



Understanding the veterinary antibiotics supply chain to address antimicrobial resistance in Lao PDR: Roles and interactions of involved stakeholders

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ABSTRACT

In response to the global call to mitigate risks associated with antimicrobial resistance (AMR), new regulations on the access and use of veterinary antibiotics are currently being developed by the Lao government. This study aims to explore how the implementation of these new regulations might effectively reduce and adapt the sale, distribution and use of veterinary antibiotics in Lao PDR. To this end, we used the theory of change, framing the AMR issue within the context of the stakeholders involved in the veterinary antibiotics supply chain.

Qualitative and quantitative methods were used to collect data, based on questionnaires (n=36 antibiotic suppliers, n=96 chicken farmers, n=96 pig farmers), and participatory tools such as a workshop (n=10 participants), semi-structured interviews (n=20), and focus group discussions (n=7 participants). The stakeholders' understanding of the AMR issue and potential challenges related to the implementation of new regulations regarding access and use of antibiotics, were also investigated.

We mapped the veterinary antibiotic supply chain in Lao PDR, and analysed the roles and interactions of its stakeholders. Twenty-three stakeholders representing the private and the public sectors were identified. Many informal and formal links connected these stakeholder within this supply chain. The lack of veterinarian-farmer interaction and the evolving nature of the veterinary antibiotics supply chain accentuated the challenges of achieving behaviour change through regulations. Most of the antibiotics found on farms were categorized by the World Health Organisation's as critically important antibiotics used in human medicine.

We argue that AMR risk mitigation strategy requires dialogue and engagement between private and public sectors stakeholders, involved in the importation, distribution, sale and use of veterinary antibiotics. This study further highlighted that AMR is a complex adaptive challenge requiring multi-sectoral approach. We believed that a sustainable approach to reduce and adapt veterinary antibiotics use should be prepared in collaboration with stakeholders from private and public sectors identified in this study, in addition to the new regulations. This collaboration should start with the co-construction of a common understanding of AMR issue and of the objectives of new regulations.

Introduction

Antimicrobial resistance (AMR) partly originates from the use of antimicrobials, such as antibiotics, in terrestrial and aquatic animals. The use of antibiotics on animals exerts a selection pressure on bacteria,

favouring the selection of resistant genes in the food chain (Bennani et al., 2020). Some studies suggests that interventions to reduce antibiotic use in food animals are associated with a decrease of antibiotic-resistant bacteria in human populations, particularly population in proximity to food animals (Tang et al., 2017). Antibiotics are

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pervasively used in food animal in Southeast Asia, where AMR is widely prevalent (Boeckel et al., 2015). In Southeast Asia, potential drivers of increasing AMR include weak or non-existent regulatory frameworks on antibiotic usage, weak enforcement guidelines and low levels of AMR awareness among both vendors and users. AMR mitigation measures in the veterinary sectors are lagging far behind those implemented in the human health sector (Goutard et al., 2017).

In Lao People's Democratic Republic (Lao PDR), the livestock sector shows significant growth potential. Livestock production also plays an important role in the household economy of poor rural populations (The World Bank Group, 2017). Most livestock producers are smallholders (more than 85%) and subsistence farming remains widespread despite the increasing demand for livestock and livestock products (Ministry of Agriculture and Forestry, 2011). In Vientiane City, the country's capital, the demand for animal products is increasing (Burgos et al., 2008). The private sector is responding to market demands for pigs and poultry, with a number of them setting up farms close to cities (Burgos et al., 2008). This increase in demand, is often associated with an increased demand for antibiotics for prophylactic or treatment uses. The high impact of infectious disease on the livestock population (World Organisation for Animal Health, 2018) and limited access to veterinary services compounds the problem of antibiotic misuse. The Lao veterinary governmental authorities may not cover all relevant aspects of regulations on veterinary antibiotics (i.e. the authorization, registration, import, production, labelling, distribution, sale and use) (Bastiaensen et al., 2011). While human antibiotics may only be purchased with a doctor's prescription, as mandated by law (Food and Drug Department et al., 2011), there are no specific laws or guidelines on the use of veterinary antibiotics (Ministry of Agriculture and Forestry, 2016). Although quantitative data on AMR are scarce in Lao PDR, bacteria isolated from pigs and humans have been found to carry different AMR genes in Vientiane capital city (Thu et al., 2019). These issues highlight the importance of addressing the AMR problem in Lao PDR by considering access and use of antibiotics in food animal.

In 2015, the World Health Assembly of the United Nations declared AMR to be a global threat and urged all countries to develop multi-sectoral National Action Plans on AMR, including a plan for food animals (World Health Organization, 2015). In 2018, the Lao PDR government developed a new decree that includes new regulations on usage and access to veterinary antibiotics, part of the National Action Plan (Ministry of Health and Ministry of Agriculture and Forestry, 2019). This decree, part of the Law on Livestock production and Veterinary matter, was signed by the Lao Prime Minister in 2020 (Ministry of Agriculture and Forestry, 2020). At the time of the study, the decree was not implemented and not enforced.

The international AMR Global Action Plan provided recommendations acknowledging that people, including farmers, are using antibiotics irresponsibly. These recommendations aim at mitigating the spread of AMR by changing farmer behaviour, through regulation and awareness raising (Food and Agriculture Organization of the United Nations, 2016; World Health Organization, 2015). However, these approaches are struggling to deliver effective results (Hinchliffe et al., 2018). Regulations on antibiotics do not systematically give rise to appropriate use. For example, the regulation about the prescription request for the sale and purchase of human antibiotics from "National Drug Policy" faced challenges in its implementation. It was adopted by the Ministry of Health in 1993 in response to the increasing number of private pharmacies, and have gone through successful policy formulation (Jönsson et al., 2015). However, the medical prescription law has been undermined because it is not strictly followed or implemented (Paphassarang et al., 2002). Indeed, the interests and power of different stakeholders can influence the implementation of regulations. This occurs namely when stakeholders are asked to change their practices despite the dissonance between their interests and the new regulations (Gilson and Raphaely, 2008; Zimmermann and Maennling, 2007). The Lao PDR government may face challenges in the implementation and

enforcement of new veterinary antibiotics regulations on usage and access it is developing.

To assess the potential of AMR risk-reduction strategies, the AMR frame can be broadened to consider the perspective of stakeholder groups, where key relations operate and influence individual strategies (Hinchliffe et al., 2018). Groups are composed of interconnected stakeholders, some of whom have strong connections with certain stakeholders, while being poorly connected with others. The AMR issue is thus considered as a complex adaptive challenge (Hinchliffe et al., 2018). A complex adaptive system is "a collection of individual agents with freedom to act in ways that are not always predictable, and whose actions are interconnected so that one agent's actions changes the context for other agents" (Plsek and Greenhalgh, 2001). For this reason, to explore the opportunities toward adaptation and reduction of the sale and use of veterinary antibiotics under new regulations, it is interesting to use the "theory of change" (Brest, 2010; Breuer, 2016). This consists of elucidating the causal links between inputs, outputs, outcomes and impacts in a given context (i.e. the impact pathway), while providing an explicit understanding of the assumptions underlying these links (Fig. 1).

The theory of change is part of the logic of place-based governance. Place-based governance is a type of governance that takes into account the uncertainty of the evolving situation, and that seeks the best possible participation of stakeholders in collective action and the adaptation of decision-making according to the evolving situation (Chhotray and Stoker, 2009). One of the starting points of the theory of change, within our context, is to identify all the stakeholders related to the veterinary antibiotics supply chain. The theory of change also implies that all stakeholders share the same objective (expected outcomes) and the same vision of expected impacts.

In this paper, we explore opportunities for effectively reducing and adapting sale and use of veterinary antibiotics by implementing new regulations on access and use of veterinary antibiotics. For this, we propose to (i) identify the stakeholders and their existing interactions within the veterinary antibiotics supply chain (the inputs), (ii) and investigate their perceptions of the AMR issue (expected impact) and objective of the new regulations (expected outcomes), including the potential constraints and interests regarding the implementation of the new regulations (the outputs). The causal link between expected outcomes and expected impacts will not be explored in this study. This paper also aims to demonstrate the interest of analysing the AMR issue as a complex adaptive system.

Materials and methods

A methodological approach based on participatory stakeholder mapping and analysis was used (Saadi et al., 2021; Schmeer, 1999; Zimmermann and Maennling, 2007).

Study area

The study was conducted in two provinces, Vientiane Capital and Vientiane Province. Both provinces were selected for their high number of farms, according to data from the Ministry of Agriculture and Forestry (2017) (Department of Livestock and Fisheries office, Ministry of Agriculture, 2017). These provinces are near Vientiane City, the country's capital.

Research instrument and sampling strategy

The study was conducted from March to July 2018 using a mixed method (qualitative and quantitative approaches). Our analyses were conducted in three different steps: (i) step 1, the "mapping of the supply chain", in which we identified the different groups of stakeholders in the veterinary antibiotics supply chain and their role and interactions, (ii) step 2, determination of "stakeholder positions", in which we analysed

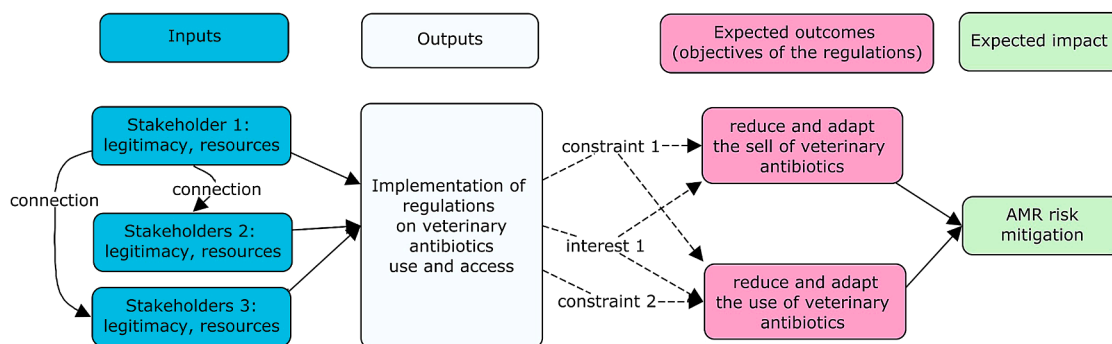


Fig. 1. Using a simplified theory of change to develop an impact pathway to explore the opportunities of effectively adapt and reduce the sale and use of veterinary antibiotics. The inputs (turquoise blue) are the stakeholder groups involved in the veterinary antibiotics supply chain and their existing interactions. The outputs (light blue) are the implementation of the new regulations on access and use of veterinary antibiotics. The expected outcomes (pink) are the objectives of new regulations: the reduced and appropriate sale and use of veterinary antibiotics. The expected impact (green) is the AMR risk mitigation. The constraints and interests of the stakeholders, related the new regulations to be implemented, might hamper the causal link between outputs and expected outcomes. The causal link between expected outcomes and expected impacts will not be explored in this study.

stakeholders interests and constraints regarding two new planned regulations, (iii) and step 3, identification of “opinions and practices”, in which we explored the opinions and practices of public sector, independent private antibiotic suppliers and farmers regarding AMR and the use of antibiotics.

Table 1 summarises the research tools used and the sampling strategies. Overall, purposive sampling, non-probability snowballing sampling and multi-stage cluster sampling were used to select study participants. Government ministers and village leaders were asked to assist in identifying study participants. Tools included a participatory workshop, semi-structured interviews, focus group discussions and survey questionnaires. The original questionnaires and focus group discussion guides were in English. These were translated into Lao and translated back into English to confirm context and clarity.

Data collection

Step 1: mapping of the supply chain: Two researchers (a French female veterinarian and a Lao male veterinarian) and four facilitators (three female and one male, all veterinary lecturers) conducted the participatory workshop. The facilitators were trained to moderate, observe and take notes during the workshop. Discussions were conducted in Lao language, ensuring that all stakeholders took part in the discussions. The meeting lasted around 3 hours.

Step 2: stakeholders' positions: The semi-structured individual interviews lasted from 15 to 35 minutes. Two research assistants conducted the interviews, one in Chinese and one in Lao. A focus group discussion, which lasted around three hours, was also conducted to review and verify the veterinary antibiotics supply chain. Participants also reviewed categories of stakeholders and their level of legitimacy, resources and connections within the supply chain. The stakeholders'

interest and constraints regarding the two new regulations were discussed and compared.

Step 3: opinions and practices: Two principal investigators and 11 students interviewed antibiotics suppliers and farmers. The interviewees entered answers on electronic devices with Sphinxdeclic® (Le Sphinx) software. The interviewees were previously trained on interviewing participants and entering answers on their electronic devices. Photos were taken of products (e.g., veterinary drugs and feeds) that independent farmers were willing to show during the field interviews.

Data processing and analysis

Workshop outputs such as drawings and notes were documented using photographs. Recorded discussions during group or individual semi-structured interviews (Lao or Chinese) were transcribed and translated into English. To improve reliability of the interpretations, another researcher reviewed the transcripts before analysis.

The drawn schema of the veterinary antibiotics supply chain developed during the *step 1: mapping of the supply chain* was reproduced on CmapTools® (IHMC) software. Depending on the level of legitimacy, resources and connections, the research team selected the groups of stakeholders to include in the step “stakeholder positions” (Schmeer, 1999).

The transcripts from *step 2: stakeholder positions* (semi-structured interviews and focus group discussions) were coded. Two themes were identified: (i) improvement of supply chain mapping, (ii) and stakeholders' positions regarding the two new regulations. The data related to improvement of supply chain mapping allowed us to confirm the mapping of the veterinary antibiotics supply chain as well as the level of legitimacy, resources and connections of nine categories of stakeholders involved in this step. The data related to stakeholder's positions were

Box 1. Rationale for the selection of two new regulations for step 2 of this study.

A decree* “decree on veterinary medicine, No 199/GoL” was developed in 2018, as part of the National action plan on AMR. Several regulations were developed as part of the implementation of the decree. It was signed and approved in 2020. At the time of the study, the decree was not finalized. In order to identify and understand the planned regulations, a semi-structured interview with a key informant from national veterinary government authorities, responsible of veterinary legislation in Lao PDR was realized. Two planned regulations mentioned by the key informant were selected and used in step 2 of this study. This selection allowed stakeholder analysis focused on a specific and “definable” policy (Schmeer, 1999). One of the regulation selected related to prescription requirement for the sale of veterinary antibiotics. A second regulation related to the need of veterinarian to oversee the agricultural retail outlet or veterinary pharmacies. The selected regulations affected antibiotics suppliers and farmers who were deemed to have important roles in the veterinary antibiotics supply chain.*The decree is now accessible for people who have created a free account on the Lao trade portal website: <https://www.laotradeportal.gov.la/index.php?r=site/display&id=1945>

Table 1

Research tools and sampling strategies of the three different steps of the study: mapping of the supply chain, stakeholders' positions and opinions and practices steps. ¹Legitimacy was defined according to the type of channel the stakeholder was using to import and/or sell antibiotics: or formal i.e., controlled and monitored by the government and for which stakeholders pay taxes, or informal. Their level of resources was described by their level of knowledge on antibiotic use, good practices and AMR, their qualifications (e.g., education, training, area of expertise) and their ability to provide advice on good practices for antibiotic use. The connection was defined by the number of interactions they had within the veterinary antibiotics supply chain at the time of the study.

²The two regulations investigated were: (1) Regulation concerning the sale of veterinary antibiotics - it states that vendors are not allowed to sell veterinary antibiotics without a prescription from veterinarian/veterinary village worker officials (veterinary village workers are local technicians with some training provided by the government on drug dispensation and who provide animal health extension services to farmers). (2) Regulation concerning the business license for veterinary antibiotic retail outlets - it requires that veterinary pharmacies/agricultural retail outlets selling veterinary antibiotics, need to have at least one veterinarian or veterinary village worker approved by the government to oversee that retail outlet.

	Step 1: Mapping of the supply chain	Step 2: Stakeholder positions	Step 3: Opinions and practices
Goal	-To identify the different groups of stakeholders in the veterinary antibiotics supply chain-To understand their roles and interactions	-To crosscheck our previous results-To analyse stakeholder positions regarding two new planned regulations ²	-To crosscheck our previous results-To explore the opinions on AMR and practices regarding the use of antibiotics
Method Research tool	Qualitative Participatory workshop following a previously-prepared guide covering: (i) the identification of stakeholders, (ii) the mapping of the supply chain, (iii) scoring of the level of legitimacy, resources and connections ¹ of each category of stakeholder (23) (Supplementary Table 1)	Qualitative -Semi-structured interviews, following a previously-prepared checklist covering: (i) the use of antibiotics and awareness of AMR; and (ii) the stakeholder's position regarding the two new regulations (Supplementary Table 2)-Focus group discussions, following previously-prepared checklist (Supplementary Table 3)	Quantitative Questionnaire containing closed and open-ended questions (36 questions for suppliers, 42 for farmers) with dichotomous (yes/no) and categorical outcomes; covering the following areas: (i) socio-demographics, (ii) farm characteristic (only for farmers), (iii) opinions toward antibiotic use and antibiotic resistance, (iv) and practices regarding antibiotic use and antibiotic resistance. The questionnaires were pre-tested among farmers (N = 5) and antibiotic suppliers (N=2), they were simplified according to the results of the pre-test.
Target population	Key informants based on their knowledge of the veterinary antibiotics supply chain	Nine groups of stakeholders, based on their level of legitimacy, connection and resources ¹ they were given in step 1: private foreign farmers, technicians and private multinational company farmers, independent farmers, independent antibiotics suppliers (middlemen, owners and staff of agricultural retail outlet, veterinary village workers, private veterinarians, human pharmacists), and public provincial veterinarian	-Independent antibiotics suppliers (owners and staff of agricultural retail outlet, veterinary village workers, private veterinarians)-Independent poultry and pig farmers in backyard and semi-intensive systems. These systems represent up to 85% of the existing farms in Lao (Ministry of Agriculture and Forestry, 2011) and according to staff from the veterinary governmental authorities the highest level of antibiotic use is found in poultry and pigs (Department of Livestock and Fisheries office, Ministry of Agriculture, 2017)
Location	-The workshop took place in the capital city	-In retail outlets, offices or households of two districts in Vientiane Capital (Xaythany and Naxaythong) and three districts in Vientiane Province (KeoOudom, Thoulakom and Phonhong) because of logistical constraints-The focus group discussion took place in the capital city	-Two districts in Vientiane Capital (Xaythany and Naxaythong) and three districts in Vientiane Province (KeoOudom, Thoulakom and Phonhong) were selected because of logistical constraints; these districts have a large number of farms (Department of Livestock and Fisheries office, Ministry of Agriculture, 2017). The interviews took place in the participant's villages: in their stores or their farms.
Sampling	Purposively selected with the help of members of the ministry of agriculture and two researchers of the faculty of agriculture	-Directly identified by the key informants of step 1; and-Non-probability snowball sampling, i.e., some interviewees assisted the researchers in identifying the next set of interviewees.-Several stakeholders of the same group to crosscheck information and to reach a saturation level (Fusch and Ness, 2015)	A multistage cluster sampling method was used: 1 to 15 villages were randomly selected for each of the 5 districts. The village chiefs helped us identify relevant respondents meeting the selection criteria. Participants included in the survey were above the age of 18 and gave their oral consent.
Participants	10 participants:-representatives from veterinary governmental authorities who supervise livestock production and health in their administrative level (2 at national, 2 at provincial and 4 at district level)-informants directly involved in the veterinary antibiotics supply chain (one private veterinarian and one veterinary pharmacy owner)	-20 (5 females and 15 males) individual semi-structured interviews, including: 1 public veterinarian, 3 members of staff from private companies, 3 private foreign farmers, 11 independent suppliers, 4 independent farmers, (Supplementary Table 4)-focus group discussion among 7 persons from private sector (1 female and 6 males), including: 2 members of staff from private companies, 2 independent farmers, 3 independent antibiotic suppliers (Supplementary Table 4)	-36 antibiotics suppliers: 4 public veterinarians, 17 owners or staff from agricultural retail outlets, 4 private veterinarians, and 11 veterinary village workers-96 chicken farmers and 96 pig farmers

analysed using content analysis. Two codes were identified in relation to their opinion on two new regulations: the informant's potential interest and their potential constraints. The stakeholder constraints were further classified into three sub-codes :

- possible lack of knowledge on the effectiveness of the new regulations, or regarding their potential for AMR reduction;
- possible lack of capacity, such as lack of alternatives or lack of human or material resources enabling the implementation and enforcement of the new regulations;

- possible lack of will to apply the new regulations for economic (such as the competitiveness of their business or their farm products), trust (such as lack of trust in the government or the accessibility of veterinary services) or personal reasons ([Schmeer, 1999](#)).

Codes and sub-codes were assigned manually by the first author of this study without using a computer program.

The questionnaires were analysed using descriptive statistics with R (x64, 3.5.1)®. Statistical association between variables were explored performing chi-square tests; statistical significance being set at p-value

of 0.05.

Results

The veterinary antibiotic supply chain in Lao PDR

We identified 23 stakeholders belonging to the veterinary antibiotics supply chain in Lao PDR, divided in three groups (international, public sector, and private sector). “International stakeholders” (n=4) played a role in technical, financial and legislative support; they also played a role in AMR-related research. The stakeholders from the “public sector: Lao government” group (n=8) were from different Ministries. They were responsible for laws and enforcement, control of antibiotics importation and distribution, education of future stakeholders (such as veterinarians) and AMR research projects. The national veterinary governmental authorities were part of the Ministry of Agriculture and Forestry and oversaw the government veterinary authorities at province and district levels. The stakeholders of the private sector were involved in the importation, distribution and use of veterinary antibiotics (n=12), and could be split into three main sub-groups: “private multinational companies”, “private foreign farmers” and “independent private actors: antibiotics suppliers and antibiotics users” (Fig. 2).

Lao PDR did not produce any veterinary antibiotics, so these antibiotics were mostly imported from Thailand, Vietnam and China, with a few imports from South Korea (Fig. 3). National veterinary governmental authorities controlled the veterinary supply unit, a public inventory of antibiotics, and provided antibiotics to the province and district veterinary governmental authorities and sold antibiotics to the private sector. The National veterinary governmental authorities would appear to import only around 20% of the veterinary antibiotics entering the country, while the rest were imported by the private sector (Fig. 3). The payment of taxes to the government at the Laotian border was the sole legal obligation related to veterinary antibiotics, and corresponded to the formal channel. Many of the stakeholders did not pay taxes when importing antibiotics (informal channel), which indicated non-regulated activity. Human antibiotics from some human pharmacies were sold for veterinary usage, without prescription, which was forbidden by law (informal channel) (Fig. 3).

Different level of legitimacy, resources and connections were

attributed to stakeholders (Table 2). The public sector, Lao government group, was not further investigated because it was rated as legitimate and well-resourced, and its connection in the supply chain was weak.

The private sector stakeholders were involved in the importation, distribution and use of antibiotics. The private sector stakeholders represented three weakly connected groups operating in parallel, which were further investigated (Fig. 3):

Technicians from private multinational companies working with contracted farmers of the same company and using antibiotics from parent companies.

Private foreign farmers with few contacts with other stakeholders, importing antibiotics directly from their home country.

Independent private actors such as independent antibiotics suppliers and independent users (farmers), representing another group linked to the government veterinary authorities.

Private multinational companies

Three private multinational companies were identified. They had large-scale swine and poultry farms that imported veterinary antibiotics from their parent company (e.g., Thailand and China). One multinational company had several inventory of veterinary antibiotics in Lao PDR. The antibiotics were imported through formal channels and private multinational companies declared their inventory. These companies were scored with a strong level of legitimacy and resources (Table 2).

Contracted farmers working for private multinational companies obtained antibiotics from technicians employed by the company. They claimed that they followed the company’s recommendations for the use of antibiotics. Farmers within these integrated systems were not allowed to use any other antibiotics than those provided by their contracting company. They mentioned that they had good access to advice from technicians during disease outbreaks. They appeared indifferent to the new regulations (Supplementary Table 5). The technicians interviewed had completed post-secondary education and had benefited from AMR awareness actions led by their companies. Some companies already had internal policies on AMR mitigation (Charoen Pokphand Foods, 2017).

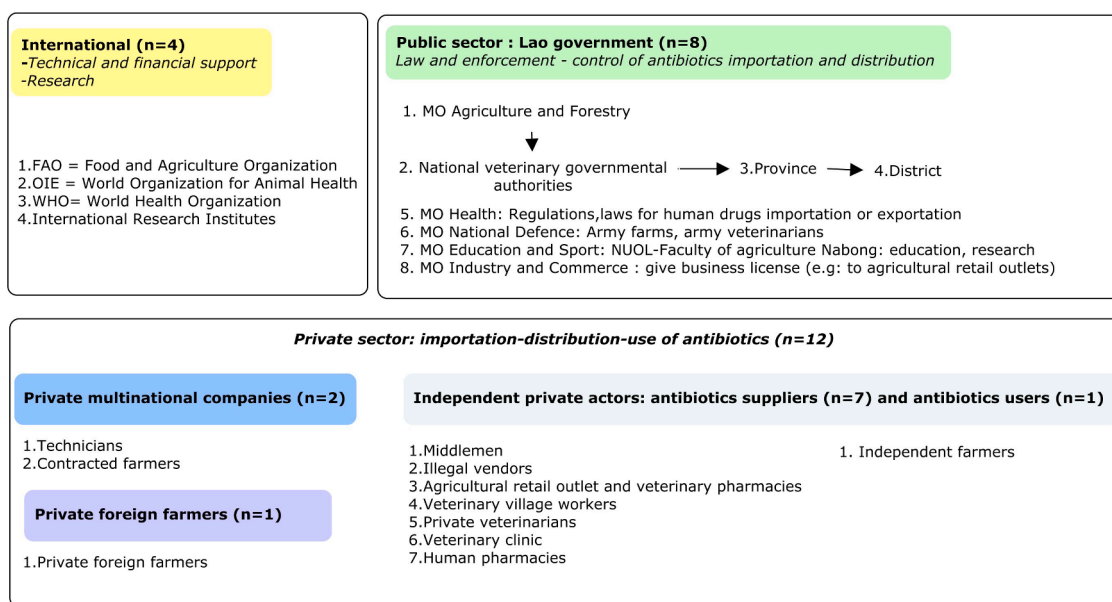


Fig. 2. Presentation of the different groups of stakeholders involved in the veterinary antibiotics supply chain in Lao PDR in 2018. Stakeholders belong to international organization (yellow square), public sector (green square) and private sector (dark blue, light blue and violet squares). MO=Ministry of.; NUOL=National University of Laos

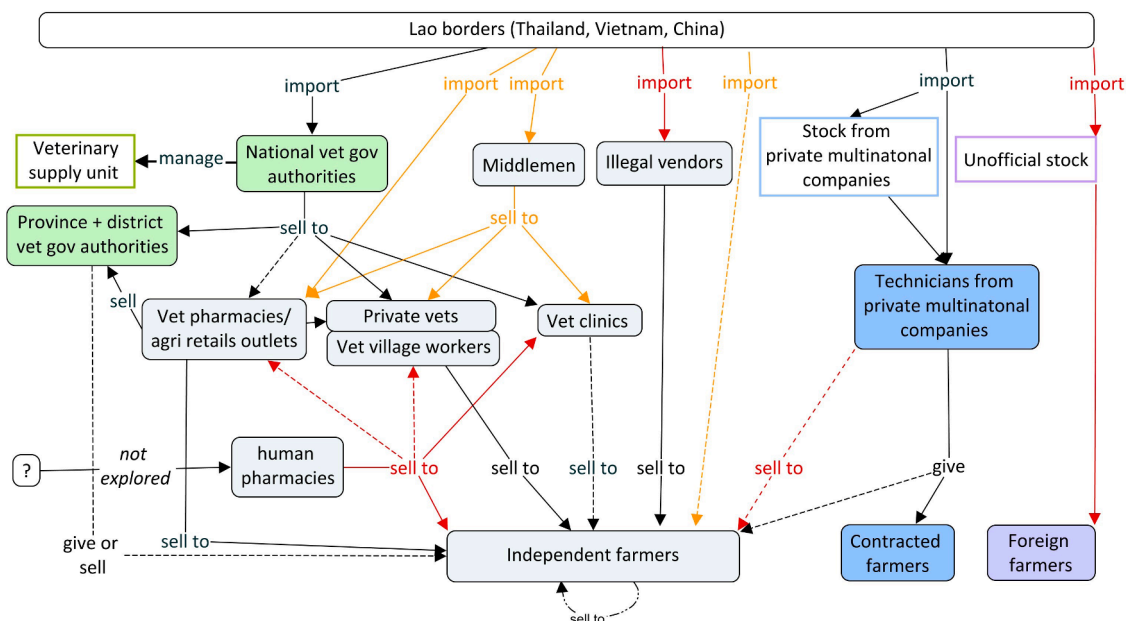


Fig. 3. Mapping of veterinary antibiotics supply chain in Vientiane capital and Vientiane Province, Lao PDR in 2018. Stakeholders were from public sector (green squares) and private sector (dark blue square=private multinational companies, violet squares=private foreign farmers, light blue squares=independent private antibiotics suppliers and users). Formal channels (black arrows) correspond to the supply chain of the stakeholders who paid the veterinary antibiotics taxes to the government, in contrast to informal channels (red arrows). Other informal channels were the sale of human antibiotics from human pharmacies for veterinary usage or the sale of veterinary antibiotics from private companies to independent farmers. Stakeholders could alternate between formal and informal channel (orange arrow). Dotted arrows correspond to infrequent supply chain. The provenance of human antibiotics has not been explored. *Vet*= veterinary. *Vet gov*= veterinary governmental.

"I don't sell the antibiotics; I only support the farmer by giving advice and treatment if needed. I only take care of pigs. [...] I don't earn more if I treat the pigs, and I have a fixed salary. I have a Master's degree in Animal Production. In Lao, there are only seven people employed in this company who are authorised to give advice on antibiotics usage. [...] I am not worried about AMR because my company already encourages farmers to use only small quantities of antibiotics, it has a project for decreasing the ABU for every farm. [...] The Lao government should apply these regulations, so the pigs will be drug-free!" [Interview, a male technician from a multinational company, Vientiane Capital province]

This integrated group seemed isolated from other actors, however, antibiotics from these companies could be sold by the technicians to independent farmers outside the integrated system, through informal channels.

"Another way to gain access to antibiotics is through the employees of multinational companies that also have private businesses and resell antibiotics to other farmers. But they did not give advice or anything. The drugs may have been thrown away by the company as the expiry date was close and the staff take them. But the company is not aware of this." [Interview, a male independent Lao fish farmer, Vientiane Province]

Private foreign farmers

Private foreign farmers were classified as informal stakeholders with a weak level of legitimacy among other stakeholders, who perceived them as big antibiotic users (Table 2).

"Those farmers do not eat their own pigs but eat the pigs from [Lao] local production. Their pigs are toxic food as they use too many drugs!" [Interview, a male member of province staff within the veterinary government authorities]

Foreigners, mostly from China, invested in the country and were involved into pig and freshwater fish production. They contributed to the overall production of meat/fish in the country.

"These foreign farmers have been widely present in my district for approximately 10 years and produce up to 80% of the total number of pigs in this district." [Interview, female staff of the veterinary governmental authorities at district level, Vientiane Capital province]

While production data, number of farms, and volume of antibiotics imported and used were largely unknown, some Lao farmers claimed that foreign farms affected the market prices of animal products.

"We are in conflict with these farmers because they decrease the price of fish and pig products on the market!" [Interview, an independent male Lao fish farmer, Vientiane Province]

The three Chinese fish-farmers interviewed reported that they imported veterinary antibiotics directly from China. This was another informal channel of veterinary antibiotics entering Lao PDR. They also mentioned that Chinese farmer groups had their own feed company in Vientiane Capital. It was unclear if veterinary antibiotics were used in the feeds they produce. The Chinese farmers were aware of AMR but did not consider it to be a problem. They claimed that their overall use of antibiotics was negligible. They never relied on services provided by the district or provincial government veterinary authorities. They expressed objections to the new regulation on prescription requirement to buy antibiotics. They claimed that inaccessibility of antibiotics will impact negatively on fish mortality and overall business performance (Supplementary Table 5).

"(if this regulation is applied) I will stop my business! Here, the vets don't know anything about fish disease and can't give me advice! I totally disagree with the need of a prescription to buy medicine! [...] In my farm, AMR is not a problem because I only use a little [...]. I

Table 2

Classification of stakeholders of the veterinary antibiotics supply chain from the public and private sector in Lao PDR in 2018, according to their legitimacy, resources, and connections.

“+++” = strong; “+” = medium; “-” = weak; “?”=undetermined.

Legitimacy was defined according to the type of channel the stakeholder was using to import and/or sell antibiotics: or formal i.e., controlled and monitored by the government and for which stakeholders pay taxes, or informal. Their level of **resources** was described by their level of knowledge on antibiotic use, good practices and AMR, their qualifications (e.g., education, training, area of expertise) and their ability to provide advice on good practices for antibiotic use. The **connection** was defined by the number of interactions they had within the veterinary antibiotics supply chain.

Stakeholders of the veterinary antibiotics supply chain	Positions and core functions of the stakeholders		
	Legitimacy	Resources	Connections
Public sector-Lao government			
-Ministry of Agriculture and Forestry	+++	+++	+
-National veterinary governmental authorities	+++	+++	+
-Province and district veterinary governmental authorities	+++	+++	+
-Ministry of Health	+++	+++	-
-Ministry of Education	+++	+++	+
-Ministry of National Defence (army farms and army veterinarians)	+++	+++	+
Private sector			
<i>Private multinational companies:</i>			
-technicians	+++	+++	+
-contracted farmers	+++	+	-
<i>Private foreign farm owners:</i>			
-private foreign farmer	-	?	-
<i>Independent private antibiotics suppliers</i>			
-middlemen	+ or -	-	+++
-illegal vendors	-	-	+
-owner or staff of agricultural retail outlet	+	+	+++
-veterinary village workers	+	+	+++
-private veterinarians	+	+++	+
-veterinarians in veterinary clinics	+	+++	+
-human pharmacists	-	+	+++
<i>Independent private antibiotics users</i>			
-independent farmers	+	+	+++

only use enrofloxacin, amoxicillin and vitamins,” [Interview, a female foreign fish farmers, Vientiane Capital province]

These farmers were not directly linked with other actors in the antibiotics supply chain. Most of the antibiotic leaflets were in Chinese and there were no Lao translations. Lao farmers did not use these antibiotics because they could not read the labels or instructions.

Independent antibiotics suppliers (connected with public sector)

Seven types of independent antibiotic suppliers were identified: middlemen, illegal vendors, owners and staff of agricultural retail outlets or veterinary pharmacies, private veterinarians, veterinary village workers, veterinary clinic and human pharmacies (Fig. 1)

Two groups, the middlemen and illegal vendors, were scored with a medium level of legitimacy and were identified by the other stakeholders as potential opponents to the two new regulations, as they were difficult to monitor. Illegal vendors were mentioned as never paying taxes and mainly selling veterinary antibiotics to farmers through direct marketing. The sale of antibiotics could be their only source of income. A middleman was an individual who imported veterinary antibiotics deemed for his “own use” but would subsequently sell them to veterinary pharmacies, agricultural retail outlets and farmers. The profiles of these middlemen were multi-fold, such as fully employed by a shop, occasional importers, or independent farmers. Middlemen seemed to be the key stakeholders who interacted with most of the other stakeholders

and privileged informal channels (i.e., not paying tax), failing to declare the antibiotics at the border control point (Supplementary Table 5).

“Middlemen are like an army of ants bringing veterinary antibiotics into Laos” [Participatory workshop – step 1, private veterinarian]

Four groups of the independent antibiotic suppliers: the owners of agricultural retail outlets, private veterinarians, veterinarians in veterinary clinics and veterinary village workers, were scored with a medium level of legitimacy, and they reported that they supported the new regulations (Supplementary Table 5). Among the 36 surveyed (4 public veterinarians and owner and staff of agricultural retail outlets, private veterinarians and veterinary village workers), almost half started their activity less than 5 years ago, showing the dynamics of these activities and the evolving nature of the veterinary antibiotics supply chain (Table 3). A large majority were male, having a high school or higher education, and about half were between 30 and 50 years old (Table 3). Most of them stated that antibiotics were essential for farmers, and about 20% of them even declared that antibiotics were required as growth promoters. A large majority were concerned about AMR and recognised that they have a role to play in AMR mitigation and that news regulations were needed (Table 3).

The agricultural retail outlets surveyed stated that they obtained antibiotics through middlemen (2/17), foreign distributor antibiotics companies (6/17) and other agricultural retail outlets (9/17) (Fig. 4). None declared to buy antibiotics from the public sector (veterinary government authorities). During the interviews, some of them declared that they ordered antibiotics to be delivered to the Thai border, or that they owned a store of antibiotics in Thailand. These stakeholders stated that they sold veterinary antibiotics over the counter without a prescription or veterinary supervision. They generally thought that farmers used too many antibiotics to treat their animals and that it was necessary to control the quantity of antibiotics used by each farmer. The interviewees were mainly in favour of the new regulations, viewing them as a business opportunity:

“If I employ a veterinarian, it will be really good [sic] for my shop, I will earn more reputation, high credit. There will be a one-hour queue to get into my shop! It would be better, because I have been working for a long time, so I have experience, but I don’t have any

Table 3

The socio-demographic characteristics of the private independent antibiotics suppliers and the public veterinarians surveyed in the step “opinions and practices”, their statement on the need of antibiotics in food animals and their concern for AMR, N=36.

Antibiotics suppliers' characteristics	%	Antibiotics suppliers' characteristics	%
1. Gender		2. Age	
Male	83.3	Young (15 – 30 years)	13.9
Female	16.7	Middle (31 – 50 years)	44.4
3. Education		Old (51 – 65 years)	
Completed master's	16.7	4. Careers	
Completed technical studies or bachelor's	33.3	Public veterinarian from district governmental authorities	11,2
High School	30.6	Agricultural retail outlets	41,7
Middle School	11.1	Private veterinarians	16,7
No school or elementary school	8.4	Veterinary village workers	30.6
5. Experience in selling antibiotics		7. Statement about their concern for AMR	
Less than 5 years	44.4	1. I am concerned by AMR problems	69.5
More than 5 years to 10 years	22.2	2. I have a role to play in the fight against AMR	91.7
Over 10 years	33.3	3. New regulations need to be implemented in Lao	80.6
6. Statement about the need of antibiotics in food animals			
1. They are necessary for disease prevention	80.6		
2. It is not possible for a farmer to raise animals without antibiotics	61,1		
3. Antibiotics are necessary as growth promoters	19.4		

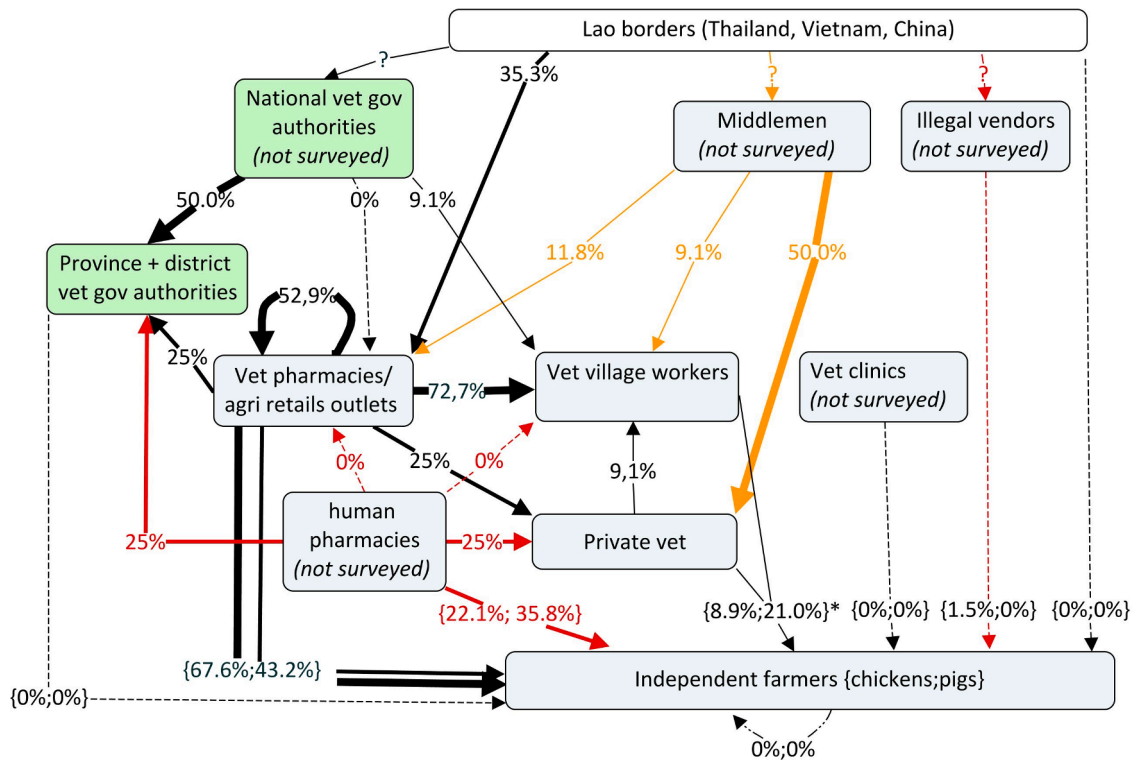


Fig. 4. Quantification of supply chain of the public sector and independent private actors groups based on the data obtained from the questionnaires. Those data were obtained during the step 3 opinions and practices: n=4 public veterinarians at district level, n=17 agricultural retail outlets, n=4 private veterinarians, n=11 veterinary village workers. The percentage results should be interpreted with caution, as the number of actors surveyed was relatively small. Only the farmers who mentioned buying antibiotics were included: n=73/96 chicken farmers, and n=83/96 pig farmers. The interrogation points mean that the data were not investigated. Dotted arrows: <2% of related survey participant mentioned this channel, thin arrows: 3-21%, intermediate arrows: 22-49%, thick arrows >50%. For the colors of the arrows and squares, see Fig. 3

*the private veterinarians and veterinary village workers were not differentiated in the questionnaires for farmers as the farmers did not always distinguish them

proper qualifications, sometimes I don't know how to help farmers! [...] I am not afraid about spending money to employ a vet because I am sure I will have many more clients. I even thought about doing this before the regulations." [Interview, owner of an agricultural retail outlets, Vientiane Capital province]

The veterinary village workers were technicians trained by the public sector (provincial or district veterinary governmental authorities). They stated that they treated animals and sold veterinary products such as vaccines to farmers, but few antibiotics. During the questionnaire survey, they stated that they obtained antibiotics from the public sector (veterinary supply unit, 1/11), or the private sectors such as agricultural retail outlets (8/11), private veterinarians (1/11), or middleman (1/11) (Fig. 4). They declared that they had another job at the same time (e.g., farming, business). They reported their limited ability to provide advice to producers. They mentioned that they were aware of AMR thanks to their own experience in the field and various information sessions (e.g., in the University of Agriculture). They thought it was a good idea that veterinary governmental authorities start to fight against AMR and hoped to receive training to be able to write prescriptions.

"I don't earn much money by helping farmers, and I give my own treatment, I never sell antibiotics to them. Most of the time I am a farmer, I grow rice. [...] I would be really interested in receiving some training from veterinary governmental authorities to have the right to write a prescription. I am too isolated at the moment, I don't receive any help from the government. [...] 3 or 4 years ago, there were about 100 cows in my village, but now they are about 400 cows. Last year, there was a disease outbreak and I was left alone to deal

with it. I couldn't help everybody!" [Interview, a veterinary village worker, Vientiane Capital province]

The private veterinarians surveyed stated that they obtained antibiotics from the private sector, such as agricultural retail outlets (1/4), middleman (2/4), and human pharmacies (1/4) (Fig. 4). The owner of the veterinary clinic interviewed appeared to be supportive of the anticipated changes in veterinary antibiotics laws and its enforcement. He believed that it would not affect his business, seeing an opportunity to increase his legitimacy to sell antibiotics.

The independent private antibiotics suppliers interacted with the public sector (Fig. 3 and 4). The public veterinarians from the district governmental authorities surveyed obtained antibiotics from the national governmental authorities (veterinary supply, 2/4), agricultural retail outlets (1/4) and human pharmacies (1/4) (Fig. 4).

The independent antibiotics suppliers interacted with the independent users (farmers) by selling them antibiotics or advising them on the use of antibiotics (Fig. 3).

Independent antibiotic users, farmers (connected with public sector)

Most of the surveyed farmers were full-time, which showed that they relied solely on livestock production for their income. Most of the farmers were female, with a level of education split between no school, primary school, secondary school or high school (Table 4). Most chicken farmers were more than 50 years old, while many pig farmers were between 30 and 50 years old. About a third of the pig farmers had less than 10 years of experience in the business while about quarter of them started less than two years ago. This shows the diversity of livestock experience among the survey participants and the dynamics of farm activities.

Table 4

The socio-demographic characteristics of the independent chicken and pig farmers surveyed in the step "opinions and practices"; n=96 chicken farmers, n=96 pig farmers

Population	Chicken farmers (%) %	Pig farmers (%) %
1. Location		
Vientiane Capital	80.2	52.1
Vientiane Province	19.8	47.9
2. Gender		
Male	36.8	37.5
Female	63.2	62.5
3. Age		
Young (15 – 30)	6.2	10.5
Middle (31 – 50)	41.2	63.2
Old (51 – 65)	51.5	26.3
4. Education		
Illiterate/no school	16.7	11.6
Primary school	38.5	25.3
Secondary school	18.8	24.2
High School or vocational studies	21.9	31.9
University or above	4.2	7.4
5. Careers		
Full time farmers	68.7	68.7
Independent worker	10.3	13.7
Governmental staff	10.3	8.4
Retired, housewife	10.3	9.5
6. Age of this activity		
Less than 2 year	14.4	25.5
More than 2 years to 10 years	22.6	37.5
Over 10 years	62.5	37.5

Surveyed independent farmers had flocks of between 7 and 200 chickens (mean of 57 heads) and herds between 2 and 160 pigs (mean of 20 heads). Most of farmers (60%) also kept other animals (Table 5). Most of the chicken flocks were free range or both caged and free-range while most of the pig herds were kept in pens or stables. Indigenous breeds were predominant for chickens, whereas pigs were equally distributed between indigenous, exotic, and cross breeds. Some of the farmers used commercial feed, however no antibiotics Fig.d in the ingredients of the commercial feed found in the farms surveyed (Table 5).

About half of the farmers declared that a health problem had occurred in their flock within the past 12 months. Only a few of the farmers could name the disease: avian influenza, fowl cholera, Newcastle disease, acute death and enteric disease in chickens; and enteric disease and classical swine fever in pigs. A minority declared that they vaccinate their chicken flocks (19.6%) or pig herds (44.6%) (Table 5).

In the event of disease outbreak, a minority of the farmers declared that they first called a veterinarian or a veterinary village worker, and about a quarter said that they treated their sick animals with antibiotics by themselves. Around half of the farmers declared that they used antibiotics for their animals (more in pig farms than chicken farms). The utilisation of antibiotics was associated to the breed of the pigs: farmers who kept indigenous pigs used less antibiotic than farmers who kept exotic breeds (p-value <0.01). It was also correlated to the number of chickens kept; chicken farmers with less than 10 chickens tended to use less antibiotic (p<0.01) (Table 5). The majority of the antibiotics found at the farms (16/29 in chicken farms and 54/73 in pig farms) were critically important antibiotics used in human medicine, such as amoxicillin, ampicillin, gentamicin, enrofloxacin, norfloxacin, ciprofloxacin, tylosin, or combinations of spiramycin-tylosin-colistin and penicillin-streptomycin (World Health Organization, 2019) (Table 6).

The farmers stated that antibiotics were necessary for their livestock for several reasons: presence of abnormal signs, growth problems, sick neighbouring animals, or depending on advice from relatives.

Most of the farmers surveyed mentioned that before using antibiotics, they sought advice from veterinarians or veterinary village workers (mainly the pig farmers), agricultural retail outlets, or relatives/other farmers (Table 5). In some districts, there were commodity-

Table 5

The farm characteristics, and opinion and practices on antibiotic use and antimicrobial resistance of the independent chicken and pig farmers surveyed in the step "opinions and practices"; n= 96 chicken farmers, n=96 pig farmers.

Farm characteristic, opinion and practices	Chickens (%)	Pigs (%)	Farm characteristic, opinion and practices	Chickens (%)	Pigs (%)
1. How the animals are kept?			2. Other animals kept at the farm (several answers possible)		
- Pens or stable	17.4	75.50	-None	32.6	27.4
- Mix: pens and free range	38	20.2	- Pigs	10.5	-
- Free-range	42.7	1.1	- Chickens	-	20
- Cage	2.1	-	- Ducks	47.4	55.8
			- Buffaloes/cows	23.2	20
			- Other (fishes, goats)	7.4	10.5
3. Use of antibiotics or vaccines			4. Species of animal kept		
Antibiotics	48.9	60.0	- Indigenous	94.8	33.7
Vaccination	19.6	44.6	- Exotic	5.2	28.4
			- Cross breed	4.1	36.8
5. Health problem in the flock/herd last 12 months			5.2 If yes, name of the last disease		
Yes	58.8	46.9	-Acute death	35.3	-
5.1 If yes, how many disease events during the last 12 months?			- Fowl cholera	4.9	-
→1	86.0	80.6	- Newcastle	5.9	-
→2	5.3	16.7	- Avian Influenza	5.9	-
→3 or more	8.8	2.8	-Diarrhoea (E. coli, salmonellosis)	4.9	47.6
			-Classical swine fever	-	9.5
6. When facing a disease, what do you first do?			7. Opinion on the need of antibiotic use in their livestock		
-Isolate the sick animals	56.2	24.5	-When they have any abnormal symptoms	81.2	85.9
-Treat the sick animals with antibiotics by themselves	31.2	25.5	-When they do not show any improvement in growth	44.3	34.5
-Call a veterinarian or a veterinary village worker	13.5	41.5	-When the animals in other farms within the village start to get sick	75.0	86.6
-Ask relatives or other farmers for advice	6.2	9.6	-When farmers or a relative advises them to use it	62.6	61.3
8. Seek advice before using antibiotics?			9. Source of antibiotics (for those who used them)		
1.yes	81.4	89.0	-Agricultural retail outlets	67.6	43.2
8.1 If yes, to whom?			-Human pharmacies	22.1	35.8
-Veterinarians or veterinary village workers	37.1	68.5	-Veterinarians/ veterinary village workers	8.9	21.0
-Agricultural retail outlets	31.4	21.9	-Illegal vendor	1.5	0.0
-Relatives or other farmers	18.5	21.9			

specific associations, such as the broiler farmers' association or the fish farmers association. Within these associations, farmers mentioned that they were able to better market their products (e.g., restaurants, hotels, local market), to discuss strategies to optimise profits (i.e., strategic marketing such as scheduled marketing of products ensuring a consistent supply that matches the local demand), to share their experiences of diseases and to give advice on how to treat animals.

Table 6

Classification of the antibiotics found in the surveyed chicken and pig farms at the time of the farm visit. Photos were taken of veterinary drugs that independent farmers, among the 96 chicken farmers and 96 pig farmers surveyed, were willing to show during the interviews. Antibiotic were identified according to the label, leaflet, or packaging. Classification was done according to the list of critically important antimicrobials for human medicine from World Health Organization (World Health Organization, 2019). This classification relies on two criteria C1 and C2. C1: The antibiotic class is the sole, or one of limited available therapies, to treat serious bacterial infections in people. C2: The antibiotic class is used to treat infections caused by bacteria possibly transmitted from non-human sources, or with resistance genes from non-human sources. The **critically important antibiotics** for human medicine are antibiotics classes which meet both C1 and C2. The **highly important antibiotics** for human medicine are antibiotics classes which meet either C1 or C2.

Grouping of antibiotics	Antibiotic class	Antibiotic agent	Chicken farms (n)	Pig farms (n)
Critically important	Penicillin	Amoxicillin	4	17
		Ampicillin	5	0
	Aminoglycosides	Gentamicin	1	9
		Fluoroquinolones	Enrofloxacin	1
	Norfloxacin		2	1
	Ciprofloxacin		0	1
	Tylosin		0	2
	Macrolides	Spiramycin-tylosin-colistin	1	0
			Penamycin-streptomycin	2
	Combination of highly and critically important	Penicillin and aminoglycosides combination	Oxytetracycline	10
Chlortetracycline			2	0
Highly important	Tetracyclines	Thiamphenicol-oxytetracycline	0	2
		Undetermined *	1	3
		Total (N)	29	73

* Some of the antibiotics found in the farms surveyed could not be identified, either because they were written in Chinese or because the photos taken were of poor quality.

“We (members of the broiler group) share the restaurants where we sell the meat. We always discuss our experience of a disease and how to treat it. In this group, we have a big farm owner and he has a great deal of knowledge, he is an unofficial veterinary village worker: he goes to the farms and give advice. [...] Those regulations are not a good idea. The antibiotics are really helpful for the farms, if we don't use them, the chicken will die, or grow slowly!” [Interview, broiler farmer and chief of the broiler group of one district, Vientiane Province]

There were many ways for an independent farmer to obtain antibiotics. The most common practices mentioned during the survey were the purchase of antibiotics from agricultural retail outlets, then human pharmacies and then from a veterinarians or veterinary village workers (Table 5, Fig. 4). A farmer might also sell his antibiotics within his network (e.g., neighbours, other farmers). Current regulations on access to antibiotics was unclear amongst farmers. There was a general lack of awareness as to whether they were using antibiotics in line with the regulations.

“I don't really know if what I am doing is legal or not because the regulations are not at all clear for me” [Focus group discussion, independent pig farmers]

Almost all the farmers interviewed had heard about AMR. They all agreed that new regulations were needed and they wanted to improve their antibiotic use practices by having access to veterinary diagnostics. However, farmers interviewed stated that they had poor access to veterinarian advice. They reported that veterinarians and staff from the veterinary governmental authorities were difficult to reach and seem concerned that this new regulation would lead to restricted access to antibiotics.

“I think it will be really difficult to apply this law [...] I am really afraid that this process will take a really long time and that veterinarians will not be available. Vets are difficult to reach, they don't answer the phone, especially in rural area. A few farmers have already had a bad experience where the vet never came to their farms. [...] That's why most of the time we try to treat sick animals by ourselves, if not, our animals die, and the disease can spread really quickly.” [Interview, independent poultry farmer, Vientiane Capital province]

Discussion

The nature of this study was exploratory, with the aim of obtaining an overall picture of the stakeholder groups related to the issue of AMR in food animals in Lao PDR (Hinchliffe et al., 2018). This study brought some understanding of the inputs of this complex adaptive system, i.e. the stakeholder groups within the veterinary antibiotic supply chain and their interactions. This study also explored the stakeholder's perception of AMR and AMR mitigation (expected impact) and of the objective of new regulations (expected outcomes). This study also investigated the stakeholders' interests and constraints they would face if the new regulations on access and use of antibiotics were implemented (the outputs) in relation to their livelihood strategies.

The stakeholder groups (inputs) and their vision of the expected outcomes and expected impact

The inputs of this complex adaptive system were composed of 23 categories of stakeholders involved in the veterinary antibiotics supply chain, with different level of legitimacy and resources. These stakeholders operated in four main groups which were weakly connected.

The stakeholders from the group “public sector” were poorly investigated.

The stakeholders from the group “private multinational companies” shared the objective of AMR mitigation. The stakeholders from the group “private foreign farmers” were not concerned with the issue of AMR. The foreign farmers also showed a general mistrust towards veterinary government authorities. As there is very little data on private foreign farmers, it would be important to organise a census of them. This would enable a better investigation of the dynamics of this group (i.e., farmers practices and strategies, group of influence) and further investigation of the overall role of the importation channel (estimated quantity, quality of products, other players involved). Even if this group appears to be completely independent from other stakeholders, their farm products are sold in Lao PDR markets and seem to influence the local economy and demand. We may draw the hypothesis that this “informal channel” influences the strategies of local farmers in their attempt to remain competitive, and thus, influencing their decision making related to antibiotics use.

The stakeholders from the private independent group were independent antibiotics suppliers and independent farmers. They shared the objective of AMR mitigation but also mentioned the important need to

use antibiotics in food animals, including those that are deemed as critically important to human medicine.

The potential interest and constraints among stakeholders that might influence the causal link between the output and the expected outcomes

The stakeholders involved in the “private multinational companies” group stated that they were supportive of the anticipated changes in AMU regulations. They appeared to have the capacity and experience to adapt to regulatory changes. Their economic strategies would be strengthened by increasing their legitimacy in the food chain in Lao PDR. The advantageous position that multinationals can take in the implementation of new regulations was studied in the pig sector during changing governance of AMR in Denmark (Food and Agriculture Organization of the United Nations, 2019; Jacobsen et al., 2006) and during the avian influenza episode in Vietnam in 2003 (Figuíé et al., 2013).

The private foreign farmers positioned themselves clearly against the new regulations. Our study also highlighted the crucial role of middlemen in the veterinary antibiotics importation process. Middlemen were hard to monitor and were potential opponents of new regulations.

The owners of agricultural retail outlets were supportive of new regulations and claimed that they would employ qualified veterinarians. This might only be true for big shops. Smaller shop owners may continue selling antibiotics illegally because of the cost of hiring a full-time licensed veterinarian.

Independent farmers were not opposed to new regulations, but they were concerned and have doubts as to the feasibility of implementing them (e.g., asking for a prescription to buy antibiotics). In line with the framework proposed by Lhermie et al. (2017), we have highlighted several elements that influenced the farmers’ decision-making process to buy and use antibiotics. These elements may concern the farmer, for example, his appreciation of the risk of disease in his environment, his experiment and his attitude towards risk (Lhermie et al., 2017). Indeed, the treatment strategies of farmers depended on contextual elements, such as the disease outbreak among their flocks/herd or in neighbouring flocks/herds. Others elements may concern the institutional environment, such as the multi-national companies with contracted farmers, the presence of veterinary governmental authorities or veterinary village workers (Lhermie et al., 2017). Farmers mentioned the weak presence of veterinary services in rural area, and depending on their perceptions of epidemic risks and on their past experience, farmers felt forced to treat their animals. It would be necessary to provide veterinary extension services and training of veterinary village workers to support the farmers. This represents a needed additional output, in parallel to the development of the new regulations.

In our study, the decision-making process to buy and use antibiotics among independent farmers was also influenced by their relatives/family groups and farmers’ association groups (Masud et al., 2020) and by the need for high productivity (“otherwise our chickens will not grow”). The need of productivity may be linked to the competitiveness of their products on the market. The need to remain competitive to survive in the economic market was not proposed in the framework of Lhermie et al. (2017), but we assume that in our study this element was important. A better understanding of the strategies of farmers, their groups of influence and their rearing practices (e.g., multi-species production, free-range production, and waste management) would help to construct a sustainable AMR mitigation plan.

Limitations of the study and perspectives

We are aware that some results might have been distorted by several factors and should hence be interpreted with caution. The translation of the different recordings and the subjective form of the method, which is based on stakeholders’ willingness to respond to questions and interact with researchers, limits the reliability of our results (Schmeer, 1999). The categorisation of the key, primary and secondary stakeholders is

somewhat subjective and could differ according to the composition of the research team. However, this should not affect the main conclusions regarding the stakeholders investigated. We only interviewed 2 “middlemen” stakeholders: as their activity is informal, most people interviewed denied that they acted as “middlemen”. For private foreign farmers, we only interviewed fish farmers as the Chinese pig farmers refused to be interviewed. Language was a clear barrier for the research team in understanding the role of the private foreign farmers and importers because most of them do not speak Lao. The opinion of other stakeholders on private foreign farmers and the visit of their farms would lead us to believe that their position is similar to that of the fish farmers. Finally, the survey area is close to the border of Thailand and may not be reflective of the other provinces of Lao PDR, such as provinces bordering China, where the composition of multinational private companies could be different. This limited study nevertheless illustrated the highly dynamic and heterogeneous nature of stakeholders involved in the veterinary supply chain in Lao PDR.

The provenance of human antibiotics sold by human pharmacies and accessed by farmers has not been explored. Furthermore, the public sector has not been fully investigated (semi-structured interview=1, questionnaires=4), and future studies should focus on veterinary governmental authorities at different levels (national, district, local). The questionnaire survey did not include contracted farmers from private companies, private foreign farmers, neither fish nor bovine farmers and those population should be investigated.

Governance of AMR mitigation

By considering the AMR issue in the light of stakeholder groups, this study identified some key elements that might influence the success of the implementation of new veterinary antibiotic regulations. Beyond the description of the veterinary antibiotics supply chain, we investigated three groups of stakeholders, and the relations and connections that influenced their decision-making on antibiotics. We also highlighted that these groups are dynamic and evolve with the context. Consistent with other low-income countries with weak enforcement of veterinary regulations, the sales of veterinary or human antibiotics for veterinary use, were largely over the counter (Mutua et al., 2020; Shryock, 2012). We believe that under current conditions in Lao PDR, relying solely on regulatory enforcement of veterinary antibiotic sales and use may not be enough. Several stakeholders indicated accessing human antibiotics in human pharmacies without prescription, including staff of district veterinary governmental authorities, even if it is forbidden by law. Furthermore, our study highlighted the lack of farmer knowledge regarding current regulations on access to antibiotics; low awareness of existing laws and regulations among the population of Lao PDR is also reported in another study (Jönsson et al., 2015).

We believed that an appropriate AMR governance system should be based on place based governance that takes into account the uncertainty around changes and builds upon multi-stakeholder inputs to establish an effective AMR risk reduction strategy (Chhotray and Stoker, 2009; Hinchliffe et al., 2018). Moreover, a study for the health sector reform in Lao PDR showed that diverse stakeholder groups should be involved in policy design and implementation in order to increase the probability of a sustainable and successful reform (Phillips et al., 2016). Indeed, it would seem that policies would be more successful if it were recognised that they require the active participation of stakeholders and if the latter were actively involved in the process of drafting and implementing the policies (Salve et al., 2018). A place based governance would allow the construction a common understanding of AMR strategy (the expected impact) by truly involving the stakeholders identified, engaging them in dialogue about the objective of new regulations. It would be interesting to learn from similar experiences (Zaidi et al., 2015). We argue that stakeholders involved in the veterinary antibiotics supply chain should be included in developing an AMR strategy, including stakeholders from the public and private sector, involved in the importation and in the sale

of antimicrobials such as antibiotics. To expect successful implementation of the new regulations, we believe that the public sector (i.e. the Lao government and the veterinary government authorities), would have to collaborate with the private sector (private multinational companies, independent antibiotics suppliers, independent farmers) and monitor the informal stakeholders. Other studies have shown the important role played by the private sector in veterinary program, such as in the surveillance of Highly Pathogenic Avian Influenza in Vietnam (Delabouglière et al., 2015). Since 2019, studies have focused on collaboration between public and private sector to manage animal health programs. These collaborations are called public-private partnerships in the veterinary domain (Galière et al., 2019). It would be interesting to identify public-private partnerships that aim to adapt and reduce the sale and use of veterinary antibiotics in Southeast Asian countries, to learn from their collaborative experiences.

Theory of change

The use of theory of change is becoming increasingly popular in the public health field, but, to our knowledge, has not been applied to an AMR mitigation program (Breuer, 2016). In particular, theory of change has not yet been applied to an AMR mitigation program in the veterinary sector, although its value has been noted (Mutua et al., 2020). This study represents the first attempt to use the theory of change for AMR mitigation in the veterinary domain. However, we used a simplified theory of change, as the link between outcomes and impacts was not explored. Furthermore, the impact pathway was not made explicit during the study and was drawn by the researchers during data analysis. It would be necessary to co-develop the impact pathway and co-explicit the causal links between inputs, outputs, outcomes and impacts with stakeholders identified in this study. Our study represent an ex-ante analysis of the situation, and the theory of change can be mobilized in itinere or ex post, to have a follow-up of the intervention program (Blundo Canto et al., 2018).

Conclusion

Contrary to studies focusing on the irrational use of antibiotics by farmers, this study adopted the perspective of multiple stakeholders, seeking to anticipate difficulties in the implementation of new regulations related to access and use of veterinary antibiotics. By applying a simplified theory of change we were able to analyse the situation as a complex adaptive system and thus to reinforce the consideration of the different stakeholders. Further participatory methods would be required to obtain a more complex theory of change, which would reflect the issues at stake and elicit ways of overcoming the obstacles to the desired changes. We believed that a sustainable strategy to reduce AMR risks should be co-constructed with the stakeholders identified. The dialogue and engagement of identified public and private sector stakeholders, through a public-private collaboration, would allow for the development of context-specific strategies. We also argue that research teams should use of the theory of change to support governments and stakeholders in implementing AMR mitigation plans, such as the reduced and appropriate use and sale of veterinary antibiotics.

Data Availability Statements

The data relative to the statistics on Lao farms analysed in this study was obtained from the Department of Livestock and fisheries of the Ministry of Agriculture and Ministry of Lao PDR. Requests to access these datasets should be directed to their office laodlf@gmail.com. The raw data supporting the conclusions of this article, the transcripts of the interviews, the pictures and the transcripts of the participatory workshop will be made available by the authors, without undue reservation.

Ethical considerations

This study had no direct relevance to issues pertaining to human health, as such, the Lao Ministry of Health's ethics committee was not able to review our study. Instead, the study was reviewed and approved by Kasetsart University Ethics Committee, Bangkok, Thailand on the 14th of September 2018 (KUREC.HS6T/023). Information sessions were held with various government groups that consisted of the heads of the Vientiane Capital City and Vientiane Province provincial livestock and fisheries, and the heads of Xaythany, Naxaythong, PhongHong, KeoOudom district livestock and fisheries offices. The context, goals, and the methodology of the study were shared; the purpose of these sessions were also to obtain additional inputs towards the refinement of the tools and methodology. An official authorisation at provincial and district level, allowing us to work on those areas, was then obtained. The participation in the workshop with key stakeholders was voluntary. Participation during the third step of our study was also voluntary through semi-structured individual interviews and through the focus group discussion with the stakeholders, and a written and informed consent, explaining the context of the study and guarantying the anonymity, was signed by each participant. No names or pictures of participants were recorded in the transcripts.

CRediT authorship contribution statement

M. Poupaud: Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft. **V. Putthana:** Investigation, Resources, Writing - review & editing. **A. Patriarchi:** Project administration, Resources, Writing - review & editing. **D. Caro:** Project administration, Resources, Writing - review & editing. **A. Agunos:** Project administration, Funding acquisition, Writing - review & editing. **N. Tansakul:** Conceptualization, Methodology, Writing - review & editing. **F.L. Goutard:** Conceptualization, Methodology, Validation, Supervision, Writing - review & editing.

Declaration of Competing Interest

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Supplementary materials

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