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ORIGINAL ARTICLE

Different kettles of fish: Varying patterns of antibiotic use on pig, chicken and fish farms in Lao PDR and implications for antimicrobial resistance strategies

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Summary

The rapid intensification of the livestock sector in Southeast Asia has been found to be associated with an expanding use of antibiotics (ABU) and the rise of antimicrobial resistance (AMR) in both humans and livestock. This study aimed to explore the views and practices of commercial pig, poultry and fish farmers regarding antibiotics in Lao People's Democratic Republic, where data on antibiotic use and AMR remain scarce. A multistage cluster sampling method, based on the random selection of villages in two provinces of Vientiane, was used. A total of 364 farmers, corresponding to 454 farm units, were surveyed using a questionnaire and farm visits. This study found a widespread use of antibiotics (261 out of the 454 farm units used antibiotics). The predominance of antibiotics considered critically important antibiotics for human medicine was of great concern. Results from a logistic regression model showed that antibiotics were found less frequently in fish farm units compared to pig and poultry farm units, and more frequently in specialized farms than in livestock-fish farms. Multiple factor analysis and hierarchical cluster analysis revealed three profiles of farmers, each with distinct patterns on knowledge, attitudes and practices regarding ABU and AMR. Cluster 1 held a positive attitude regarding preventive measures and information about antibiotics. In cluster 2, there was a view that antibiotics should be used for prophylactic treatment such as disease prevention. Cluster 3 was characterized by farmers with weak knowledge who were unfamiliar with antibiotics and uncertain about details concerning antibiotic use. This cluster was associated with a significantly lower use of antibiotics than the two other clusters in the regression model. The results of this study may help the Laotian government to adapt strategies to control AMR by focusing on the use of critical antibiotics and prophylactic treatments and by tailoring measures to farmers' profiles.

KEYWORDS
antimicrobial resistance, behaviour, knowledge–attitude–practices, livestock, stewardship

1 | INTRODUCTION

Antimicrobial resistance (AMR) is a natural phenomenon partly exacerbated by the misuse and overuse of antimicrobials, including antibiotics, to treat humans and terrestrial and aquatic animals and plants (Martin et al., 2015). The use of antibiotics (ABU) on animals exerts a selection pressure on bacteria, which may favour the selection of resistance genes in the food chain (Bennani et al., 2020). Reducing the misuse and overuse of antibiotics in livestock is one of the actions promoted by international organizations to tackle AMR (Food and Agriculture Organization of the United Nations, 2016). This strategy is supported by a growing body of evidence suggesting that interventions leading to a reduced ABU in livestock production are associated with a decrease of antibiotic-resistant bacteria in human populations living near food animals (Tang et al., 2017).

Lao People's Democratic Republic (Lao PDR) remains an agrarian society with two thirds of the labour force engaged in agriculture (The World Bank Group, 2017). Poultry and pig farming play an important role in the nutrition and household economy of rural communities. In both sectors, the average farm size is increasing, and the commercial production appears to be growing (Keonouchanh & Dengkhounxay, 2017). Fish are the primary source of protein for rural populations. Livestock-fish farms are common, with pigs and chickens kept above fishponds fertilized with their manure (Mekong River Commission, 2013).

In Southeast Asia, the intensification of farming systems due to increasing demand for livestock products is leading to a wider ABU in livestock production, with a consequent widespread increase of AMR (Van Boeckel et al., 2015). Data on ABU and AMR remain scarce in Lao PDR, as in most low and middle-income countries. However, bacteria isolated from pigs and humans have been found to carry different AMR genes in the capital city Vientiane (Sinwat et al., 2016; Thu et al., 2019).

Potential drivers of increasing AMR include weak regulatory frameworks on ABU in livestock production, weak enforcement guidelines and low levels of AMR awareness (Goutard et al., 2017). The Lao PDR government designed a National Action Plan in 2018 and developed new regulations on the usage and access to antibiotics, including veterinary antibiotics (Ministry of Agriculture and Forestry, 2020). However, regulations may not be sufficient to decrease AMR risks. In Lao PDR, despite this successful formulation of policy regulating access to antibiotics in the human health sector, laws are not strictly followed or implemented (Paphassarang et al., 2002; Jönsson et al., 2015). To be effective, health strategies must understand and rely on quality data covering the knowledge, skills, priorities and practices of actors and should recognize the various constraints on human behaviour (Panter-Brick et al., 2006). Knowledge, attitudes and practices (KAP) surveys provide a methodological framework that can be used to analyse behavioural patterns and thus better tailor public health interventions to stakeholders' needs. In Lao PDR, this framework was used to guide the foot-and-mouth disease vaccination program (Nampanya et al., 2018), as well as to provide health authorities information to improve physicians' antibiotic prescription practices (Quet et al., 2015). KAP surveys have been used to document drivers for ABU and inform AMR control strategies in livestock production in Southern countries, including Southeast Asia. Previous work showed that ruminant farmers in Malaysia were little aware of the prudent use of antibiotics and the impact of AMR on animal and human health and suggested that given the heterogeneity observed in awareness and perception, efforts should be adjusted to farmers' experience and herd size. A low awareness of the risks and consequences of AMR also was observed in small-scale urban pig farms in Cambodia. A recent study carried out on a large sample of farmers specialized in pig, poultry and aquaculture production in Vietnam showed that only a small proportion of farmers had favourable attitudes towards ABU and AMR prevention (Pham-Duc et al., 2019). This study also evidenced contrasting KAP according to the species farmed, although these divergent trends regarding species were not always consistent across the themes considered in the analysis. Together, these results indicate that there are numerous, frequently interrelated factors underlying ABU on farms which form a complex constellation, rendering it extremely challenging to isolate the effect of a single variable.

The paucity of data and information available in Southern countries, including Lao PDR, on ABU across livestock production sectors, as well as on farmers' motives for using antibiotics, may hinder efforts to adapt an overall strategy to reduce the sale and use of veterinary antibiotics. In this context, this study aimed to (1) characterize the KAP of farmers regarding ABU in four different livestock production sectors (poultry, pigs, fish and livestock-fish farms) in two provinces of Lao PDR and (2) analyse the relationship between farm characteristics and ABU in these four sectors.

2 | METHODS

2.1 | Target population

Four populations were included: poultry (broilers and layers) farms, pig farms, fish farms (corresponding to farms with fishponds and/or fish-cages) and livestock-fish farms corresponding to pig–fish and poultry (layer, broiler or duck)-fish farms. Commercial farms, that is farms of any size where eggs, meat or fish products are sold in markets, restaurants or companies, were targeted. Backyard chicken and pig farmers keeping livestock for their own or friends' consumption were not included. Large integrated production systems, where farmers are contracted by a large private company, were also not included as no official data of these farms were available.

2.2 | Study design

Two provinces of Vientiane with the largest number of commercial livestock and fish farms in Lao PDR (Vientiane Province and Vientiane Capital Province) were chosen. Using data obtained from the Ministry of Agriculture, two districts in Vientiane Capital Province (Xaythany and Naxaythong) and three districts in Vientiane Province (KeoOudom,

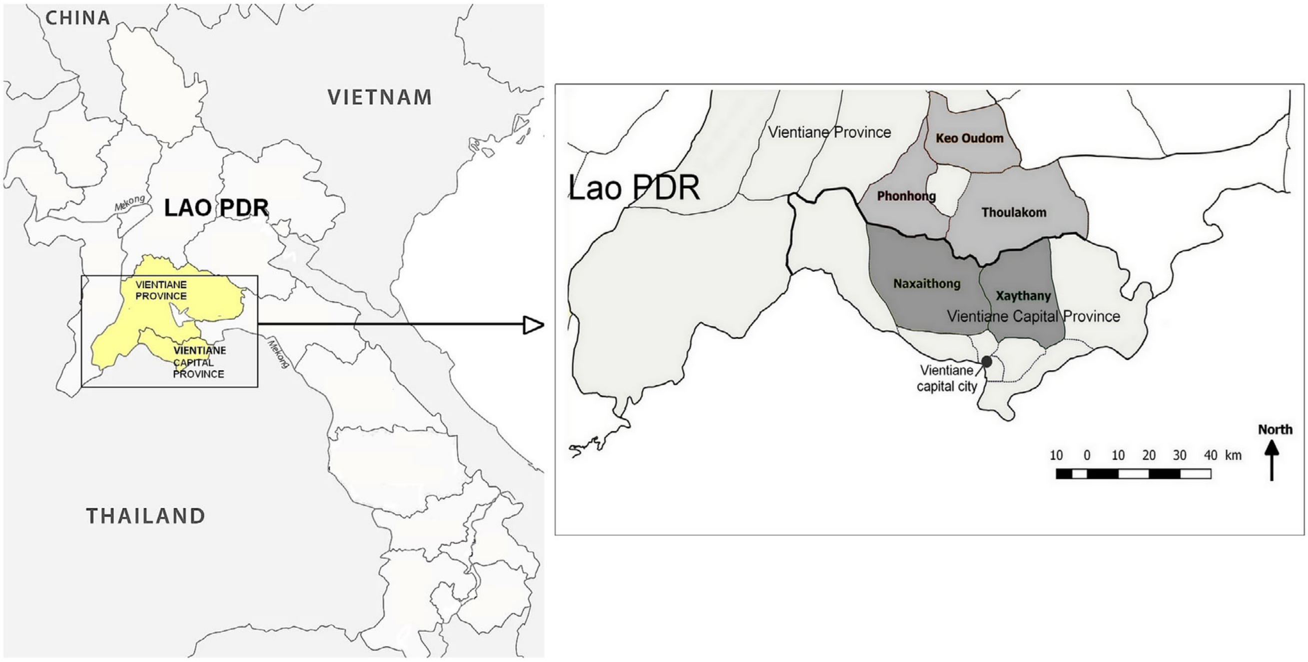

FIGURE 1 Map of Lao People's Democratic Republic (Lao PDR) showing the two provinces (in light grey) and the five districts selected for the 2018 survey

Thoulakom and Phonhong) were selected based on the large number of farms in these areas (Figure 1).

Sampling calculations were done considering the national number of farms, a prevalence of 50%, a confidence interval of 95% and an accepted error of 7% (Supporting Information Appendix 1). A multi-stage cluster sampling method was used, with 1 to 15 villages randomly selected for each of the 5 districts. Farmers were identified with the help of village heads. Participants included in the survey were above the age of 18 and gave their individual oral consent.

2.3 | Questionnaire

The research team developed four KAP questionnaires (one for each population) containing closed and open-ended questions. KAP questionnaires are based on the health belief model developed in the 1950s to predict and explain health behaviours. The hypothesis of this model is that a potential obstacle to behaviour change may be a lack of knowledge of the benefits of new practices, or a lack of knowledge of the problem and its severity (Maiman & Becker, 1974).

One questionnaire was developed for each farm category (poultry farms, pig farms, farms, livestock-fish farms). The questionnaires were based on a common structure, which consisted of six sections: (i) sociodemographics, (ii) farm characteristics, (iii) knowledge, (iv) attitudes, (v) general practices regarding ABU and AMR and (vi) ABU during the preceding 12 months (name of antibiotic, method of administration, number of animals treated). For the livestock-fish farms, the questionnaire contained more questions, one set of questions concerning livestock, the other set of questions concerning fish. The questionnaires were based on dichotomous and categorical outcomes (yes/no; 1/2/3/4), as well as ordinal outcomes (5-point Likert scale type). They were pretested among farmers ($N = 5$) and were simplified according to the results of the pretest. The questionnaire was developed in English, translated into Lao and translated back into English.

2.4 | Data collection

Two principal investigators and 11 students from the Faculty of Agriculture of Nabong of Lao PDR, who were trained prior to the start of the survey, interviewed farmers over a 3-week period from 3 to 24 April 2018. Interviews were conducted in Lao. Responses were entered on electronic devices with Sphinxdeclic (Le Sphinx) software. The interviews lasted for 1 h on average. Photos were taken of products (e.g. veterinary drugs and feed) that farmers were willing to show during the field interviews. The presence of antibiotics on a farm was identified by examining the label, leaflet or packaging of drugs and feed present on the farm at the time of the visit.

2.5 | Data management and analysis

Responses of the poultry, pigs, fish and livestock-fish farmers were merged into a single database. Responses were duplicated for livestock-fish farms, with one observation (row) corresponding to a poultry or pig unit, and one observation corresponding to fish unit. Initial descriptive analyses, in effect, showed that the responses (regarding KAP) of livestock-fish farmers differed greatly depending on the type of unit which was considered (fish vs. livestock). The data obtained from the sixth section of the questionnaire (type of antibiotics, number of treated animals and methods of administration) were stored in a separate database. Of the 102 variables corresponding to the responses to the questionnaires, 14 were removed because they were deemed irrelevant to the analysis or because there were too many missing responses.

First, a multiple factor analysis was performed with the 88 remaining variables. Multiple factor analysis is a method used to summarize and visualize a complex dataset containing variables split into groups, taking into account the contribution of all groups to define the distance between individuals. These analysis synthesized in a lower Euclidian multidimensional space the information contained in structuring and supplementary variables (Husson et al., 2017). Among the 88 variables, 67 variables of the groups 'knowledge' ($n = 15$), 'attitudes' ($n = 22$) and 'practices' ($n = 30$) were used as structuring variables, whereas 32 variables of the groups 'sociodemographics' ($n = 10$) and 'farm' ($n = 11$) were used as supplementary variables.

The multiple factor analysis was followed by a hierarchical clustering analysis. The hierarchical clustering analysis aggregated observations into clusters based on their locations in the Euclidian multidimensional space derived from the multiple factor analysis. The representation of modalities of the variables in each cluster was assessed with a hypergeometric test, the *v*-test. If a modality was significantly over or underrepresented in the cluster, then it was interpreted as characteristic of the cluster. Modalities with positive scores are overrepresented in the cluster, and categories with negative scores are underrepresented. A *v*-test also was performed on the modalities of the supplementary variables in order to identify the association between cluster and these modalities (Husson et al., 2017).

The statistical association between farm characteristics and the actual use of antibiotics (yes vs. no, according to farmers' declaration and pictures from farm visits) was then further explored using logistic regression models. The clusters previously identified from hierarchical clustering analysis were introduced as an explanatory variable in regression models. The effect of supplementary variables, which did not contribute to the construction of the clusters, but have been found relevant for ABU according to the literature, also was investigated. These variables included farmer's age, farmer's gender, farmer's highest educational attainment, farmer's experience in livestock farming, type of farm (one species only vs. livestock-fish farms), species and presence of disease in the preceding 12 months. An initial multivariable logistic model was built based on all the variables with $p \leq .25$ in the univariable screening. Potential multicollinearity in the starting model was investigated by checking the variance inflation factors. Variable selection for the final model was carried out through a backward elimination process based on the Akaike criteria until all the remaining variables were significant ($p \leq .05$).

Statistical analyses were conducted using R software. Multiple factor and clustering analyses used the 'FactoMineR' and 'factoextra' packages (Lê et al., 2008).

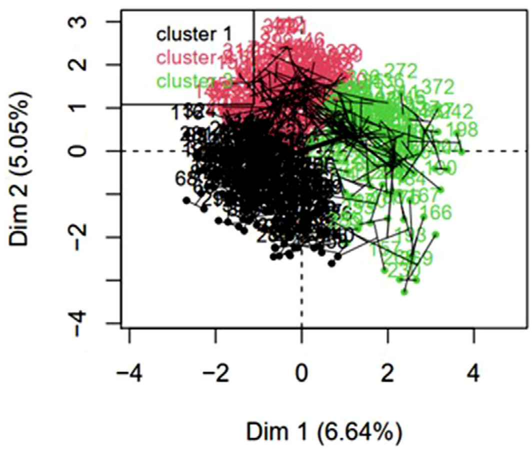

FIGURE 2 Hierarchical clustering of farm units projected in the two main dimensions of the multiple factor analysis of structuring variables from the knowledge, attitudes and practices groups

3 | RESULTS

3.1 | General characteristics of farms and farmers surveyed

A total of 364 farmers completed the questionnaire, which corresponded to 454 observations (farm units), as the responses from fish-livestock farms were divided into observations on livestock unit and on fish unit. Out of these 454 farm units, 82 corresponded to specialized pig units, 73 to specialized poultry units (including 54 layers and 19 broilers), 109 to specialized fish units, 30 to pig units on livestock-fish farms, 70 to poultry units on livestock-fish farms and 90 to fish units on livestock-fish farms. Out of 100 livestock-fish farms, 10 did not provide information on fish. More information on farmers and farms characteristics is provided in Supporting Information Appendixes 2 and 3. Descriptive statistics on farmers' KAP are provided in Supporting Information Appendix 4.

3.2 | Typology of the farmers based on their knowledge, attitudes and practices regarding ABU and AMR

The multiple factor analysis was conducted on the first 12 dimensions, accounting for 33.8% of the variance. The hierarchical clustering revealed three clusters, identified as cluster 1 ($n = 168$ farm units), cluster 2 ($n = 171$ farm units) and cluster 3 ($n = 114$ farm units) (Figure 2).

The modalities of the structuring variables from the KAP groups that influence the three different clusters are presented in Figures 3–5. The modalities of the supplementary variables are presented in Supporting Information Appendix 5.

In **cluster 1,** no specific knowledge item was under or overrepresented (Figure 3). In this cluster, farmers who strongly agreed with

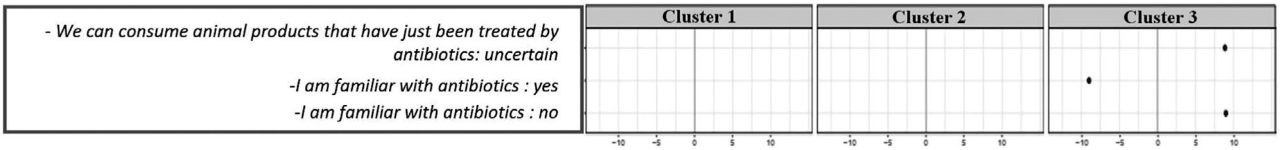

FIGURE 3 Characteristics of the three clusters based on the modalities of variables from the knowledge group obtained with the multiple factor analysis and the hierarchical clustering analysis. The values were obtained from the hypergeometrical test (*v*-test). The larger the absolute value, the better the cluster is described by this modality of variable. Positive values refer to overrepresentation in the given cluster, and negative values refer to underrepresentation. Only the 50 modalities that were statistically overrepresented and underrepresented in the knowledge, attitudes and practices groups are represented.

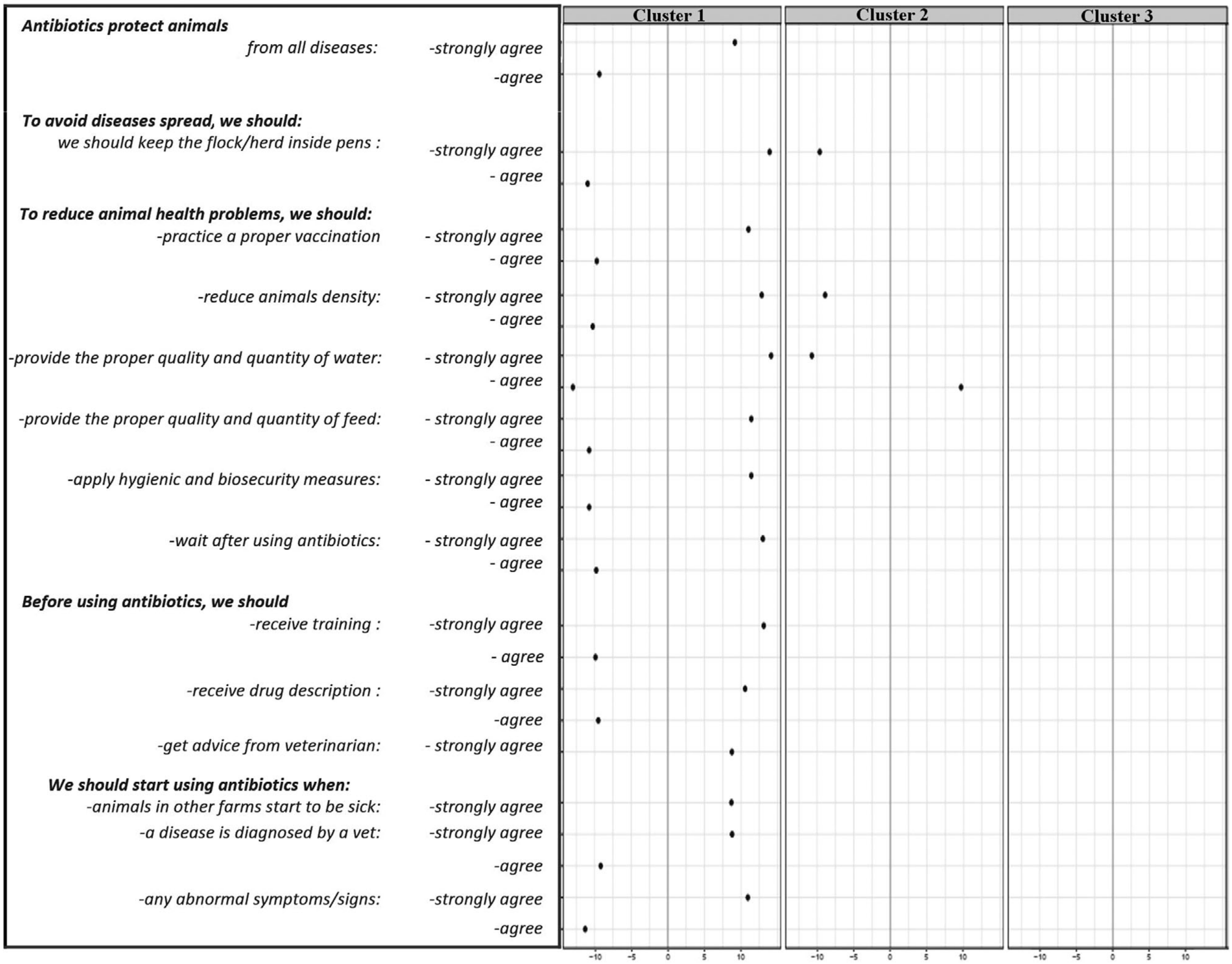

FIGURE 4 Characteristics of the three clusters based on the modalities of variables from the attitude group obtained with the multiple factor analysis and the hierarchical clustering analysis. The values were obtained from the hypergeometrical test (*v*-test). The larger the absolute value, the better the cluster is described by these modalities of variables. Positive values refer to overrepresentation in the given cluster, and negative values refer to underrepresentation. Only the 50 modalities that were statistically overrepresented and underrepresented in the knowledge, attitudes and practices groups are represented.

keeping their flock or herd inside pens to avoid disease spread, and who considered that preventive measures (use proper vaccination, reduce animal density, keep food and water of proper quality and quantity, apply hygienic measures) can help to avoid animal diseases, were overrepresented. Regarding antibiotics, most of the farmers in this cluster sought training, information on drug description and advice before using antibiotics (Figure 4). Most of them strongly agreed that antibiotics protect against all diseases and that antibiotics should be used when animals in other farms are sick, or when animals show any abnormal signs (Figure 4). When selecting antibiotics, farmers prioritized the

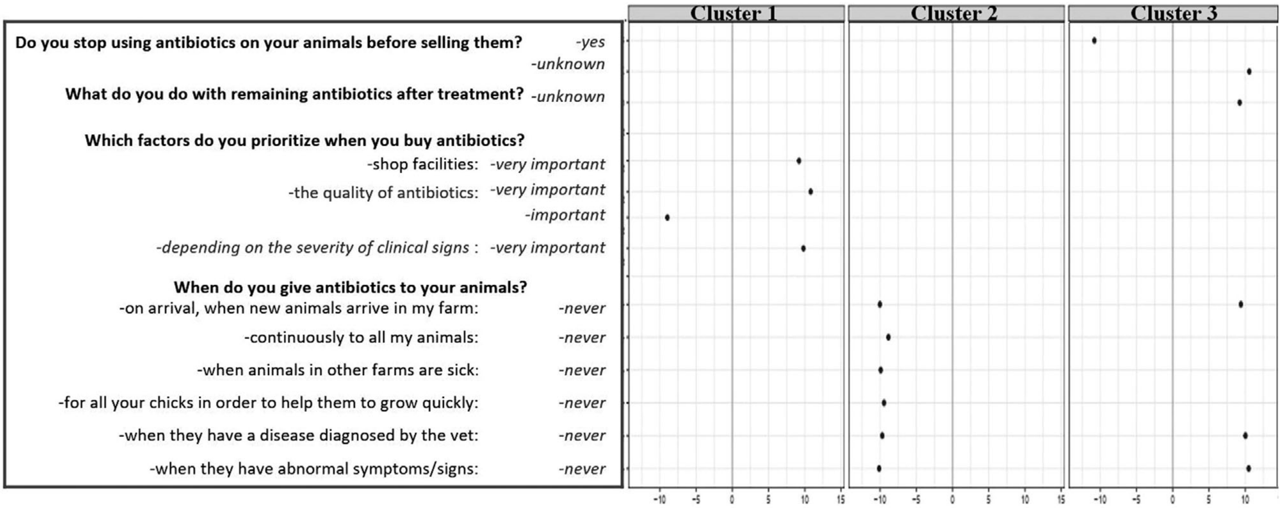

FIGURE 5 Characteristics of the three clusters based on the modalities of variables from the practices group obtained with the multiple factor analysis and the hierarchical clustering analysis. The values were obtained from the hypergeometrical test (*v*-test). The larger the absolute value, the better the cluster is described by these modalities of variables. Positive values refer to overrepresentation in the given cluster, and negative values refer to underrepresentation. Only the 50 modalities that were statistically overrepresented and underrepresented in the knowledge, attitudes and practices groups are represented.

quality of antibiotics and its adequacy to the severity of clinical signs (Figure 5). Farmers using antibiotics and vaccines for their animals were overrepresented (Supporting Information Appendix 6).

In **cluster 2,** like cluster 1, no specific knowledge item was under or overrepresented (Figure 3). Responses related to attitudes regarding disease prevention measures were less pronounced than in cluster 1. For example, the 'agree' modality was overrepresented for the variable 'to keep water of proper quality and quantity', but the 'strongly agree' was underrepresented (Figure 4). The farmers declared using sometimes, often or always (but 'never' was underrepresented) antibiotics for different reasons, including in a preventive context (when new animals arrive in their farm, continuously for all of their animals, when animals in other farms are sick, for all newborns in order to help them grow quickly). Farmers using antibiotics and vaccines for their animals were overrepresented (Supporting Information Appendix 6).

In **cluster 3,** no specific attitude item was under or overrepresented (Figure 4). The farmers mentioned that they were not familiar with antibiotics, and that their knowledge about antibiotic resistance was uncertain (Figure 3). Farmers from cluster 3 who did not give antibiotics to their animal and did not use vaccines were overrepresented (Supporting Information Appendix 6).

The analysis of supplementary variables showed that one species was overrepresented in each KAP cluster (Figure 6, Supporting Information Appendix 6): pigs in cluster 1, poultry in cluster 2 and fish in cluster 3. Farmers who had not experienced diseases in their farm over the past 12 months were underrepresented in cluster 1, whereas they were overrepresented in cluster 3 (Supporting Information Appendix 5). Regarding feed, farmers who bought commercial feed were overrepresented in cluster 2, whereas those who gave traditional feed or no specific feed to their animals were overrepresented in cluster 3 (Supporting Information Appendix 5).

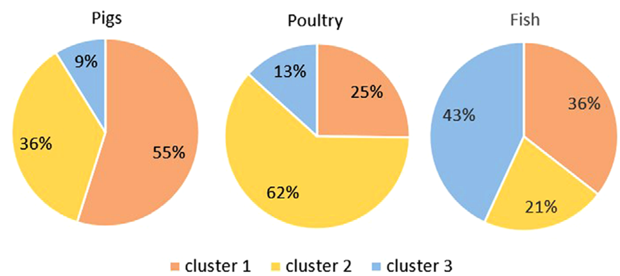

FIGURE 6 Distribution of pig, poultry and fish farm units in the three clusters identified from multifactorial and clustering analyses ($n = 168$ farm units in cluster 1, 171 units in cluster 2, 114 units in cluster 3)

3.3 | Actual use of antibiotics and influence of farms' characteristics on antibiotic use

Out of 454 farm units considered in the analysis, 261 farm units (57.5%) declared using antibiotics. None of the medicated feed identified in the survey contained antibiotics.

Out of 454 farm units, 24 were discarded from the regression model as they had missing data regarding antibiotic use (15 farm units), or explanatory variables (9 farm units). Of the eight explanatory variables examined, three were not associated with ABU in univariable analysis: farmers' age, farmers' education and farmers' experience in livestock. The final model included five significant variables (Table 1). Regarding KAP profiles, results indicated that ABU was less frequent in cluster 3 than in cluster 1. No significant difference was found between clusters 1 and 2 regarding ABU. Results indicated that ABU was more frequent in specialized farms than in livestock-fish farms, and in pigs and poultry farms than in fish farms. ABU was less frequently observed

TABLE 1 Results of the multivariable regression for the probability of using antibiotics (ABU) in poultry, pigs, fish and livestock-fish farm units in Lao People's Democratic Republic (Lao PDR) in 2018 ($n = 430$ farm units)

Variable	No. of farm units		Odds ratio	95% CI	*p*-Value
	ABU: yes	ABU: no			
Cluster					
1	111	53	Reference		
2	129	30	1.42	0.07–2.91	.34
3	17	90	0.11	0.04–0.23	<.01
Farm type					
Livestock-fish	90	88	Reference		
One species only (pig, poultry or fish)	167	85	2.04	1.09–3.81	.02
Species					
Fish	41	145	Reference		
Pigs	101	9	28.86	11.36–73.35	<.01
Poultry	115	19	15.07	7.22–31.48	<.01
Farmers' age					
Less than 31-year old	80	33	Reference		
31–51-year old	118	73	0.75	0.35–1.62	.46
More than 51-year old	59	67	0.39	0.17–0.91	.03
Presence of disease in the past 12 months					
Yes	128	30	Reference		
No	131	114	0.77	0.38–1.53	.45
Do not know	2	33	0.06	0.007–0.56	.01

in units where farmers were more than 51-year old in comparison with less than 20-year old, and in farms where farmers did not know if any disease occurred in the past 12 months.

The analysis of the packages found on farms during the visit provided more details on the type of antibiotics used. In total, 263 packages containing an antibiotic (or a combination of antibiotics) were identified, with 0 to 4 packages found per farm. A total of 65% of the antibiotics found (171/263) were included on the World Health Organization's list of critically important antibiotics for human medicine (World Health Organization, 2019). The main critically important antibiotics found were penicillins (amoxicillin, 54 packages), aminoglycosides (gentamicin, neomycin in 25 and 10 packages, respectively), fluoroquinolones (enrofloxacin and norfloxacin in 15 and 13 packages found on farms, respectively) and combination of aminoglycosides and macrolides (gentamicin-tylosin, 11 packages) (Supporting Information Appendix 7).

These critically important antibiotics were mostly found in clusters 1 and 2 (Figure 7). In cluster 1, 57/168 farm units (33.8%) had at least one critically important antibiotic; in cluster 2, these figures were 63/171 farm units (36.8%).

4 | DISCUSSION

This study explored the role of farmers' knowledge, attitudes and sociodemographic characteristics, as well as the characteristics of their farms, in the use of important antibiotics for human medicine in Lao PDR.

Although the study was designed to be nationally representative (the sampling calculations were based on the national livestock population), we must acknowledge some limitations in our sampling strategy. The study was conducted in five districts close to the capital Vientiane and the Thai border, whereas provinces closer to China or Vietnam may have different characteristics with regard to, for example farm densities, sources of drugs and access to markets. No farms managed by non-Laotian owners were included because these farmers declined to be interviewed, but their presence in these provinces is increasing (mainly pig and fish farmers), and their responses could have changed our results (Poupaud et al., 2021). Despite these limitations, 364 farmers were interviewed in 2 different provinces, representing 4 different farmer populations (poultry, pig, fish and livestock-fish commercial farms). Our study thus included the diversity of farms described in Lao PDR (Poupaud et al., 2021) and therefore provides an accurate picture of the current patterns of ABU in the livestock sector in this country. Data were collected based on questionnaires, reporting the respondents' statements and we acknowledge that farmers' declarations may differ from their actual practices (Maiman & Becker, 1974). In order to limit bias, the interviewers adopted a neutral attitude towards the farmers. Measuring ABU was particularly challenging in this study given the fact that, unlike in other contexts, there is no farm register in which on-farm treatments are recorded. To overcome this obstacle, interviewers took pictures of all of the drugs and feed present on the

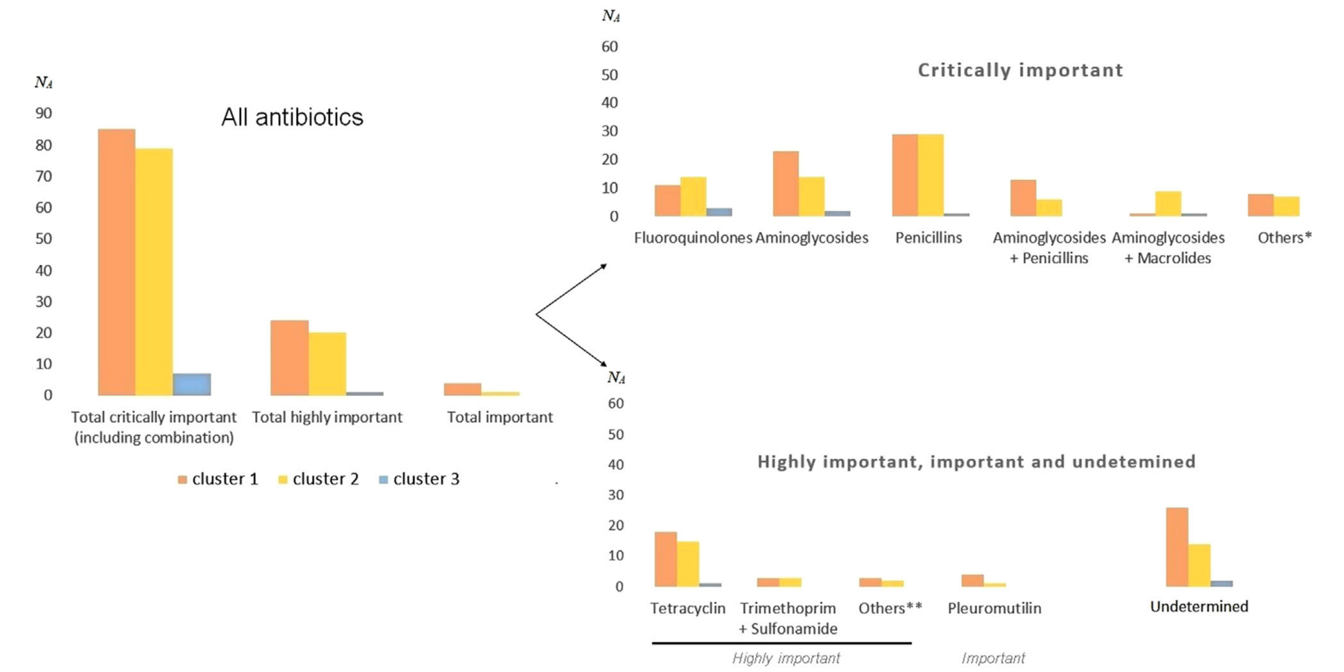

FIGURE 7 Classification of the antibiotic packages found in the surveyed poultry, pig, fish and livestock-fish farms, Lao People's Democratic Republic (Lao PDR) 2018. The number of antibiotic packages (N_A) corresponds to the number of packages (e.g. boxes, cans and bottles) containing antibiotics, including the combination of antibiotics. In cluster 1, 139 antibiotic packages were found in 85 out of the 168 farm units of the cluster; in cluster 2, 114 antibiotic packages were found in 82 out of the 171 farm units of the cluster; in cluster 3, 10 antibiotic packages were found in 7 out of the 114 farm units. *Classification was done according to the list of critically important antimicrobials for human medicine from the 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. The important antibiotics for human medicine are those which do not meet any of the criteria. See the details of the data in* Supporting Information Appendix 7. *Others critically important antibiotics include antibiotics from the Macrolides class, third-generation cephalosporins class and glycopeptides class. **Other highly important antibiotics include antibiotics from the penicillins class, amphenicols class and mix amphenicols–tetracyclin class.

farms at the time of visit. Bias cannot be excluded as the antibiotics analysed were those that the farmers were willing to show us (some farmers said they did not have any, others did not have time to show them to us). However, we believe that this study represents a valuable source of information given the paucity of data on antibiotic use on farms in Laos.

This study documents ABU in commercial farms in Lao PDR, thus complementing previous research focusing on the backyard sector in the same setting (Poupaud et al., 2021). Analysing ABU practices and associated determinants in commercial farms is of primary importance as previous research carried out in other Southeast Asian countries highlighted that this sector has relatively higher ABU in comparison to backyard or large integrated systems, and misuses of antibiotics are common (Coyne et al., 2019).

Results from this study showed that critically important antibiotics for human medicine were found in more than 30% of the farms which declared using antibiotics. These critically important antibiotics also were frequently found in pig and poultry farms in Vietnam and Thailand (Nhung et al., 2016). Critically important antibiotics are one of the limited therapies available to treat serious bacterial infections in humans, and their use in animal population should be restricted as much as possible (World Health Organization, 2019). Results also suggest that access to critical antibiotics is now easy for livestock farmers in Lao PDR. Farmers obtain antibiotics by importing them from other countries (Thailand, China and Vietnam), or by purchasing them over the counter from agricultural retail outlets, human pharmacies and veterinary clinics (Poupaud et al., 2021). The data collected in this study did not allow us to quantify the actual ABU in the farms visited. Further studies are therefore needed to evaluate actual exposure of pigs and poultry, as was done for chicken production in Vietnam (Carrique-Mas et al., 2015). Our results also emphasize the need to closely monitor antibiotic sales and use at the farm level.

Our findings call for specific ABU policy interventions tailored for poultry and pig farmers as these species were found to have a higher probability to use antibiotics in the regression models. This finding is consistent with previous studies pointing out high antimicrobial use in pig and poultry farms in Indonesia, Thailand and Vietnam (Coyne et al., 2019; Pham-Duc et al., 2019). Economic analysis showed that, in these three countries, the cost of antibiotics was low relative to other farm inputs and that ABU was driven by farm profitability, disease prevention and reducing mortality rates (Coyne et al., 2019). Further studies are needed to better investigate trends in ABU and associated drivers in the pig and poultry sector in Lao PDR. The fact that most of the farmers started their activities within the past 5 years shows the dynamism of the pig and poultry sector in Lao PDR. Given the lack of control of the veterinary antibiotic supply chain (Poupaud et al., 2021), it is possible that the rapid expansion of these sectors represents a threat regarding AMR. Concerning fish units, results from the regression model evidenced that antibiotic use was significantly lower compared to other species. This contrasts with other studies showing that the Asia-Pacific region represents the largest share of global antimicrobial consumption in aquaculture (Schar et al., 2020) and the widespread use of antibiotics on fish farms in Vietnam (Dang et al., 2021). This result might be due to differences in fish production systems, the small-scale fish farms present in Lao PDR (Thongsamouth, 2021) contrasting with the rapid intensification of aquaculture observed in Vietnam (Luu et al., 2021). In Lao PDR, modern commercial-oriented fish farming only emerged a few years ago, but this sector is likely to grow in coming years as aquaculture is included in the Ministry of Agriculture's development plans. Furthermore, our study showed some heterogeneity in the KAP of fish farmers regarding ABU and AMR as, although predominant in cluster 3, some fish units were also found in clusters 1 and 2. As clusters 1 and 2 were found associated with higher ABU in the regression model, it is likely that the expansion of commercial fish farming in Laos may be associated with an increase in ABU. This calls for a specific awareness plan to accompany prudent use of antibiotics in new fish farms in Lao PDR.

Results from the regression model also indicate that ABU is more frequent in specialized farms (which raise only one species) than in livestock-fish farm. This finding may be explained by a higher level of intensification in specialized farms, as indicated by the larger size of flocks/herds. Concerning the clinical context of ABU, this study failed to detect a significant difference between farmers who reported disease in the past 12 months and those who did not. However, ABU was less frequently reported by who did not know if any disease occurred in the past 12 months. Previous research carried out in Vietnam showed that the administration of antibiotics in pig, poultry and aquaculture occurred for real, imagined and anticipated infections (Pham-Duc et al., 2019). In low and middle-income countries, the analysis of the clinical context in which antibiotics are used remains challenging. The definition of a health problem or a disease occurrence may vary from the farmers' perspective, especially as knowledge about diseases and infections is limited (Imam et al., 2020), and farmers have difficulties in accessing veterinary services to diagnose diseases (Eltayb et al., 2012).

In this study, multiple factor analysis and hierarchical clustering identified three different farmers' profiles based on farmers' knowledge, attitude and practices regarding ABU and AMR. As KAP studies often result in a large number of variables that are difficult to synthesize, most published papers have generated a single KAP variable through the construction of indexes and scores for each KAP domain. However, indexes are based on what researchers consider to be a correct answer for each item, what may appear quite normative. Scores may also mask the heterogeneity of the interviewees' responses to different items within the same domain. Finally, many studies, including our study, found that an increase in knowledge does not systematically translate into better attitude and practice scores (Pham-Duc et al., 2019), and that relationships between KAP are extremely complex. Given these drawbacks, we used multifactorial and clustering analyses as an alternative approach to synthetize information and identify patterns of KAP. This approach brings additional insights to previous KAP studies based on descriptive statistics (Coyne et al., 2019) or scoring approaches (Pham-Duc et al., 2019) of ABU in Southeast Asia. The percentage of explained variance (33.8%) in the present study is in-line with values found in similar works (Delpont et al., 2020; Denis-Robichaud et al., 2019). Values observed in multifactorial analyses are known to be lower than those found with principal component analysis, as in principal component analysis, only linear relationships are studied, whereas in multifactorial and clustering analyses, much more general relationships are studied (Husson et al., 2017).

Although each of the three species populations (pigs, poultry and fish) was overrepresented in a different cluster, all three species were found in each of the three clusters. This finding showed that farmers raising different species may present similar trends in KAP regarding ABU. It is worth noting that none of the farmers' specific knowledge was under or overrepresented in clusters 1 and 2, meaning that farmers from these two clusters had a heterogeneous level of knowledge. In cluster 1, farmers show a better attitude than farmers in cluster 2 in terms of preventive measures (such as application of hygienic and biosecurity measures), but this is not reflected in their ABU, as the logistic regression model does not show a difference of ABU between clusters 1 and 2. The World Health Organization (2019) recommends that farmers stop using antibiotics to prevent disease in healthy animals, but our results suggest Lao farmers used antibiotics in a preventive manner. Farmers from cluster 2 declared using antibiotics as a preventive tool for disease management. The practices of farmers in cluster 1 are less clear with regard to ABU for prophylactic treatment. Farmers' statements on their attitude regarding antibiotics suggest that they also considered antibiotics in a preventive perspective (e.g. most farmers from cluster 1 strongly agreed that 'antibiotics protect from any disease'). This result is consistent with previous studies, which showed that the preventive use of antibiotics is widespread in Southeast Asian countries (Zellweger et al., 2017), notably in poultry farms in Vietnam (Carrique-Mas et al., 2015).

As the link between knowledge or attitude and practices is not straightforward, an intervention to better inform farmers about the risk of AMR, as usually assumed in the health belief model (Campenhoudt et al., 2017), may not be sufficient to modify ABU practices. The impact of AMR communication and education campaigns in low and middle-income contexts remains largely undocumented. An education campaign in two Lao villages on the ABU in humans showed an influence on awareness and understanding of AMR, whereas evidence of behavioural change was sparse and mixed (Haenssgen et al., 2018). Another education campaign on ABU in humans in Thai villages did not demonstrate changes in practices (Charoenboon et al., 2019). These studies call into question the dominance of education as a tool to combat AMR. In lieu of education campaigns, these authors advise alternative approaches to behaviour change that address contextual constraints such as poverty rather than alleged knowledge gaps.

Designing an AMR mitigation plan is challenging. Our findings suggest that to implement appropriate interventions to control AMR, the heterogeneity of livestock farms must be considered. A 'one size fits all' intervention to address ABU and AMR problems in Lao PDR farms thus may not be successful. Rather, results call for interventions tailored to the different farmer profiles identified.

5 | CONCLUSION

This survey of 364 Lao farmers revealed the frequent ABU across the different farms, especially specialized pig and poultry farms. This is of concern as 65% of the antibiotics found on farms corresponded to antibiotics of critical importance for human medicine. We found that ABU was significantly less frequent in fish than in poultry and pig units, and more frequent in specialized farms than in livestock-fish farms. This study made it possible to identify three different profiles determined by farmers' KAP regarding ABU and AMR. The results of this study may help the Laotian government to adapt the section related to food animals of the National Action Plan on AMR, for example by developing strategies focusing on the use of critical antibiotics and prophylactic treatments. Findings also suggest that, in addition to such general guidelines, antibiotic stewardship strategies should take into account farmers' heterogeneity.

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CONFLICT OF INTEREST

Nothing to declare.

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ETHICS STATEMENT

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to, and the appropriate ethical review committee approval has been received. This study had no direct relevance to issues pertaining to human health, as such, the Lao Ministry of Health's Ethics Committee could not review our study. Instead, the study was reviewed and approved by Kasetsart University Ethics Committee, Bangkok, Thailand on 14 September 2018 (KUREC.HS6T/023). Before the start of the study, information sessions were held with various government groups comprising the heads of the Vientiane Capital City and Vientiane Province provincial livestock and fisheries offices, and the heads of Xaythany, Naxaythong, PhongHong and KeoOudom district livestock and fisheries offices. The context, goals and methodology of the study were shared. An official authorization at provincial and district levels allowing us to work on those areas was then obtained. Participation in the survey was voluntary. No names or pictures of participants were recorded. No minors were included in this study.

DATA AVAILABILITY STATEMENT

The questionnaires used for the study are available on request (email to the corresponding author). The database of the answers to the questionnaire and the database of antibiotics found on farms are publicly available at https://dataverse.cirad.fr/dataset.xhtml?persistentId=doi%3A10.18167%2FDVN1%2FUM7YUS&version=DRAFT.

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