverage in the frames since many households did not keep chicken anymore, or kept a different number than registered. This negatively impacted the randomness of the sample since replacements households were not selected randomly. For all districts, there was a larger proportion of small-scale farms that needed to be replaced than medium-scale farms, making the randomness in the sample of small-scale farms lower in comparison. Also, the over-coverage probably affected the stratification since the proportion of replaced households differed between districts. Under-coverage of the frames is also possible if not all small-scale farmers are in the official registers.

Another factor to consider is the risk for different kinds of biases when performing questionnaire-based surveys, e.g., desirability and recall bias. Further, 43 of the prospective respondents did not agree to participate, which means that there might be some nonresponse bias.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author. The original contributions presented in the study are publicly available. This data can be found here: https://hdl.handle.net/20.500.12703/4023.

Ethics statement

The studies involving humans were approved by Institutional Review Board of Hanoi School of Public Health (HUPH). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

SN: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. TN-T: Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing. HX: Investigation, Project administration, Resources, Supervision, Writing – review & editing. JL: Formal analysis, Methodology, Validation, Writing – review & editing. SB: Conceptualization, Methodology, Validation, Writing – review & editing. JJ: Conceptualization, Methodology, Validation, Writing – review & editing. UM: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

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Conflict of interest

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

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2024.1319933/full#supplementary-material

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III

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ORIGINAL ARTICLE

WILEY

Understanding veterinary drug shop workers' knowledge and practices to identify drivers of antibiotic use in Vietnamese livestock farms

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Abstract

Background: Antimicrobial resistance (AMR) is a One Health issue and a major threat to animal and human health. Antibiotic use (ABU) drives AMR development, and several hotspots for ABU, and AMR, in livestock have been identified in Southeast Asia, including Vietnam. There are often multiple drivers of ABU at farms, and to identify all of them there is a need to look beyond farm level.

Objectives: The overall aim of this study was to identify routines and/or competencies, related to antibiotic sales, among veterinary drug shop workers that may be improved in order to decrease the medically non-rational use of antibiotics in livestock production.

Methods: A questionnaire-based survey was conducted at 50 veterinary drug shops in northern Vietnam.

Results: Results showed high education and knowledge levels. According to the respondents, antibiotic treatment advice was almost always provided to the farmers, and the recommended treatment was most commonly based on recommendations for the specific disease. However, farmers had almost never had their animals properly diagnosed. Antibiotics were the most sold drug category, penicillins being the most common. Several broad-spectrum antibiotics were also quite frequently sold. Further, >50% of respondents recommended antibiotics for disease prevention.

Conclusions: Even though education and knowledge levels might be high, several challenges can prevent drug shop workers from contributing to more prudent ABU at farms, for example, lack of proper diagnosis, commercial interests and individual farmer motives, often in combination with poor compliance to regulations.

KEYWORDS
anti-bacterial agents, antibiotic sales, drug resistance, livestock, veterinary pharmacy, Vietnam

1 | INTRODUCTION

Antimicrobial resistance (AMR), the ability in bacteria to resist antibiotic treatment, poses a major threat to human and animal health worldwide. It is estimated that in 2019, 1.3 million people died from resistant infections, and in this silent pandemic, low- and middle-income countries (LMICs) are the most severely affected (Antimicrobial Resistance Collaborators, 2022). As for humans, AMR negatively affects the health and welfare of animals and by extension, animal productivity (Bengtsson & Greko, 2014; World Bank, 2017).

That antibiotic use (ABU) is what drives AMR development is commonly acknowledged, as well as that this process is accelerated when antibiotics are over- or misused (FAO, 2016; Holmes et al., 2016). Such irrational use is frequently seen in livestock production when antibiotics are used for disease prevention and growth promotion (FAO, 2016; Marshall & Levy, 2011). On a global level, the use of antibiotics in food-producing animals exceeds the use in humans, and ABU in livestock is expected to increase even more as a result of increased demand for animal-source foods (Van Boeckel et al., 2015). Since AMR is a One Health issue, connecting human and animal health together, these circumstances make reducing ABU in the livestock sector critically important.

However, there are many challenges to reducing ABU in livestock, especially in LMICs, where regulations regarding antibiotic sales might not be in place, or more commonly, are not properly enforced for various reasons. For example, regulations regarding the need for a prescription to buy antibiotics are often in place, but over-the-counter (OTC) sales of antibiotics for both humans and animals have for a long time been, and still is common practice in many LMICs (Circular 12/2020/TT-BNNPTNT, 2020; Coyne et al., 2019; European Commission, Directorate-General for Health and Food Safety, 2018; Malijan et al., 2022; Puspitasari et al., 2011; Sakeena et al., 2018; Van Duong et al., 1997; Zellweger et al., 2017).

Another challenge in many LMICs is lack of access to professional animal health services and laboratory capacity, which together with easy access to OTC antibiotics, increases the risk for irrational ABU (Magnusson et al., 2021; Paul & Varghese, 2020). In these settings, veterinary drug shop workers become vastly important in order to mitigate this irrational use.

Vietnam is a relevant example of such a country, where livestock farmers to a large extent visit veterinary drug shops for buying OTC antibiotics, but also for other services. For example, studies have shown that farmers rely heavily on veterinary drug shop workers for advice on when and how to use antibiotics, as well as for diagnosing sick animals (Carrique-Mas et al., 2015; Luu et al., 2021; Nohrborg et al., 2024; Pham-Duc et al., 2019; Phu et al., 2019). A high dependence on veterinary drug shop workers for advice has also been reported from several other Asian countries (Hallenberg et al., 2020; Hassan et al., 2021; Heyman, 2020; Huber et al., 2021). Hence, in Vietnam and other LMICs, the knowledge and practices regarding animal disease symptoms, antibiotics and AMR among drug shop workers may have a significant impact on whether the chosen treatment regime is medically rational and prudent, or not, from an AMR perspective. Subsequently, these veterinary drug shop workers are potential key targets for interventions aiming towards a more rational ABU in livestock in many LMICs.

The overall objective of this study, conducted in Vietnam, was to identify routines and/or competencies, related to antibiotic sales to farmers, among veterinary drug shop workers that may be improved in order to decrease the non-rational use of antibiotics in livestock production. To reach this objective, the study aimed to increase the understanding about veterinary drug shop workers': (1) professional experience and education, (2) routines regarding antibiotic sales, and (3) knowledge about antibiotics, and AMR development and spread.

2 | MATERIALS AND METHODS

2.1 | Study area

Vietnam has a population of nearly 100 million people as of 2023, of which a large share reside in rural areas and is engaged in agriculture (General Statistics Office 2021, 2023; United Nations Population Fund, n.d.). Chicken and pig farming are two of the most important livestock raising activities in the country. Even though the number of large-scale farms is increasing for several livestock species, small-scale production is still dominating (General Statistics Office, 2021).

The current study was conducted in Thai Nguyen province in the northern midlands and mountain areas north of the Vietnamese capital Hanoi (Figure 1). The province is divided into nine districts, where some are mainly rural and others more urban. The human population of the province was 1.3 million in 2022 (General Statistics Office, 2023), and the number of households that kept chicken and pigs in 2016 was 173,000 and 92,000, respectively, which reflects about 2% and 3% of the chicken- and pig-keeping households in the country (General Statistics Office, 2018). In a previously conducted study among chicken farmers in the Thai Nguyen province, the province was selected based on its location, as well as size and distribution of the chicken population (Nohrborg et al., 2024).

The same districts as in the chicken farmers study were included in the current one: Thai Nguyen City, Dong Hy and Vo Nhai, with 360,000, 94,700 and 69,800 inhabitants, respectively, in 2022 (Thai Nguyen Statistics Office, 2023). As previously described (Nohrborg et al., 2024), the majority of the population in Thai Nguyen City lives in urban areas, while the rural population makes up the largest share in Dong Hy and Vo Nhai.

2.2 | Study population and sampling design

Official lists of all registered veterinary drug shops in Thai Nguyen City, Dong Hy and Vo Nhai were obtained from the local authorities in Thai Nguyen province, the sub-Department of Animal Health (sub-DAH). In total, there were 85 listed shops, 50 in Thai Nguyen City (59%), 18 in Dong Hy (21%) and 17 in Vo Nhai (20%).

FIGURE 1 Map of the continent of Asia (left) with Vietnam marked in green, and map of Vietnam (right) with the province Thai Nguyen marked in red. Yellow marks the capital province of Hanoi for reference. *Source*: https://mapchart.net, retrieved 18 January 2024, license: https://creativecommons.org/licenses/by-sa/4.0/.

A random sample of 50 shops was taken from the official lists and the sample was stratified according to the proportion of shops in each district. The stratification resulted in 29 shops being selected from Thai Nguyen City, 11 from Dong Hy and 10 from Vo Nhai, using an online randomisation tool (Urbaniak & Plous, 2013).

For each district, a list of shops which were not included in the original sample was kept for possible replacements. In total, 11 shops (22%) needed to be replaced during the field work, due to reasons such as the shop being closed, several shops having the same owner, or the owner/staff not being present at the time of the visit. One shop needed to be replaced because the respondent did not want to finish the interview. If possible, a replacement shop in the same commune was chosen. Only nine shops, instead of 10, could be visited in Vo Nhai district, since there were not enough shops in the replacement list. Therefore, the number of shops visited in Dong Hy was increased from 11 to 12.

2.3 | Data collection

2.3.1 | Questionnaire

To investigate veterinary drug shop workers' sales practices, and knowledge regarding antibiotics and AMR, a structured questionnaire containing 44 questions was developed and divided into the following sections: (a) demographics and shop characteristics, (b) antibiotic sales and advice routines and (c) knowledge about antibiotics and AMR (Supporting Information S1). The questionnaire was developed in English and translated into Vietnamese.

The survey was conducted in face-to-face interview format by one experienced enumerator from the National Institute of Veterinary Research (NIVR), Hanoi. Before starting the field work, the enumerator went through a 1-day training to get familiar with the questionnaire. Two pilot interviews were also performed in the field, in veterinary drug shops not situated in the study area. Feedback on the questionnaire from the training and field test was taken into account and adjustments to the questionnaire were made. The field work took place between 20 February and 1 March 2023, with the first author of this article present. Completing an interview took approximately 15–20 min.

Six out of the 50 drug shop workers were interviewed in other locations than in their veterinary drug shop since they worked in several locations. Three shop workers were interviewed via telephone because they were not present at the shop by the time of visit. Answers were recorded on tablets through the online survey tool platform Netigate (Netigate, n.d.). Each respondent was given 100,000 VND (approximately 4 USD) after the interview, as a compensation for taking time away from their business. The respondents were not aware of the compensation beforehand.

2.4 | Statistical methods

2.4.1 | Data processing and analyses

The survey data were downloaded from Netigate to Microsoft Excel for processing. Removal of the one unfinished interview was performed and free-text answers were translated from Vietnamese to English and entered to the dataset. The dataset was then imported to Stata version 18.0 (StataCorp, 2023), where descriptive statistics were compiled for all questions. For knowledge questions, number of correct answers, and proportion of correct answers, were generated for each respondent, as well as means for the whole respondent group.

3 | RESULTS

3.1 | Demographics and shop characteristics

In total, 50 veterinary drug shop workers in Thai Nguyen province answered the questionnaire. Respondents had a mean experience of work in a veterinary drug shop of approximately 15 years and the visited shops were small, with a mean number of staff of 1.8 (details for demographics and shop characteristics are in Table S1, Supporting Information S2).

Two thirds of the respondents had an education from college or university, and second most common was having vocational training. Of those who had a college or university education, or vocational training, >90% were trained within veterinary medicine. A little more than half of all respondents had received some training or education regarding animal diseases and treatment, and antibiotic mechanisms and antibiotic treatment recommendations in particular. Most commonly, this education or training had been provided for one or a few days by the sub-DAH or a drug company. Fewer had received any education regarding regulations concerning ABU and sales.

Chickens/hens were the most commonly owned species by farmers visiting the shop. Second most common was owning pigs.

3.2 | Veterinary drug shop worker–farmer relationship and advice routines

According to the drug shop workers, visiting farmers mainly come to them on their own initiative, and in almost 90% of the shops, farmers who come to buy antibiotics had never or seldom had their animals examined by an animal health professional prior to the visit (Table 1). In addition, in almost 90% of shops, farmers seldom or never brought a veterinary prescription when wanting to buy antibiotics. Further, half of the drug shop workers seldom or never asked for a prescription before selling antibiotics.

Treating sick animals was the purpose for recommending antibiotics for all respondents while half of the respondents also recommended antibiotic treatment for disease prevention. According to the respondents, recommending antibiotics for growth promotion was never occurring.

The most considered factors when recommending an antibiotic to a farmer that asks for advice regarding treatment of sick animals were: the treatment recommendations for the particular disease, price and previous feedback on effectiveness. The respondents said they never considered factors such as antibiotics kept most in stock, or having the shortest expiry date. Whether the antibiotic is critically important for human use was not considered either.

Advice regarding treatment length, dosage, administration procedure and preparation of the drug were always, or almost always, given. Also, information regarding withdrawal times was provided by four out of five respondents. Less common was to give advice regarding which animals to treat, how to handle leftover antibiotics or when to stop treatment, for example, in case of adverse effects.

Treatment length and dosage advice were for half of the respondents usually based on package recommendations. For dosage, it was almost equally common to recommend a higher dose than what was stated on the package. Information regarding the risk for/with AMR development was provided to farmers by almost all drug shop workers.

3.3 | Antibiotic sales, recommendations and disposal

The most commonly sold drugs in the shops were antibiotics, followed by vitamins (Table 2). Almost two thirds of respondents kept records of antibiotics sold.

The most commonly sold antibiotics overall, and to poultry farmers in particular, were penicillins and tetracyclines (Table 3). Details regarding specific antibiotic recommendations for poultry are found in Table S3, Supporting Information S2. Macrolides, quinolones, polypeptides and aminoglycosides, which belong to the highest or high priority critically important antimicrobial groups for human use (World Health Organization, 2019), were also among the most commonly sold antibiotics for 20%–25% of respondents.

When taking care of expired/leftover antibiotics in the shop, the most common practice was to throw them in the trash or latrine. It never occurred that those antibiotics were sold to farmers at a cheaper price.

3.4 | Experience and advice regarding ineffective treatment

Almost all respondents said that none, or less than 25%, of the farmers that buy antibiotics to treat sick animals come back and say that the treatment did not work. In case antibiotic treatment was not effective, the most commonly recommended action was to switch to another antibiotic (one third of respondents). To call a veterinarian or animal health worker for advice was less common. For details, see Table S2, Supporting Information S2.

TABLE 1 Drug shop worker–farmer relationship and advice routines based on a survey among veterinary drug shop workers in Thai Nguyen City, Dong Hy and Vo Nhai districts, Thai Nguyen province, Vietnam.

Question	Option	Number (%)
When farmers come to buy antibiotics in your shop, on who's initiative do they usually come? *n* = 50	Their own initiative	34 (68.0)
	After recommendation from a veterinarian (governmental or private)	9 (18.0)
	After recommendation from other	7 (14.0)
Have farmers that come to you to buy antibiotics had their animals examined by an animal health professional (e.g., veterinarian or animal health worker)? *n* = 50	Always or mostly	3 (6.0)
	Sometimes	3 (6.0)
	Seldom or never	43 (86.0)
	I don't know	1 (2.0)
Do the farmers that want to buy antibiotics bring a veterinary prescription? *n* = 50	Always or mostly	0 (0.0)
	Sometimes	7 (14.0)
	Seldom or never	43 (86.0)
Do you ask for a veterinary prescription before selling antibiotics to farmers? *n* = 50	Always or mostly	9 (18.0)
	Sometimes	16 (32.0)
	Seldom or never	25 (50.0)
For which purposes do you recommend antibiotics to farmers? (multiple choice) *n* = 50	To treat sick animals	50 (100.0)
	To prevent animals from becoming sick	27 (54.0)
	To make animals grow faster/better	0 (0.0)
When recommending an antibiotic to a farmer that asks for advice regarding treatment of sick animals, which factors do you mainly consider? (up to three can be chosen) *n* = 50	Preference of the farmer	11 (22.0)
	Price	28 (56.0)
	That the antibiotic should have a broad treatment spectrum	7 (14.0)
	That the antibiotic should have an as narrow treatment spectrum as possible	10 (20.0)
	Administration route (e.g., mixed in feed, injection or tablets)	2 (4.0)
	Treatment recommendations for the particular disease	41 (82.0)
	What you have most in stock	0 (0.0)
	The antibiotic not being critically important for human use	0 (0.0)
	What has the shortest expiry date	0 (0.0)
	Previous feedback from farmers on effectiveness	23 (46.0)
	Other (specify)	9 (18.0)
Do you give the farmer advice on how to use and handle the antibiotics? *n* = 50	Yes, mostly	48 (96.0)
	Sometimes	2 (4.0)
	No	0 (0.0)
If yes or sometimes, which kind of advice? (multiple choice) *n* = 50	Preparation of the drug (e.g., mixing it with feed or water and preparing injections)	47 (94.0)
	Administration procedure (i.e., how to give the antibiotic)	50 (100.0)
	Treatment length	48 (96.0)
	When to stop treatment (e.g., if adverse effects occur)	4 (8.0)
	Withdrawal times (i.e., the time you should wait before consuming products like eggs, milk and meat from the treated animal(s))	40 (80.0)
	Dosage	49 (98.0)
	Handling of leftover antibiotics	17 (34.0)
	Which animals to treat (e.g., only the sick animals, the whole flock, or in contact animals)	27 (54.0)

(Continues)

TABLE 1 (Continued)

Question	Option	Number (%)
If you give advice regarding treatment length, what do you usually recommend (when treating the disease for the first time)? *n* = 48	What is stated on the package	24 (50.0)
	What is recommended by veterinary professionals	13 (27.1)
	To treat until the animal(s) begin to recover	0 (0.0)
	To treat until the animal(s) completely cured	9 (18.8)
	Other (specify)	2 (4.2)
If you give advice regarding treatment dosage, what do you usually recommend (when treating the disease for the first time)? *n* = 49	What is stated on the package	24 (49.0)
	What is recommended by veterinary professionals	2 (4.1)
	A higher dose than what is stated on the package/recommended	22 (44.9)
	A lower dose than what is stated on the package/recommended	0 (0.0)
	Other (specify)	1 (2.0)
If you know about antibiotic resistance, do you inform farmers about the risk for/with resistance development? *n* = 48	Yes, often	47 (97.9)
	Sometimes	1 (2.1)
	No	0 (0.0)

TABLE 2 Antibiotic sales, recommendations and disposal in veterinary drug shops in Thai Nguyen City, Dong Hy and Vo Nhai districts, Thai Nguyen province, Vietnam.

Question	Option	Number (%)
What drug category is the most sold in your shop?	Antibiotics	29 (58.0)
	Anthelmintics	0 (0.0)
	Anti-inflammatory drugs	0 (0.0)
	Vitamins and probiotics	19 (38.0)
	Ectoparasiticides	0 (0.0)
	Vaccines	0 (0.0)
	I don't know	1 (2.0)
	Other (specify)	1 (2.0)
Do you keep records of antibiotics sold at your shop?	Yes	29 (58.0)
What do you usually do with expired/leftover veterinary antibiotics?	Throw in the trash/latrine	21 (42.0)
	Send for hazard destruction	4 (8.0)
	Sell to farmers at a cheaper price	0 (0.0)
	Return to drug company/wholesaler	0 (0.0)
	I have never experienced expired drugs	21 (42.0)
	Other (specify)	4 (8.0)

n = 50.

3.5 | Knowledge about antibiotics and AMR

Almost all respondents had heard about antibiotic, or antimicrobial, resistance, but the definition varied from a more general definition of drug resistance, to more elaborative explanations about underlying mechanisms such as over- or misuse of antibiotics.

One third of respondents believed that antibiotics are supposed to be used for treating sick animals. Almost twice as many believed that antibiotics should be used for disease treatment and disease prevention (Table 4).

Almost all respondents believed that antibiotics can treat bacterial disease and not all kinds of diseases or diseases caused by viruses. Further, almost all respondents knew that bacteria can become resistant to antibiotics if used in the wrong way or too often.

That antibiotic resistance can make it more difficult to succeed with antibiotic treatment in sick animals was understood by almost all drug

TABLE 3 Antibiotic classes sold in veterinary drug shops in Thai Nguyen City, Dong Hy and Vo Nhai districts, Thai Nguyen province, Vietnam.

	Number (%)										
Question	TET	MAC	PEN	QLO	TRI/SU	POL	CEP34	CEP12	AMI	ACO	FT
Which are the **most commonly** sold antibiotics in your shop? (up to 3 can be chosen)	29 (58.0)	10 (20.0)	38 (76.0)	12 (24.0)	3 (6.0)	9 (18.0)	1 (2.0)	0 (0.0)	12 (24.0)	11 (22.0)	3 (6.0)
Which are the **most commonly** sold antibiotics to poultry farmers in your shop? (up to 3 can be chosen)	31 (62.0)	10 (20.0)	35 (70.0)	10 (20.0)	3 (6.0)	13 (26.0)	0 (0.0)	0 (0.0)	7 (14.0)	8 (16.0)	3 (6.0)

n = 50.
Abbreviations: ACO, amphenicols; AMI, aminoglycosides; CEP12, 1st to 2nd generation cephalosporins; CEP34, 3rd or 4th generation cephalosporins; FT, free text; MAC, macrolides; PEN, penicillins; POL, polypeptides; QLO, quinolones; TET, tetracyclines; TRI/SU, trimethoprim/sulphonamides.

shop workers. A majority of respondents knew that resistant bacteria can spread between animals and through manure, while fewer knew that spread can happen between animals and humans, and through animal-source foods.

The number of correct responses to the 15 knowledge questions varied from 7 to 15 with a mean close to 11. Converted to proportion correct answers, the mean was approximately 0.7. Almost 60% of respondents had a proportion of 0.6–0.8 correct answers.

4 | DISCUSSION

To understand the drivers behind ABU in livestock farms, there is a need to go beyond the practices at farms and look at the broader system in which farmers operate. Drivers may exist in the supply chain of antibiotics to the farmer, and therefore the current study focused on an important player along this chain: the veterinary drug shop workers. Thus, novel findings about Vietnamese veterinary drug shop workers' practices and knowledge related to antibiotics and AMR are presented here.

The visited drug shops were generally small, with few employees, and the main categories of customers were poultry and pig farmers. A majority of respondents had an education from college or university, and almost all respondents had received education in veterinary medicine. Only two previous studies have investigated education level among veterinary drug retailers in Southeast Asia (SEA), both conducted in Cambodia. The first one showed, similar to the current study, that a majority of respondents had a university education (Heyman, 2020), while the other showed that secondary school or high school education was the most common (Chea et al., 2023). Hence, the limited number of studies makes it difficult to put the results from the current study into perspective.

The current study showed that a majority of farmers that came to buy antibiotics did so on their own initiative, and that they almost never had their animals examined by a veterinarian prior to the visit. Another study performed among chicken farmers in the same districts echoes this picture, where the most common response to disease among the chickens was to give drugs from a veterinary drug shop (Nohrborg et al., 2024). To give antibiotics at the first sign of clinical disease was also documented as common practice in another study on Vietnamese chicken farms (Luu et al., 2021), as well as among small-scale pig farmers in Thailand (Hallenberg et al., 2020). In the study by Nohrborg et al., more than half of the farmers also stated that they usually diagnose their animals themselves. As previously described for many LMICs (Coyne et al., 2019; European Commission, Directorate-General for Health and Food Safety, 2018; Hallenberg et al., 2020; Malijan et al., 2022; Zellweger et al., 2017), the current study and the study among chicken farmers in the same districts (Nohrborg et al., 2024) confirm the picture that OTC sales of antibiotics are dominating. It is interesting to note that these OTC sales are commonly occurring in Vietnam even though regulations are in place that prohibit sales of veterinary drugs without a prescription (Circular 12/2020/TT-BNNPTNT, 2020), as well as regulations stating that veterinary drug shops must be officially registered and certified (Law on Veterinary Medicine, 2015). The circumstances of disease treatment without prior diagnosis from a veterinary professional, in combination with extensive sales of antibiotics OTC, increase the risk for incorrect treatment, and subsequently, the risk for resistance development.

Another general complicating factor, relating to the relationship between drug shop workers and farmers, is poor compliance to science-based treatment recommendations and instructions. In the current study, drug shop workers reported that they almost always provided instructions regarding treatment length, dosage, drug administration and preparation and withdrawal times. However, several respondents spontaneously, outside the structured questionnaire, expressed difficulties in getting farmers to follow their advice. The earlier study, conducted among poultry farmers in the same districts, also reflects this (Nohrborg et al., 2024). Even though taking advice from a veterinary drug shop worker was the most common, 20%–25% of farmers in that study did not think they needed any advice on when, and how, to use antibiotics. Similar difficulties with compliance to treatment recommendations have been expressed by veterinary drug shop workers in Cambodia (Heyman, 2020). Other results from a study on Vietnamese farms showed that reliance on veterinary drug shop workers for consultation regarding antibiotic treatment may differ between livestock species kept (Luu et al., 2021). In that study, the majority of chicken farmers used veterinary drug stores for advice, while pig farmers to a larger extent consulted veterinarians.

TABLE 4 Knowledge about antibiotics and antimicrobial resistance among veterinary drug shop workers in Thai Nguyen City, Dong Hy and Vo Nhai districts, Thai Nguyen province, Vietnam.

Question	Option	Number (%)
What are antibiotics supposed to be used for? (single choice)	Prevent animals from becoming sick	0 (0.0)
	Treat sick animals	17 (34.0)
	Make animals grow faster/better	0 (0.0)
	Prevent animals from becoming sick and make animals grow faster/better	1 (2.0)
	Prevent animals from becoming sick and treat sick animals	32 (64.0)
	Treat sick animals and make animals grow faster/better	0 (0.0)
	Prevent animals from becoming sick, treat sick animals and to make animals grow faster/better	0 (0.0)
Do you think that the following statements are true or false? The correct option is presented.		
(a) Antibiotics can treat all kinds of diseases	False	46 (92.0)
(b) Antibiotics can treat diseases caused by viruses	False	48 (96.0)
(c) Antibiotics can treat diseases caused by bacteria	True	49 (98.0)
(d) Antibiotics are the same as anti-inflammatory drugs	False	31 (62.0)
(e) Animals can become resistant to antibiotics if antibiotics are used in the wrong way/too often	False	22 (44.0)
(f) Bacteria can become resistant to antibiotics if used in the wrong way/too often	True	48 (96.0)
(g) Viruses can become resistant to antibiotics if used in the wrong way/too often	False	49 (98.0)
(h) Resistance against antibiotics can make it more difficult to succeed with antibiotic treatment in animals when they get sick	True	49 (98.0)
(i) Bacteria resistant to antibiotics can spread from one animal to another	True	37 (74.0)
(j) Bacteria resistant to antibiotics can spread between animals and humans	True	28 (56.0)
(k) Bacteria resistant to antibiotics can spread from animals to humans through animal-source foods, for example, meat	True	13 (26.0)
(l) Leftovers of the antibiotic can be transferred to meat, milk or eggs	True	48 (96.0)
(m) Bacteria resistant to antibiotics can spread through manure from animals	True	32 (64.0)
(n) Antibiotic resistance in human bacteria is only linked to the use of antibiotics in humans and not in animals	False	18 (36.0)
Item	**Measure**	**Number (%)**
Correct responses to knowledge questions (maximum of 15)	Mean	10.7 (71.3)
	Median	11
	Range	7–15 (46.7–100.0)

$n = 50$.

Half of the drug shop workers believed that antibiotics are supposed to be used not only for disease treatment, but also for prevention. This was reflected in their practices, as half of the respondents reported that they recommend antibiotics for disease preventive purposes, which may increase ABU, and then AMR. The previous study among chicken farmers in the same districts also showed that antibiotics were used for disease prevention in two thirds of farms (Nohrborg et al., 2024). High use of antibiotics for disease prevention in the livestock sector has also been described in several other studies conducted in Vietnam and other SEA countries (Carrique-Mas et al., 2015; Coyne et al., 2019; Luu et al., 2021; Nguyen et al., 2016).

Treatment recommendations for the particular disease were the most commonly considered factor when recommending an antibiotic to a farmer that asks for advice regarding treatment of sick animals, which may obviously be beneficial from an AMR mitigation perspective. Nevertheless, choosing the accurate antibiotic is complicated by the lack of a proper diagnosis of the animal(s) prior to the veterinary drug shop visit. This situation is a recurring issue in many LMICs because of farmers' lack of access to, or use of, affordable professional animal health services and diagnostic testing (Dione et al., 2021; Magnusson et al., 2021; Nohrborg et al., 2024; Paul & Varghese, 2020). Without a specific diagnosis, the drug shop staff is likely prone to choose a broad-spectrum antibiotic that can treat a wide range of pathogens, but this practice unfortunately also drives AMR development to a larger extent than narrow-spectrum antibiotics (Modi et al., 2014; Rao, 1998; Spaulding et al., 2018). Even though penicillins, which are narrow-spectrum antibiotics, were the most commonly sold antibiotic class in this study, several broad-spectrum antibiotic classes were also frequently sold in many shops. This is worrisome, both for the increased risk of resistance development in treated animals, but also because several of these broad-spectrum antibiotic classes, macrolides, quinolones, aminoglycosides and polypeptides, are listed as critically important for human use by the World Health Organization (WHO; World Health Organization, 2019). Numerous studies in Vietnam and other SEA countries have also shown that use of critically important antimicrobials is frequently occurring in poultry farming (Carrique-Mas et al., 2015; Cuong et al., 2019; Luu et al., 2021; Malijan et al., 2022). In addition, the current study found that the most common recommendation when antibiotic treatment was not effective was to switch to another antibiotic, which may further increase the risk for AMR development. Contacting a veterinarian for further disease investigation and advice would have been more favourable, but was unfortunately uncommon.

The knowledge level among the drug shop workers about antibiotics and AMR in general seemed to be quite high, especially regarding antibiotic efficacy and the development and risks of AMR. Even so, it appears that knowledge regarding the One Health aspect of AMR, that is, the links between AMR in humans and animals, could be improved. Only a little more than half of respondents believed that AMR bacteria could spread between animals and humans, and only one out of four that AMR bacteria could spread to humans through animal-source foods. Further, about two thirds believed that AMR in humans is only linked to ABU in humans and not in animals. Lacking knowledge regarding the One Health aspect of AMR has previously been described among veterinary drug retailers in Cambodia, as well as veterinary practitioners in Uganda (Dione et al., 2021; Heyman, 2020). Compared to the knowledge level about antibiotics and AMR among poultry farmers in Thai Nguyen province (Nohrborg et al., 2024), the knowledge was generally higher among drug shop workers, as would be expected. However, as for the drug shop workers, the One Health aspect of AMR was where knowledge among the poultry farmers was lacking the most.

Antibiotics was the most commonly sold drug category in the visited shops, making them an important source of income for veterinary drug shops. It is reasonable to believe that this may create a conflict between commercial interests and what is considered responsible ABU from an AMR perspective. This means that even though the education level, and knowledge about antibiotics and AMR, was generally high among the drug shop workers, there is still a considerable risk that their sale practices contribute to over- and misuse of antibiotics at farms. Clearly, this conflict between interests is enabled by a system with lacking enforcement of regulations regarding the need for a prescription to buy antibiotics. The conflict is also further exacerbated by individual farmer drivers for ABU, for example, economic interests, which drug shop workers need to adapt to in order to keep their customers. Where to find the incitements for change towards a more prudent use of antibiotics in such a system is therefore a major challenge. However, by looking beyond farm level, and understanding more about common AMR-related practices in the antibiotic supply chain, it is hopefully possible to bring guidance towards successful interventions.

5 | CONCLUSION

In conclusion, this study shows that even though education level, and knowledge about antibiotics and AMR, may be high among Vietnamese veterinary drug shop workers, there are multiple challenges preventing them from effectively contributing to prudent use of antibiotics in livestock farms. Lack of proper diagnosis of sick animals and competing commercial interests, in a LMIC setting where implementation of regulations is insufficient, are some of the major challenges. As a result, antibiotics are sold OTC to a large extent, including broad-spectrum antibiotics critically important for human use, making this a One Health issue. This study highlights the need to take a broader approach when aiming for interventions to reduce, and apply a medically rational use of, antibiotics in farms, including other key actors than just farmers. It also shows that increasing knowledge among veterinary drug shop workers is not necessarily what is needed, but other interventions that help finding incitements for change.

5.1 | Limitations of the study

In this study, official registers of veterinary drug shops were used as sampling frames. When the field work was initiated, it was noticed that there were over-coverage in the frames since six shops had either closed, stopped selling drugs or were duplicates of other shops in the lists. In addition, six shops needed to be replaced due to the owner/staff not being present. This negatively impacted the randomness of the sample since replacements shops were not selected randomly.

Further, different kinds of biases need to be considered when interpreting results from a questionnaire-based survey, for example, desirability and recall bias.

AUTHOR CONTRIBUTIONS

Sandra Nohrborg: Conceptualisation; data curation; formal analysis; investigation; methodology; project administration; visualisation; writing—original draft; writing—review and editing. **Thinh Nguyen-Thi**: Investigation; methodology; project administration; resources; supervision; writing—review and editing. **Huyen Nguyen Xuan**: Investigation; Project administration; Resources; Supervision; Writing—review & editing. **Yen Luu Thi Hai**: Investigation; writing—review and editing. **Johanna Lindahl**: Formal analysis; methodology; validation; writing—review and editing. **Sofia Boqvist**: Conceptualisation; methodology; validation; writing—review and editing. **Josef D. Järhult**: Conceptualisation; Methodology; Validation; Writing—review & editing. **Ulf Magnusson**: Conceptualisation; funding acquisition; methodology; project administration; resources; supervision; validation; writing—review and editing.

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CONFLICTS OF INTEREST STATEMENT

The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript or in the decision to publish the results.

DATA AVAILABILITY STATEMENT

The data have been submitted to the SND public repository at https://hdl.handle.net/20.500.12703/4973.

ETHICS STATEMENT

The study was conducted according to the guidelines of the declaration of Helsinki, and approved by the Institutional Review Board of Hanoi School of Public Health (HUPH; ref. no. 022–457/DD-YTCC). Informed consent was obtained from all respondents that participated in the study prior to the start of the interviews.

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PEER REVIEW

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Due to the overuse and misuse of antibiotics, antimicrobial resistance (AMR) in bacteria has become a serious threat to animal and human health worldwide, with the greatest burden seen in low- and middle-income countries. Vietnam's poultry sector is rapidly expanding, with extensive antibiotic use and alarmingly high AMR being reported. This thesis investigates AMR in Vietnamese poultry through a cross-disciplinary approach, exploring its connection to drivers at various levels. The findings may inform evidence-based interventions and policies to mitigate AMR.

Sandra Nohrborg received her postgraduate education at the Department of Clinical Sciences, Swedish University of Agricultural Sciences. She obtained her MSc in Veterinary Medicine at the Faculty of Veterinary Medicine and Animal Science at the same university.

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