University of Reading

Evaluating and understanding antimicrobial use and antimicrobial resistance in Fijian livestock production systems: A mixed-methods study

Thesis submitted for the degree of

Doctor of Philosophy in Agriculture, Environment and Food Economics

School of Agriculture, Policy & Development, Department of Animal Sciences
School of Chemistry, Food and Pharmacy, Department of Pharmacy

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Declaration of original ownership

I confirm that this is my own work, and the use of all material from other sources has been properly and fully acknowledged.

Xavier R S Khan

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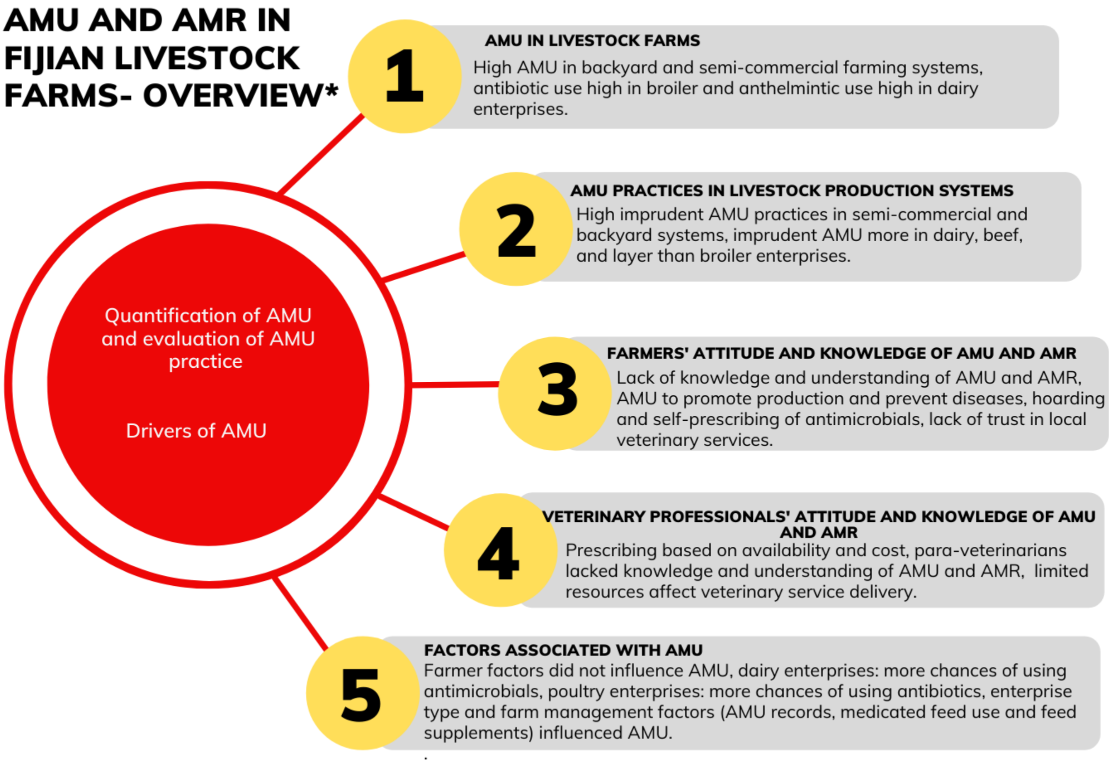
Dedication

I dedicate this thesis to my great, humble, and loving parents for their endless love, support, and encouragement. Their lessons have taught me to be modest, self-disciplined, and remain dedicated to my aspirations.

Graphical highlights of my thesis



*AMU- Antimicrobial use, AMR- Antimicrobial resistance

Abstract

Introduction: Antimicrobial resistance (AMR) is a global threat to humans and livestock. Even though the direct links between the increase in AMR in humans and antimicrobial use (AMU) in livestock is unclear, the reduction and prudent use of veterinary antimicrobials (antibiotics, anthelmintics) in livestock production has been advocated as a mitigation measure. Lack of policies regulating AMU and self-prescribing have been identified as drivers of inappropriate AMU practice, particularly in developing countries. Lack of access to qualified veterinarians and farmers' lacking knowledge on AMU and AMR have also been identified as drivers of high and inappropriate AMU practices. While the availability of data on AMU patterns is increasing in developed countries, this is currently unknown in Fiji. The drivers of AMU and AMR in livestock production systems including Fiji is also limited in many countries across the globe. Like other developing countries, AMR has been reported in the Fijian human health sector; however, the psychological and contextual drivers of AMU and AMR in Fijian livestock production remains unknown.

Aim: This PhD thesis aimed to quantify AMU in Fijian cattle (beef, dairy) and poultry (broiler, layer) enterprises and farming systems (backyard, semi-commercial and commercial), develop a framework for and to evaluate AMU practice, and explore and understand the drivers of AMU and AMR in Fijian livestock production systems located in Central and Western division on Viti Levu, Fiji.

Methods: The programme of research in this thesis used a mixed methods approach. The Theory of Planned Behaviour (TPB) was used as a theoretical framework that informed the design of qualitative studies, and a comprehensive literature review informed the development of a conceptual framework, which underpinned the design of the quantitative studies. Livestock farms and managers were recruited in a cross-sectional survey using purposive and snowball sampling methods to collect socio-economic, demographic, livestock production and management, AMU, other medicines use, and feed and feeding systems data. To explore experiences and knowledge on AMU and AMR, livestock farmers and veterinary professionals (veterinarians and para-veterinarians) were recruited to take part in a one-off one to one semi-structured interview using purposive and snowball sampling methods. The survey data were analysed using ANOVA and logistic modelling.

Semi-structured interview transcripts were analysed using reflexive thematic analysis and deductively using TPB.

Results and Discussion: In the first quantitative study (Chapter 4), a total of 236 farms comprising of 276 enterprises (beef, n = 72, dairy, n = 74, broiler, n = 57, layer, n = 73) were recruited. The survey revealed a little over half (56%) of 276 livestock enterprises used antimicrobials. The quarterly antibiotic use was highest in broiler enterprises (12.4 mg/PCU), and anthelmintic use was highest in dairy enterprises (24,120 mg). The estimated annual antibiotic use in Fijian livestock farms (beef, dairy, broiler, and layer) was 44 mg/PCU (lower than the global average of 118 mg/PCU). The study revealed AMU was higher in the backyard and semi-commercial farming systems.

In the second quantitative study (Chapter 5), antimicrobials were used on 309 occasions over 90 days in 276 enterprises. A 7-step framework for categorising AMU practice was developed and used. The decision-making steps revealed that in 298 of 309 (96%) incidents, antimicrobials were used imprudently, comprising antibiotics, 160 of 170 (94%) and anthelmintics, 138 of 139 (99%). The prudent use of antibiotics was associated with commercial farming systems ($X^2 = 13$, $p = 0.001$); nonetheless, no association was observed with anthelmintic use ($p > 0.05$). The imprudent antibiotic use was associated with dairy (OR = 7.6, CI = 1.41,41.57, $p = 0.018$) followed by layer and beef ($p > 0.05$) compared to broiler enterprises. The study revealed that imprudent AMU was more common in backyard and semi-commercial enterprises compared to commercial broiler enterprises.

In the first qualitative study (Chapter 6), 19 livestock farmers and managers took part. The analysis generated four themes: 1) Uninformed use of antimicrobials and lack of awareness of AMR, 2) Safeguarding livestock and generating income source as primary motivators for using antimicrobials 3) Medicine shortage results in hoarding and self-prescribing, and 4) Farm decisions on AMU and livestock management are influenced by foreign farmers and veterinarians. The livestock farmers used antimicrobials to prevent diseases and promote production. However, they lacked knowledge of antimicrobials and were unaware of the risks associated with imprudent AMU. The farmers hoarded and self-prescribed antimicrobials for their animals and rationed antimicrobials by not completing the entire course of antibiotics to save them for future use. The farmers expressed dissatisfaction with their local provision of veterinary services; therefore, they accessed help online and from foreign farmers and veterinarians.

In the second qualitative study (Chapter 7), a total of 10 participants (para-veterinarians n = 8, veterinarians n = 2) took part. The analysis generated three key themes: 1) Antimicrobials prescribed and used based on availability and cost rather than clinical need, 2) Para-veterinarians awareness and knowledge of AMR influence treatment decisions , and 3) Limited resources impede effective consultation and veterinary service delivery. The para-veterinarians lacked knowledge and understanding of AMU and AMR. They prescribed and dispensed antimicrobials without knowing the risks associated with inappropriate AMU. The para-veterinarians did not clinically examine sick animals and based their treatment decisions regarding AMU on farmers' perceived diagnoses. This study demonstrated the lack of knowledge and understanding of para-veterinarians towards AMU and AMR.

The final quantitative study (Chapter 8) revealed that farms that raised cattle only for dairy were more likely to use antibiotics and anthelmintics ($p = 0.018$, OR = 22.97, CI 1.713,308.075). The layer only, broiler only, and layer and broiler mixed farms were most likely to use antibiotics ($p > 0.05$). Farms that maintained AMU records were more likely to use antibiotics ($p = 0.045$, OR = 2.65, CI 1.024,6.877) and, similarly, anthelmintics only ($p > 0.05$). AMU in livestock farms was not influenced by the socio-economic and demographic characteristics of the farmer. Although livestock production and management are different between systems and enterprises, the AMU practice was uncommon. This study demonstrated that the lack of knowledge of AMU may have influenced the AMU practice amongst the livestock farmers.

The quantitative studies (Chapter 4 and 5) in this PhD thesis highlighted the need for antimicrobial stewardship (AMS) programmes targeting a reduction in AMU and promoting the prudent use of antimicrobials in smaller livestock production systems and enterprises in Fiji. Additionally, AMS programmes should be tailored to specific enterprises and livestock production systems. The qualitative studies (Chapter 6 and7) highlighted the need for AMS programmes promoting awareness on AMU and AMR amongst Fijian livestock farmers and para-veterinarians. The quantitative study (Chapter 8) highlighted the need for AMS programmes targeting awareness on AMU and livestock management amongst livestock farmers. Additionally, the need to improve the veterinary services infrastructure to allow farmers better access to veterinarians for farm veterinary extension advice on livestock production and management is also recommended. Allocation of physical and human resources to Fijian veterinary services should be considered part of AMS programmes to improve veterinary services to Fijian livestock farmers.

This programme of research has generated new knowledge and made an original contribution about AMU and AMR in Fiji. The practice of AMU and the contextual and psychological drivers of AMU and AMR were identified. This contribution has the potential to inform the development of AMS programmes to optimise the use of veterinary antimicrobials in livestock production systems and mitigate AMR risks in the Fijian agri-food value chain at the country level. Future studies exploring the attitude and knowledge on AMU and AMR of other key actors (such as abattoir meat inspectors, farm gate buyers, commercial processors, and consumers) in the agri-food value chain are recommended. Future studies exploring the anthropological, socio-cultural, economic, and environmental factors that may influence AMU behaviour in livestock farmers are required to gain a broader systems knowledge to inform the design of AMS programmes targeting behavioural interventions, improving access to veterinary services and veterinary antimicrobials to promote prudent AMU in livestock production systems nationally.

List of publications

Published peer-reviewed papers:

Khan X, Rymer C, Ray P, Lim R. Quantification of antimicrobial use in Fijian livestock farms. *One Health*. 2021 Sep 13; 13:100326. http://doi.org/10.1016/j.onehlt.2021.100326.

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Khan X, Lim R, Rymer C, Ray P. Fijian farmers' attitude and knowledge towards antimicrobial use and antimicrobial resistance in livestock production systems - a qualitative study. *Frontiers in Veterinary Science.* 2022; 9; 838457. https://doi.org/10.3389/fvets.2022.838457

Khan X, Lim R, Rymer C, Ray P. Fijian veterinarian and para-veterinarians' behaviour, attitude and knowledge towards antimicrobial use and antimicrobial resistance in Fijian livestock production- a qualitative study. *Frontiers in Veterinary Science.* 2022; 9; 898737. https://doi.org/10.3389/fvets.2022.898737

Khan X, Rymer C, Lim, Ray P. Factors associated with antimicrobial use in Fijian livestock farms. *Antibiotics* 2022; 11; 587. https://doi.org/10.3390/antibiotics11050587

Peer-reviewed conference abstracts

Khan X, Lim R, Rymer C, Ray P. Fijian farmers' attitude and knowledge towards antimicrobial use and antimicrobial resistance in livestock production systems- a qualitative study (abstract). *International Journal of Pharmacy Practice.* 2022, Vol. 30; S1; i6. https://doi.org/10.1093/ijpp/riac021.008

Khan X, Lim R, Rymer C, Ray P. Fijian veterinarian and para-veterinarians' behaviour, attitude and knowledge towards antimicrobial use and antimicrobial resistance in Fijian livestock production- a qualitative study, Quantification, Benchmarking and Stewardship of Veterinary Antimicrobial Usage, Third International Conference Abstracts Book, May 2022. https://www.aacting.org/aacting-conferences/#abstract

List of conferences attended

Local:

Khan X, Rymer C, Lim, Ray P. Antimicrobial use in poultry and cattle, Department of Animal Sciences Seminars, School of Agriculture, Policy and Development, University of Reading, Frank Parkinson room, December 7, 2017. Oral presentation.

Khan X, Rymer C, Lim, Ray P. Evaluating and understanding antimicrobial use in food producing animals in Fiji, Department of Animal Sciences Seminars, School of Agriculture, Policy and Development, University of Reading, Frank Parkinson room, March 6, 2020. Oral presentation.

National:

Khan X, Lim R, Rymer C, Ray P. Fijian farmers' attitude and knowledge towards antimicrobial use and antimicrobial resistance in livestock production systems - a qualitative study. The online Health Services Research & Pharmacy Practice Conference, April 2022, University of Bath, UK. Oral presentation.
*The abstract was awarded Day-Lewis Scholarship and 3rd place for best oral presentation.

International:

Khan X, Lim, R, Rymer C, Ray P. Fijian veterinarian and para-veterinarians' behaviour, attitude and knowledge towards antimicrobial use and antimicrobial resistance in Fijian livestock production- a qualitative study, 3rd AACTING Conference "Quantification, Benchmarking and Stewardship of Veterinary Antimicrobial Usage", May 2022, University of Veterinary Medicine, Hannover, Germany. Oral presentation.

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AMR	Antimicrobial resistance
AMS	Antimicrobial stewardship programmes
AMU	Antimicrobial use
API	Active pharmaceutical/antimicrobial ingredient
APVMA	Australian Pesticides and Veterinary Medicines Authority
AVM-GSL	Authorised Veterinary Medicine- General Sales List
BVA	British Veterinary Association
Dose - animal per day	Number of doses per animal per day
EMA	European Medicines Agency
EPRUMA	European Platform for the Responsible Using of Medicines in Animal
ESVAC	European Surveillance of Veterinary Antimicrobial Consumption
EU	European Union
FAO	Food and Agricultural Organization of United Nations
GLASS	Global Antimicrobial Surveillance System
HBM	Health Belief Model
HP-CIAs	High-priority critically important antimicrobials
mg	Milligrams
mg/kg	Milligrams per kg of body weight of animal treated
mg/PCU	Milligram per population correction units
MOA	Ministry of Agriculture
*n*DCDvet	Number of Defined Course Doses
*n*DDDvet	Number of Defined Daily Doses
NFA-VPS	Non-Food Animal Veterinarian, Pharmacist, Suitably Qualified Person
NOAH	National Office of Animal Health
*n*UDDs	Number of Used Daily Doses
NZMPI	New Zealand Ministry of Primary Industries
OIE	World Organization of Animal Health
PCU	Population correction units (total weight of population at risk)

POM-V	Prescription Only Medicine- Veterinarian
POM-VPS	Prescription Only Medicine-Veterinarian, Pharmacist, Suitably Qualified Person
RUMA	Responsible Use of Medicines in Agriculture
TF	Treatment Frequency
TPB	Theory of Planned Behaviour
TRA	Theory of Reason Action
UK	United Kingdom
VMD	Veterinary Medicines Directorate
WHO	World Health Organization
% Treated	Percentage treated

Chapter 1

General introduction and thesis outline

1.1 Overview

Antimicrobial Resistance (AMR) is a significant threat to humans and animals globally [1-3]. Even though a direct link between antimicrobial use (AMU) in livestock production systems and increasing AMR in humans has yet to be established, there is an acknowledgement of the need to reduce the use of antimicrobials (antibiotics and anthelmintics) in livestock farms [1-3]. Globally, the World Health Organization (WHO), World Organization of Animal Health (OIE) and Food and Agricultural Organization of United Nations (FAO) have collaborated through the One health approach to combat the growing risks of AMR and promote prudent use of antimicrobials in livestock production [1-3].

Nevertheless, with the increasing global demands for food of animal origins (meat, milk, and eggs), livestock farms have intensified and commercialised where large herds/flocks of livestock are raised for sales [4-8]. Subsequently, these drastic changes in production systems have increased farm biosecurity risks and striking a balance between sustaining production and maintaining farm biosecurity has been quite challenging for farmers [9,10]. Antimicrobials including antibiotics, anthelmintics and other agents such as vaccines, medicated feed, nutraceuticals, and other herbal preparations have been used by livestock farmers to mitigate risks of microbial infection in livestock production systems [11-19]. Antimicrobials have traditionally been used to treat diseases in livestock herds/flocks; however, the prophylactic use and use for growth promotion are of concern [12,20,21]. Moreover, the prophylactic use without prescription from and supervision of a veterinarian is becoming a concern [22-24]. Other studies have highlighted concerns with a blanket herd/flock level administration due to exposure of clinically healthy herds and flocks of animals to antimicrobials, which may contribute to AMR risk [25-27]. Developed countries such as the European Union (EU) and United Kingdom (UK) took necessary steps and have banned the use of antimicrobials for growth promotion; however, antimicrobials are still used for growth promotion in developing countries [28,29], (this is explored in detail in Chapter 2).

There have been growing impetus and discussions on the suitability of the metrics and framework for quantifying AMU [30-32]. More evidence of AMU has been demonstrated in developed countries; however, the quantification of AMU in developing countries is in its infancy or remains unquantified [33,34]. In the South Pacific region, AMU data have been reported in Australia [33,35] and New Zealand [34,36]; however, quantification and outdated or no data is available for many developing countries [37], including Fiji. Several resources and policy gaps have been reported in the Fijian animal and human health sectors [38]. Although AMR in the Fijian human sector has been reported [38], AMU and AMR in the livestock sector remain unknown. Fiji was the first Pacific Island country to develop and launch a national plan to tackle AMR in 2015 and much work has taken place in the human health sector. There have however been limited work to address the knowledge gap in the livestock sector to date [39-41] (This will be appraised in more detail in Chapter 2).

Evaluating the patterns and practice of AMU is needed; however, understanding the drivers of AMU have been proven to be more critical than ever before [42]. Chapter 2 discusses the importance of quantifying patterns of AMU and imprudent AMU practices [12,20] and highlights the current lack of knowledge and understanding of the drivers of AMU. Therefore, to effectively implement behavioural change through antimicrobial stewardship (AMS) programmes, the target area of intervention needs to be first established [1-3]. The literature demonstrates that AMU behaviour of farmers are influenced by psychological (knowledge and attitude) and contextual drivers (environmental factors, economic status, and resource accessibility) that shape the farmers' intention and decisions on AMU [43-45]. Additionally, generic intervention policies have been developed and published; however, they need to be tailored to the specific psychological and contextual drivers of AMU behaviour locally [45-48] due to the disparities in the socio-economic and livestock production and management practices between countries [20,49,50]. More importantly, studies have either quantified or explored the attitude and knowledge; however, few studies have quantified, analysed, and explained the AMU and AMR. Targeted AMS programmes could be developed; however, would not be very effective unless the theory informed psychological and contextual drivers of AMU and AMR is clearly understood in the local context.

This thesis used a range of parameters with corresponding metrics to quantify AMU in Fiji. It addressed the knowledge gaps in livestock production, but it also helped demonstrate the novelty of using a range of metrics to understand AMU patterns better. Using quantitative and qualitative methods, this thesis investigated the patterns and drivers of AMU from a broader perspective. It provides valuable information that may assist in developing educated strategic interventions through AMS programmes promoting prudent use of

AMU and reducing the burdens of AMR locally [1,3,51]. (This will be discussed in more detail in chapter 9).

1.2 General aim and objectives

This thesis aimed to evaluate and understand the AMU and AMR in Fijian livestock production systems using a mixed-methods approach. This thesis adds AMU data by livestock enterprises and systems and adds knowledge on AMU drivers from psychological and contextual standpoints. Literature indicates AMU and AMR information gaps in the Fijian livestock sector. Therefore, the thesis used various methods and combined animal, social, veterinary, and pharmaceutical sciences to design and collect data on farms, farmers, and veterinary services professionals on AMU and AMR.

The thesis aims to investigate the following research questions:

1. *What is the current AMU in livestock production systems and enterprises raising livestock in Fiji?*
2. *How do the attitudes and knowledge of Fijian livestock farmers on AMU and AMR influence AMU practice in their flocks/herds of livestock?*

To address the research questions above, Chapter 2 reports a comprehensive literature review that identified a range of metrics for quantification of AMU and informed the development of a conceptual framework that directed the quantitative studies (Chapter 4, 5 and 8) and theoretical framework that guided the Chapter 6 and 7.

A programme of research consisting of five studies were undertaken. The specific objectives were:

1. To investigate the effects of farming systems (backyard, semi-commercial and commercial) and enterprises (beef, dairy, broiler, and layer) on the AMU quantified using European Surveillance of Veterinary Antimicrobial Consumption (ESVAC) and non ESVAC metrics in the Western and Central divisions of Viti Levu, Fiji (Chapter 4).
2. To develop a framework for categorising AMU practice (prudent/imprudent) and investigate the extent of imprudent AMU in Fiji and determine whether imprudent AMU was affected by either farming system or farm enterprise type (Chapter 5).

3. To explore and understand the attitude and knowledge of Fijian livestock farmers towards AMU and AMR in the Central and Western Divisions of Viti Levu, Fiji (Chapter 6).
4. To explore and understand the attitude and knowledge of Fijian veterinarians and para-veterinarians' towards AMU (in contexts of prescribing, dispensing, and using) and AMR in the Central and Western division of Viti Levu, Fiji (Chapter 7).
5. To evaluate the agri-food value chain factors (farmer and livestock enterprise production and management) and investigate the agri-food chain value factors associated with AMU in livestock farms in the Central and Western regions of Viti Levu, Fiji (Chapter 8)

1.3 Thesis outline

This PhD thesis is presented as a collection of papers with nine chapters in total with the references listed at the end of each chapter. Figure 1 illustrates the outline of this thesis.

The first three chapters provides an introduction to the thesis, research questions, the study rationale, and methodology. The remaining five chapters reports studies conducted to address specific research objectives. The concluding chapter discusses the findings of the programme of research work as a whole, its implications for practice and research, and future work.

Chapter 2 explores the literature extensively to establish the current knowledge on AMU and AMR in developed and developing countries. It explores the current AMU practices in livestock enterprises and systems and current strategies used to mitigate the risks of imprudent AMU and AMR. A review of the metrics used to quantify antimicrobials use was provided. The chapter also explored the legislative frameworks underpinning prescribing, dispensing, and using antimicrobials. The socio-psychological and contextual drivers of AMU and AMR were explored. The farmers', veterinarians', and para-veterinarians' attitudes and knowledge on AMU and AMR were reviewed in detail. Subsequently, different behavioural theories were described. The rationale for adopting the TPB, which aided the design of the programme of research was discussed .

Chapter 3 encompasses the methodology used to address the research questions. The different methodological approaches are reviewed, and the rationale for using mixed methods is described. The conceptual and theoretical framework used in the thesis is described. The specific sampling, data collection and data analysis techniques are described. The philosophical viewpoints of the researcher are also described.

Chapter 4 presents the first quantitative study . The data on AMU is presented, and findings of the effects of enterprises and farming systems on AMU are presented and discussed.

Chapter 5 presents the second quantitative study, which used a framework for categorising AMU practice and investigated the effects of farming systems and enterprises on imprudent AMU practice.

Chapter 6 presents the findings of first qualitative study that explored the attitude and knowledge of Fijian livestock farmers' towards AMU and AMR.

Chapter 7 presents the results of second qualitative study that explored the attitude and knowledge of Fijian veterinarians and para-veterinarians' towards AMU and AMR.

Chapter 8 presents the final quantitative study, which investigated the factors associated with AMU in Fijian livestock farms using the conceptual framework.

Finally, in Chapter 9, the findings of the programme of research work was discussed as a whole. Additionally, the key findings and outcomes are summarised. The limitations, including methodological rigour and future research perspectives, are discussed.

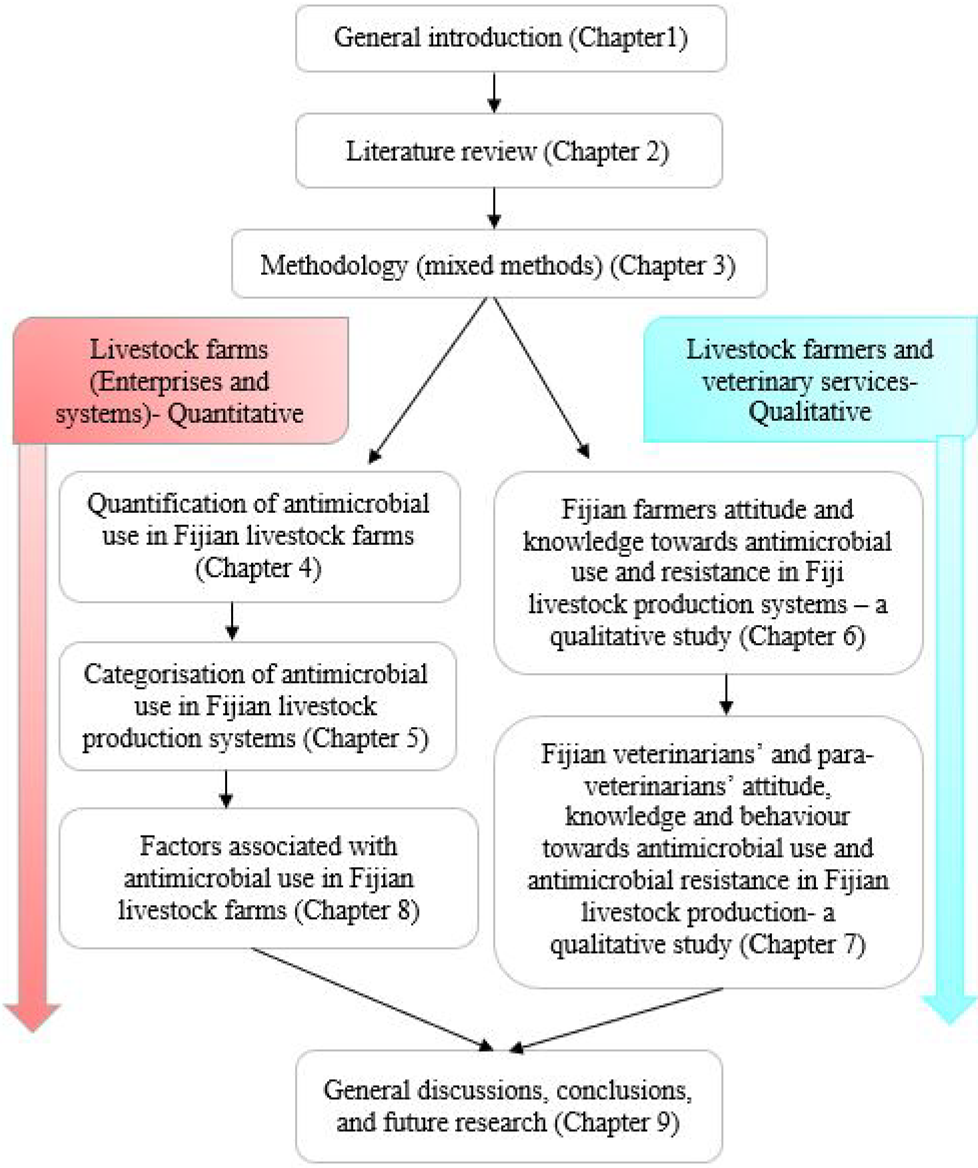

Figure 1 Thesis outline.

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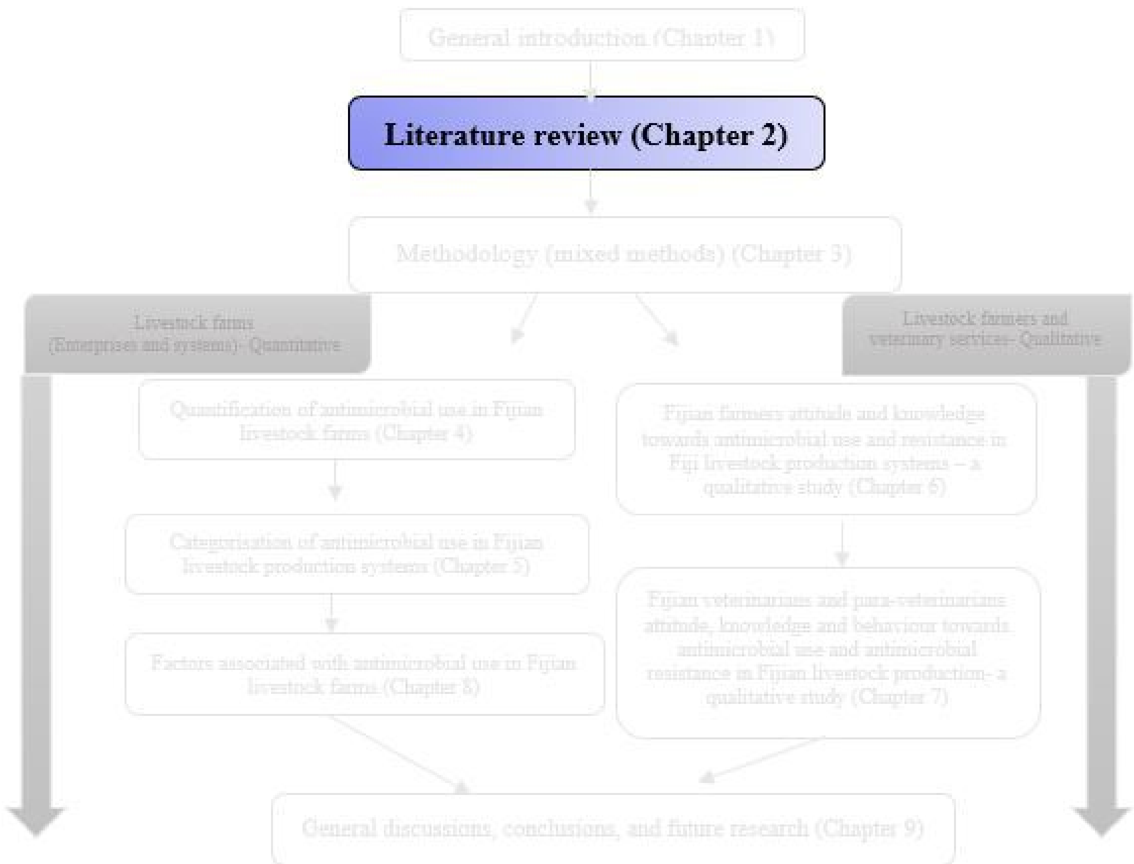
Chapter 2
Literature review

Review of antimicrobial use and antimicrobial resistance in livestock production systems: a focus on developing countries

Chapter summary: In this chapter, a literature review was conducted to develop the conceptual framework and select an appropriate theoretical framework to inform the evaluation and understanding of AMU and AMR in Fijian livestock production. The first section focuses on AMR, AMU in livestock production focusing on cattle and poultry enterprises, surveillance programmes and metrics for quantifying AMU, and later parts focus on drivers influencing livestock farmers' and veterinary service professionals. In the last part, the socio-psychological theoretical frameworks are discussed, and the conceptual framework for this programme of research is presented.



2 Antimicrobial resistance phenomena: a one health approach

2.1 Overarching research framework

This review's primary purpose was to explore the literature to establish the current knowledge on AMU and AMR in developing countries. Initially, the review consolidates the literature on AMR as a global phenomenon and further explores the interrelationships between humans, livestock, and the environment in the agri-food value chain. Additionally, the review identifies the current AMU practices in livestock production systems and farm biosecurity management strategies used to mitigate animal health risks. The review provides insight into the access to and current status of veterinary services in developing countries. Further, the review provides an overview of the different metrics used in quantifying AMU in livestock production. It proposes a quantification framework and suitable metrics for quantification.

The review also provides insight into the legislative frameworks underpinning prescribing, dispensing, and using antimicrobials and the surveillance programmes on AMU and AMR in developed and developing countries. The review identifies the theoretical frameworks used by researchers in exploring and understanding AMU behaviour. It further identifies key studies that explored the psychological and contextual drivers of AMU and AMR. The review also consolidates the literature on the interrelationship between the farmers' and veterinary professionals' attitudes and knowledge of AMU and AMR.

The literature and information on AMU and AMR in livestock production systems in the Oceania region, particularly in Fiji, excluding Australia and New Zealand, is scarce [1-3]. Therefore, the literature on AMU and AMR from developing countries in the Oceania region, Asia Pacific, African and Caribbean regions were reviewed and used to frame the overall research questions listed in Section 1.3 above [1-3]. The following sections present a synthesis of current knowledge on AMU and AMR in developing countries, including Fiji. The review proposes a conceptual framework incorporating the factors identified and the identified hypothesized relationships, which are discussed in sections below. The methodology used in developing the overarching research framework is presented in chapter 3.

2.2 AMR: a global threat

AMR is a major global threat to human and animal health [4-6]. Although the direct links between AMU in livestock production systems and the increase in AMR in humans have yet to be established, the WHO, OIE and FAO advocate reduction in AMU and responsible use of antimicrobials. [4,6-8]. Globally, WHO, OIE and FAO have collaborated to combat AMR through the One Health approach, which promotes prudent use of antimicrobials via AMS programmes which aim to safeguard the health of humans, animals, and the environment [4-6].

Many farm level AMU monitoring studies have highlighted the increase in AMU in livestock globally [9-15]. The inappropriate use of antimicrobials in livestock production systems is of grave concern due to the risk of emergence and transmission of AMR genes via the agri-food value chains to humans [14,16]. The WHO has developed a global list of antibiotic resistant pathogens such as *Actinebacter baumannii, Pseudomonas aeruginosa*, and Enterobacteriaceae, such as *Escherichia coli* to enhance research on AMR [17]. Additionally, *Escherichia coli (E. coli),* followed by *Staphylococcus aureus, Klebsiella pneumoniae, Streptococcus pneumoniae, Acinetobacter baumannii, and Pseudomonas aeruginosa* have been reported to be the leading pathogens contributing to death globally [18]. The WHO has classified high-priority critically important antimicrobials (HP-CIAs), which are reserved for humans; however, these HP-CIAs are used in livestock production [19,20]. AMR is becoming more prevalent with the increasing number of microorganisms becoming resistant to many antimicrobials. Therefore, safeguarding these antimicrobials for future use is an important consideration [4-6,21].

The microorganisms develop antibiotic resistance over time, acquiring resistance due to gene mutations that can be transferred amongst microorganisms through transformation, transportation, or conjugation [21,22]. Different antibiotic resistance mechanisms have been identified, including limiting antimicrobial uptake, modification of its cell target, inactivation, and active efflux of antimicrobials [21,22]. Although the mechanism of antibiotic resistance action is understood, anthelmintic resistance is still not well understood. Figure 1 shows current understanding of anthelmintic resistance that includes helminths acquiring resistance through receptor loss or a decrease in target site attraction for the anthelmintics [23,24].

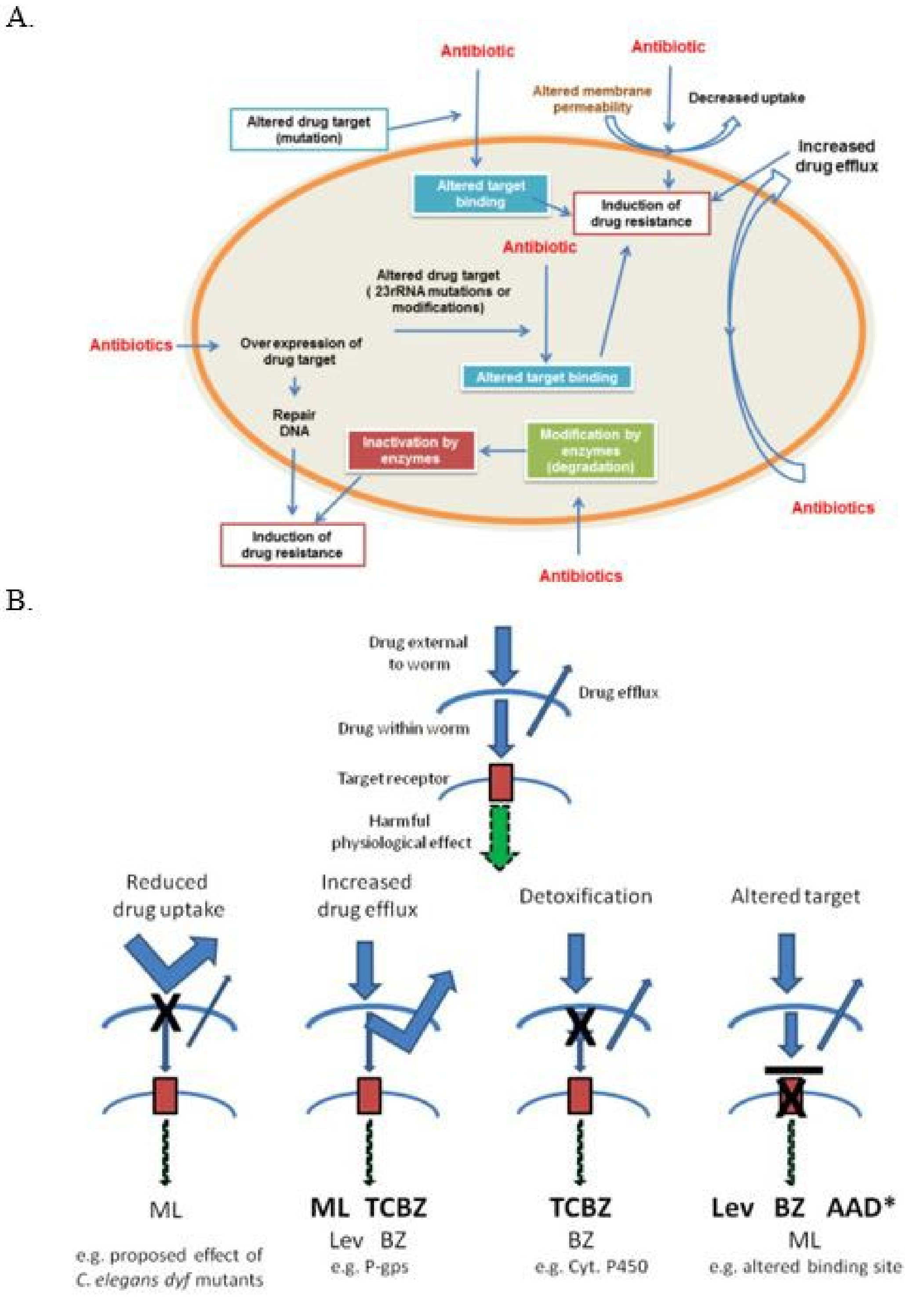


Figure 2.1 Mechanism of action of AMR (A. antibiotic resistance [22], B. anthelmintic resistance [24].

Livestock serve as dormant carriers of AMR genes, which can be easily transmitted to humans through the agri-food chain, direct contact, and the environment [4-6,21]. The AMR genes can be transmitted directly and indirectly through food, manure, sewage into the environment, which can be transmitted to animals and humans (illustrated in Figure 2) [4-6,21,25].

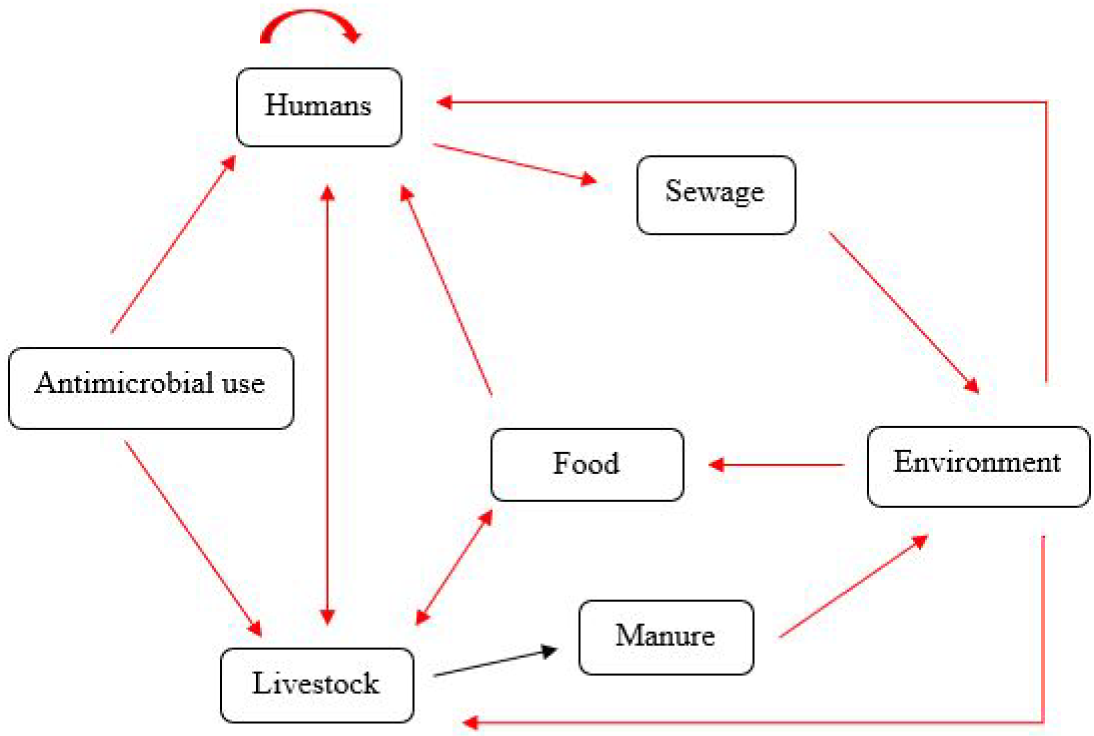


Figure 2.2 Transmission pathway of AMR, adopted from Woodhouse and Ward, 2013 [25].

Nevertheless, with the growing risks of transmission of AMR microbes from livestock farms into the environment and agri-food chain, as a one health mitigation measure, AMS programmes in the human and animal sector have been advocated [4,5,26]. Although much is known about AMR in humans, limited information is available on the AMU and AMR in the livestock production sector, especially in developing country contexts [4,6,8]. Although a greater emphasis is given to antibiotic resistance, anthelmintic resistance is also becoming an issue [22,24]. AMR is a risk to all countries; therefore, strategies and policies promoting responsible use need to be developed globally to curb the growing risks of AMR to humans [4,6,8]. Critical data on AMU and the drivers of AMU is required to create these AMS programmes, which may assist in curbing the drivers of AMU and AMR in developed and developing countries. Moreover, various robust interventions may perhaps be developed and re-designed once there is a better understanding of the psychological and contextual drivers of AMU and the AMR phenomena in all contexts [4,6]. The next section explores the AMR situation in Fiji.

2.3 AMR in Fiji

In the Oceania region, AMU surveillance programmes in both the animal and human sectors are in place in Australia [10,27] and New Zealand [28,29], but this is not the case in Fiji, where AMU remains unquantified. Additionally, the antimicrobial sales data for livestock raised for food use is also unknown. AMR in the Fijian human health sector, however, has been reported primarily in the clinical setting [30-32]. Additionally, in Fijian healthcare settings, AMR has been observed in pathogens that have been reported to be leading pathogens contributing to deaths globally, such as *Escherichia coli, Klebsiella pneumonaie, Staphylococcus aureas, Acinetobacter baumannii, pneumococcal* and *Shigella flexneri* [18,30-34]. In other developing countries, such as Vietnam, Ecuador, Ghana and India, a high prevalence of multidrug-resistant *E. coli* has been reported mainly in small scale, backyard poultry, including broiler and layer enterprises [35-38]. Similarly, AMR of salmonella in lactating cows has been reported in Ethiopia and beef cattle in Senegal [39,40]. However, AMR in the Fijian livestock sector is unknown. Although antibiotic use in dairy farming and anthelmintic use in sheep farming have been reported, the AMR is unknown [41,42]. Fiji adopted the National AMR action plan in 2015, and work has been carried out in the human health sector, but the livestock sector has been overlooked [43-45]. Therefore, evaluating and understanding the drivers of AMU and AMR and developing strategies to optimize the appropriate use of antimicrobials in the Fijian livestock sector is necessary. Addressing AMU and AMR at the national level contributes to and improves the AMR crisis globally due to its risk to humanity [46] .The livestock production and farming systems focusing on developing countries, including Fiji, will be discussed in the next section in detail.

2.4 AMU in livestock production systems: a focus on developing countries

2.4.1 Livestock production systems: a shift from traditional systems

Livestock production plays a significant role in farmers' livelihoods in developing countries [47-49]. Livestock production is rapidly changing globally due to the increasing global food demands [47-49]. In developing countries, almost one-third of gross domestic product is contributed by livestock production [47,48]. Additionally, 20% of the world population are small-holder livestock holders [50,51]. Globally, several millions of resource-poor farmers depend on small-holder livestock production systems that provide food and financial security [47-49,52]. Additionally, besides serving as a source of income, it assists in soil fertility, draught power and transportation [47,48]. Livestock production has been an important lifelong activity because it is a major source of protein and nutrition for humans [47,53,54]. Nevertheless, with the increasing global population, the demand for food of animal origins such as meat, milk and eggs has simultaneously increased [51,55].

Livestock were traditionally raised in extensive farming systems; however, there has been a radical shift into intensive commercial farming systems [56-58]. Although intensification of livestock production assists in meeting the demands which could not be achieved with traditionally practised extensive systems, it adds an array of risks such as deforestation, greenhouse gas emissions and loss of biodiversity due to more land cleared for livestock farming and cropland cleared for feed production [54]. It further adds burdens of risks to the agri-food value chain; therefore, sustaining the food supply of animal origin is an important consideration [47-49,56-58]. FAO has categorised different farming systems depending on the production practices and agro-ecological zones; however, such classification systems are not applicable when the climatic conditions and livestock production practices differ between developing and developed countries [47-49,59].

In developing countries, grazing systems are predominant and increasing herds of ruminants (cattle) raised in mixed (crop and livestock) systems indicates the increase in livestock production [47-49]. Pigs and poultry are mostly reared in intensive commercial production systems[47-49]. Mixed farming (crop and livestock) is predominant in developing countries; backyard farmers produce livestock for domestic consumption and, at times, sell excess animal products in the local market to buy plant-based food products [60-62]. These traditional backyard farming systems predominate in developing countries [48,59,63].

Livestock farmers are becoming market-orientated, where they produce livestock for both sale and domestic consumption [63-65]. However, there are no global criteria to differentiate between semi-commercial and backyard farming, as many factors influence backyard and semi-commercial farming production. Hence, farmers who produce and sell more than 50% of their products are considered to be raising animals in a semi-commercial farming system [47,62-65]. Intensive and commercial systems, with a higher stocking density per land mass, produce livestock only for sales. In these systems, disease control, higher production, quality, and reducing costs are the main goals [63-66]. However, environmentally sustainable organic systems are considered an alternative to intensive farming systems [47,48,59,67,68].

As global livestock production increases to meet increasing demands, poultry production is becoming the largest sector of livestock production [47,69]. Cattle and poultry production are the most common food animals produced in developing countries [47,62,69]. Poultry meat is one of the cheapest animal protein sources with less labour intensive production systems and requiring little land [66,70,71]. Small farms, usually less than 2 hectares, are predominant in developing countries; therefore, poultry production becomes more lucrative as it is ideally suited and is more profitable than extensive grazing animals [66,70-72]. Although small farms hardly employ farm labourers, it is less labour intensive than commercial systems [47,64,66]. Generally, farms are household-owned, with the male being the head of the household taking the lead in farm decisions on livestock which generate income compared to females who are more involved in small animals [49,73].

Globally, livestock production is on a trajectory of change in both developed and developing countries [47,69]. However, very little is known about Fijian livestock production systems. Even though Fiji is a small island country located in the South Pacific region, the food demands of animal origin are presumed to be like other developing countries [74-76]. Fiji comprises many small islands with two major islands, Viti Levu and Vanua Levu, where the majority of Fijians live and raise livestock. The largest island of Viti Levu is made up of Central and Western divisions and eight provinces (Rewa, Tailevu, Naitasiri, Namosi, Serua, Nadroga-Navosa, Ba and Ra) [74-76] (see Figure 2.3). The Central region is distinctly wetter compared to the drier Western part. Livestock contributes 10.6% to the national gross domestic product (GDP), and the last animal census was carried out in 2009 and, most recently, in 2021 [74-77].

The Fijian Ministry of Agriculture, through its Animal Health and Production division, promotes agricultural production and provides livestock services to Fijians [78,79]. Poultry and cattle are the primary farmed livestock, with most beef cattle farms located in the Western region and dairy farms in the Central area [42,74-76]. However, poultry (broiler chickens and laying hens) are distributed all over and are mostly commercial enterprises

[74-76,80,81]. Additionally, cattle herds have reduced due to ongoing cattle diseases [78,79]. However, recent livestock production and performance data are limited. Fiji has considerably smaller pastureland compared to other tropical countries [78]; however, very little is known about the livestock production systems used for cattle and poultry raised in Viti Levu, where the majority of livestock is produced to meet the local demands of food of animal origins. Farm biosecurity, including livestock management, plays an integral role; therefore this will be explored in next section.

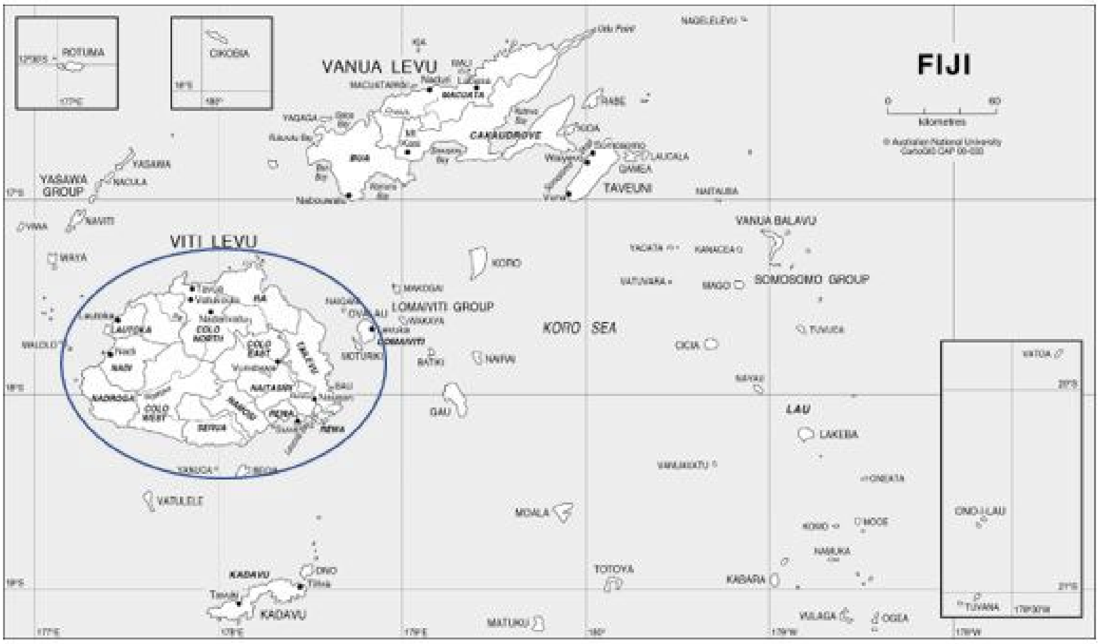


Figure 2.3 Island of Viti Levu with its provincial boundaries [82].

2.4.2 Farm biosecurity in livestock production

Biosecurity is defined as a range of measures implemented to mitigate the risk of introducing and spreading microorganisms amongst the herds and flocks of animals [83]. These biosecurity risks are higher when larger herds and flocks of animals are raised in smaller confinements [84-86].

Livestock, especially poultry, are usually raised in cages and sheds and cattle in paddocks over a shorter duration than traditional, extensive, and free-range systems [84-88]. Therefore, preventive, and therapeutic measures are used to mitigate risks that may be detrimental to livestock affecting livestock outputs and losses [66,84]. Biosecurity measures are employed by farmers to improve production, which results in increased household income, improved animal welfare and overall improved herd and flock health [53,84,89-93].

Different biosecurity measures are used in livestock farms, including separating sick animals from healthy herds and flocks, limiting personnel and visitors to farms by having barriers, manure, and carcasses management, and separating new animals from existing animals on the farm [84,87,88,94]. Maintaining safe and clean drinking water and feed systems, vermin and rodent control, cleaning and disinfection of sheds, cages, and paddocks, all in- all out batch systems for poultry and more importantly, disease management are other means of maintaining biosecurity [84,87,94]. A robust farm biosecurity infrastructure results in a healthy herd and flock of animals on farms and reduces the incidence of diseases in animals [53,84,89-93]. Maintaining farm biosecurity and production has been challenging for farmers in developing countries due to farmers' inability to implement biosecurity infrastructure [60,95-97]; therefore, striking a balance between increasing production and managing farm biosecurity risks has been a challenge faced by livestock farmers in developing countries [98,99].

Commercial systems are more financially capable of implementing farm biosecurity infrastructure [100-102]. Risk mitigation is the ultimate priority due to losses that may occur due to compromised farm biosecurity; however, it may be difficult for backyard and semi-commercial systems where farmers have limited resources accessibility [53,84,89-93]. Hence as part of a farm-level biosecurity risk management strategy, antimicrobials including antibiotics and anthelmintics (as well as other agents such as vaccines, medicated feed, nutraceuticals, and other herbal preparations) have been used to reduce the risk of microbial infection in the agri-food value chain [103-111]. In livestock production, antimicrobials are used to prevent diseases in healthy herds/flocks, also defined as prophylactic use [53,104,112-117]. Antimicrobials are also used to treat herds/flocks before any infection occurs, also described as metaphylactic use [113,118]. Antimicrobials used to treat any diseases are defined as therapeutic or curative, whilst antimicrobials used to increase production are defined as growth promotion [48,110,119-125]. Antimicrobials have traditionally been used to treat diseases in livestock; however, antimicrobials have also been used prophylactically in flocks/herds of animals and for growth promotion [53,104,112,116]. The prophylactic use may be predominant in commercial systems due to higher stock density, while AMU for growth promotion is predominant in developing countries [110,124,125].

On the contrary, developed countries like UK and EU have banned the use of antimicrobials for growth promotion; however, many developed and developing countries have not yet done the same [126,127]. Antibiotics continue to be used for growth promotion in the Asian Pacific region [104,128]. The EU has banned the prophylactic use of antimicrobials since January 2022 [129]. Although medicines [42] and herbal medicines [130] have been used in Fijian livestock production, AMU practice (prophylactic use, metaphylactic use and growth promotion) in Fijian livestock production is unknown. Unnecessary and inappropriate use of antimicrobials in livestock production systems is of grave concern due to the risk of emergence and transmission of antimicrobial resistance (AMR) genes via the agri-food value chains to humans [14,16]; therefore, an on-farm biosecurity risk management strategy is necessary which may assist in improving herd and flock health at farm level. Livestock production systems will be discussed in detail in the next section.

2.4.3 AMU in cattle and poultry production

Cattle and poultry production differ significantly in developed countries where the production is very specialist compared to developing countries [47,62,69]. Cattle production in developing countries tends to be dual purpose where milking cows provide milk and then, upon retiring, are slaughtered for meat; however, herds are not specialised dairy and beef breeds which are predominant in developed countries [47,62,69]. Poultry production is specialist due to the nature of birds: broiler birds (also referred as meat birds) raised purely for meat compared to layers raised for eggs; however, retired birds are slaughtered for meat also [47,62,69]. The highest amounts of antimicrobials are used in poultry production to mitigate risks from overcrowding and poor farm biosecurity [66,131-133]. This means that the demand for antimicrobials for livestock production has generally increased in developing countries [13,117,134-136]. Approximately 73% of all antibiotics are believed to be used in agriculture, with the highest antibiotic use reported in poultry and cattle enterprises [55,137,138]. The overall global consumption of antimicrobials is set to increase by 2030 [55,137,138].

AMU in cattle is highest in the earlier stages of production; calves are prone to scouring and are more susceptible to infectious disease compared to heifers, steers, breeding bulls and cattle [29,106,139-141]. The milking and dry cows are more prone to mastitis; therefore, antibiotics are used more than anthelmintics [141], which are more predominant in beef production [142,143]. Since cattle tend to graze and have higher chances of being exposed to parasites compared with pigs and poultry, they are usually administered anthelmintics to prevent helminth infections [142-144].

In poultry production, diseases are common in earlier stages of life compared to adult birds, and AMU tends to be higher in broiler enterprises than layer hens [29,106,140,141,145]. However, in breeder enterprises, the birds tend to have more chances of contracting diseases and are usually managed with antibiotics (for the broiler breeder), whilst the use of both antibiotics and anthelmintics have been reported in layer enterprises [106,117,135,136,140,146]. Antibiotic classes such β-lactam penicillins, tetracyclines, aminoglycosides, lincosamides, macrolides, quinolones, polypeptides, amphenicols and sulphonamides, and anthelmintics such as benzimidazoles and imidazothiazole derivatives are some of the standard antimicrobial classes used in developing countries [110,127,128,147]. These antimicrobials are often obtained over the counter without a prescription from a veterinarian in developing countries [53,148,149] Antimicrobials are usually administered individually in cattle, but at flock level in poultry flocks due to antimicrobials primarily being administered via drinking water in poultry production [29,117,136,145,150]. However, anthelmintics are administered to all cattle when dewormed compared to antibiotics which are mainly administered to animals individually and only to sick animals [29,136,145]. Additionally, antimicrobials have been used as growth promoters in developing and some developed countries [53,104,116].

Livestock farmers administer antimicrobials orally and parenterally to animals in different breeding stages based on the animal health risks [117,151-155]. However, farmers select antimicrobials based on availability and treatment outcomes [114,156-159]. Antimicrobials are also mixed in feed and administered [14]. Some livestock illnesses result from a lack of nutrition in feeds, which is common in the backyard and semi-commercial farming systems in developing countries where household refuse is used as feeds for livestock [160]. Livestock feed helps increase production as it supplements the nutrition required for production; however, due to the inflated costs of feeds, farmers opt to use antimicrobials as the first line of defence to mitigate any farm biosecurity [160-163]. Farmers also use other medicines to maintain farm biosecurity, but the use of any medicine increases the chance of residues being found in animal products [103-111,153,164,165]. Administering antimicrobials in excess of the prescribed therapeutic levels results in the transfer of antimicrobial residues to animal food products [116,166].

In the Oceania region, leptospirosis, highly pathogenic avian influenza, brucellosis, Newcastle disease, foot and mouth disease, tick-borne and gastrointestinal parasites are commonly reported animal diseases, and parasitic infections, flu/cold and coccidiosis were common diseases observed in animals [79,167]. In Fiji, the most common diseases reported are mastitis in dairy cows, and brucellosis and bovine tuberculosis in all cattle. Minimal information is available on the diseases in poultry production as animal health surveillance data is limited [42,79,130,167]. Additionally, the seasonal effects on animal health status are unknown even though seasonal changes are known to affect disease outbreaks in livestock herds and flocks [42,79,130,167].

There is little information available on the livestock production systems and the animal health status in Fijian livestock farms, are unknown. Therefore, it is essential to establish the AMU in cattle and poultry production so that policies targeting a reduction in AMU at the enterprise level could be targeted. Veterinary services are essential for livestock production; therefore, the next section will explore veterinary services, particularly in developing countries.

2.4.4 Veterinary services in developing countries

Veterinary services are also referred to as animal health services, one of the most critical infrastructures in developed and developing countries [168,169]. The veterinary services professionals advise livestock farmers on animal health and welfare and help implement other standards required to mitigate animal health risks and sustain food security [168,169]. The roles of veterinarian are becoming more evident and necessary with the threat of global animal health risks; therefore, the need for veterinarians to oversee the veterinary services delivery, including farm biosecurity risk management and, more importantly, manage and prescribe AMU in livestock production, is needed so that antimicrobials are more rationally used [168-172]. Additionally, the veterinarians are the ultimate guardians of the AMU in livestock [173]. However, farmers in developing countries are deprived of veterinary services due to a lack of qualified veterinarians [170-172]. Contrarily, veterinary services are much better in developed countries where farmers have access to specialised veterinarians who actively prescribe and dispense antimicrobials in livestock farms [174-176].

Nevertheless, instead of veterinarians, the para-veterinarians take the lead role in veterinary service delivery to the farmers due to the lack of veterinarians in developing countries [177]. Therefore, this adds further burdens of inappropriate AMU because the farmers mitigate risks themselves [172,178,179]. Additionally, para-veterinarians and veterinarians face many challenges, including the lack of clinical guidelines and veterinary legislative frameworks that guide effective veterinary services [180-182]. Essential resources such as trained professionals in veterinary and livestock production, transportation, consumables, and veterinary medicines required by veterinary professionals in executing their services are also limited [178,182,183]. Therefore, these limitations hinder the veterinary services and deprive farmers of veterinary services, particularly the smallholder farmers [182,184,185]. Additionally, there is a lack of political will to improve veterinary services and animal health in general [178,184].

Public-private partnerships have been considered an option in developing countries where veterinarians are in limited numbers to provide services to smallholder farmers [174,178,182]. International organisations such as OIE advocate that only veterinarians should prescribe antibiotics; however, the para-veterinarians continue to prescribe antibiotics in livestock production in developing countries [180-182]. This is not usually practised in developed countries where only veterinarians are authorised to prescribe antibiotics, but there is still limited information on antimicrobial prescribing patterns globally [175,181,186,187].

OIE provides competency guidelines for veterinarians, including guidance on antimicrobial prescribing and livestock management [184,188]. In addition, OIE delivers advice on training and development of para-veterinarians; however, few countries have sought assistance even though such help is provided free of charge to member countries [172,177]. In the Oceania region, apart from Australia and New Zealand, which have a robust veterinary services infrastructure, the veterinary services are limited in other countries [189]. Fiji is a member of OIE; however, it has not utilised the services of OIE in the area of improving veterinary legal frameworks and improving veterinary capacity [184,188]. A shortage of qualified veterinarians has been reported in Fiji [97]. The information on overall Fijian veterinary services delivery is unknown. In most developed countries such as the UK, the British Veterinary Association (BVA), in collaboration with Veterinary Medicines Directorate (VMD), set good practice guidelines for the use of veterinary medicines to assist veterinarians, pharmacists, and suitably qualified personnel [187,190]. Subsequently, these guidelines provide direction on the classification, administration, prescribing and supply of veterinary medicines, as well as requirements for record-keeping, development of standard operating procedures, the reporting of suspected adverse reactions, management of drug residues and withdrawal periods, disposal of medicines, and farm biosecurity measures [187,190]. In the Fijian context, the standards-setting bodies similar to UKs' VMD [186] and the BVA [187,191] for veterinary medicine use and veterinary services is unknown. However, the presence of para-veterinarians in Fiji has been reported, yet para-veterinarians' roles remain undefined in the Fijian veterinary legislation [177,192,193]. Additionally, the para-veterinarians' role in the Fijian veterinary services delivery and prescribing, dispensing, and using antimicrobials remains unknown [184,188]. Therefore, improving the legislative framework which governs the veterinary services is essential; however, understanding AMU behaviour amongst the veterinary services professionals is equally crucial so that targeted interventions could be made so that veterinary services are equipped to mitigate the risks posed by animal health and AMR which may have a devastating impact at country level [4,6,7]. Although a better understanding of AMU practice in livestock production is equally important, thus, this will be discussed in the next section.

2.4.5 AMU practice in livestock production

Unnecessary and inappropriate AMU practice in livestock production systems has been identified as one of the primary drivers of AMR [14,16]. Inappropriate AMU practices reported in developing countries have been attributed to a lack of veterinary oversight [53,99,104], but the definitions of categorising the inappropriate AMU practice remains ambiguous in both developed and developing countries [194].

Even though OIE discourage unnecessary and prolonged use of antimicrobials in livestock production, farmers continue to self-prescribe antimicrobials in livestock production systems in developing countries [195-197]. These imprudent AMU practices are prevalent in the backyard and semi-commercial production systems because AMU decisions are based on livestock farmers' clinical diagnoses rather than veterinarians, which is more common in commercial systems [53,99,140]. OIE and WHO advocates the responsible use of antimicrobials; however, compliance to such standards has been challenging, especially in resource-deprived developing countries [4,5]. The OIE published guidelines for the responsible and prudent use of antimicrobials, and the member countries set specific policies and guidelines on AMU [197,198]. The EU commissioned the ESVAC project and further implemented guidelines for prudent use of antimicrobials across Europe through the European Platform for the Responsible Using of Medicines in Animals (EPRUMA) [195,199,200].

Similarly, in the UK, the VMD implemented policies on the responsible use of animal medicines in farm animals for livestock keepers, including guidelines for accessing, using, and recording AMU [201]. Subsequently, the VMD, BVA, and National Office of Animal Health (NOAH) implemented national-level guidelines and compendiums that provide guidance to animal health, public health, and environmental health specialists [201-203]. Subsequently, the Responsible Use of Medicines in Agriculture (RUMA) set guidelines for beef, dairy, broiler, layer and other enterprises [204]. Policies on responsible antibiotic use for farm livestock under cascade were also established in the UK, where veterinarians are authorised to prescribe unauthorised antimicrobials that are not otherwise allowed for use [205]. The EMA and RUMA published the categorisation of antibiotics for use in livestock, particularly antibiotics by risk categories and antibiotics which were restricted for use as last resort [199,204,206].

The OIE has also published a comprehensive list of antimicrobials of veterinary importance and WHO identified several critically important antimicrobials for human medicine [19,20]. The use of WHO classified critically important antimicrobials in livestock production systems is prohibited and considered imprudent [19,20]. In the UK, VMD further implemented guidelines on off label and cascade use of antibiotics which is only permitted for use under the supervision of veterinarians [190,205]. The UK legislation legally categorises the antimicrobials and defines the prescribing authorisation such as Authorised Veterinary Medicine- General Sales List (AVM-GSL), Non-Food Animal Veterinarian, Pharmacist, Suitably Qualified Person (NFA-VPS), Prescription Only Medicine-Veterinarian, Pharmacist, Suitably Qualified Person (POM-VPS), and

Prescription Only Medicine- Veterinarian (POM-V)[203,207-209]. The suitably qualified person and trained professionals are authorised to sell medicines from authorised agricultural stores. However, antibiotics are legally classified as POM-V and can only be prescribed by veterinarians; therefore, deviating from the set regulatory framework and classification on prescribing and dispensing of the antimicrobials is considered imprudent [207,208].Such legal classification of antimicrobials is unheard of, however, in Australia, but antimicrobials are regulated by the Australian Pesticides and Veterinary Medicines Authority (APVMA) [210] and in New Zealand by the Ministry of Primary Industries(NZMPI) [211] and these legal categories and classifications are similar to the UK and other developed countries [207,208]. In South Pacific regions, clinical guidelines for use of antimicrobials have been published and used in the Australian cattle and poultry sectors [212,213]. However, a lack of legislation restricting AMU in livestock and standard clinical guidelines has been reported in Fiji [44]. In addition, Fijian veterinary legislation [193] and the Medicinal Products Act [214] does not provide interpretation and guidance on the antibiotics and anthelmintics for use in livestock.

Additionally, the legislation targeting antimicrobial residue levels in animal products only outlines standards on milk and milk products and excludes all other animal products [193,214,215]. The veterinary medicines, including antimicrobials, are not legally categorised, and the prescribing authorisation are not defined [214]. Therefore, the current AMU practice in livestock production is unknown. Globally, there has been a huge impetus to promote responsible use of antimicrobials; however, information on such strategies is limited in developing countries, particularly in the Oceania region, excluding Australia and New Zealand. No set standard framework is available for use in livestock production systems that could assist in categorising AMU practice in developing countries where irresponsible AMU practices are prevalent [53,99,104]. On the contrary, AMU practices in human health have taken the lead, and frameworks have been used to categorise the AMU practice [127]. With the vast difference in the AMU practice in developed and developing countries, it is evident that there is a need for an understanding of the AMU practice at the country level. Understanding of current surveillance programmes used for evaluating and understanding AMU is important; therefore, this topic will be discussed in the next section.

2.4.6 Surveillance programmes and challenges in quantifying AMU

AMU surveillance systems have been implemented, such as the ESVAC project [200,216,217], Global Antimicrobial Surveillance System (GLASS) [218], OIE surveillance on veterinary medicines use [219] and have been developed and implemented by many developed countries such as the USA, EU Canada, Japan and UK [4,6,220]. Additionally, the metrics for quantifying [221] and standardised reporting systems have been implemented in UK [209,222] and in EU [200,216,217,223]. However, this is not the case in many developing countries where data on AMU is not extensively available, and most remains unquantified [53,104]. Although there has been much impetus to quantify AMU in all contexts, there is no best and internationally accepted metric available for quantification of AMU, which can be used in all contexts [224,225]. The OIE has taken the lead in developing a national database and aggregated AMU report published annually; however, country-level data is still limited [219]. The EU developed a framework for AMU data collection parameters for each metric and set reference standards such as the defined daily and course dose [200,216,217]. Apart from AMU data, antimicrobial sales data was also recorded, and similarly, countries like the UK implemented AMU surveillance in the human and animal sectors [209,222,226]. Although various metrics are used with EU countries, the mg/PCU has been used to compare AMU at global level [219,227]. Various metrics with various parameter requirements poses a significant challenge for quantifying AMU at the country level [29,136,145,224,225,228]. Using a range of metrics adds to challenge of comparing AMU and benchmarking [209,217,228,229]. However, using multiple metrics allows for a better comparison of AMU at system and enterprise level. In the Fijian context, there has been no AMU surveillance conducted; therefore, the challenges are unknown. However, studies in other countries have demonstrated the complexities of quantifying AMU and how some challenges could be overcome [224,225,228,230,231]. AMU can be considered both quantitatively and qualitatively; it may be quantified as amounts used, or considered qualitatively in terms of practice (behaviour). Therefore, specific metrics used currently will be discussed in the next section. Also, the AMU practice in terms of behaviour will be discussed in later sections (Section 2.6).

2.5 Quantification of AMU: metrics and parameters

Globally OIE and EU established the milligram per kilogram (mg/kg) and milligram per population correction units (mg/PCU), respectively; however various metrics have been used globally [200,219,229]. The AMU and sales data have been reported using the mg/PCU (EU), and mg/kg (OIE) to report the AMU and sales data in the EU; however, antimicrobial sales data is reported by tonnes and AMU by mg/kg using OIE method [200,219,229].

Although a range of metrics has been used globally, there is no set standard metric that can be used for comparison between systems and enterprises, nationally and internationally, apart from the mg/PCU metric [200,204,217,224,227,229,231-234]. Additionally, various metrics require a range of different parameters (live weight, reference defined dose, course dose and population) for quantification [145,200,204,217,229,231-234]. However, the questions arise with a range of metrics; the metric that best explains AMU in different enterprises and systems, noting that all metrics report AMU based on various parameters. The milligram metric (mg) is the easiest for quantification as it accounts for the total mg of the active pharmaceutical/antimicrobial ingredients (API) used; however, it does not provide much information considering the livestock live weights differ considerably (cattle versus poultry) [200,217,229,233,234]. Therefore, using the mg adjusted by the PCU has been suggested by ESVAC while mg adjusted by animal biomass (weight in kg) and expressed as mg/kg biomass has been suggested by OIE; although the population of animals administered antibiotics but later died after administration are excluded from the quantification [200,217,229,233,234]. One PCU is equivalent to one kilogram of animal administered antimicrobials. The PCU, also referred to as the total weight of the population at risk, is calculated by multiplying the total population (number of animals on the farm, number of animals slaughtered (sold and on-farm), number of animals imported/exported) with the average live weight [200,217,229,233,234]. Although the EU has published standardised weights for use in the quantification of AMU, those weights are not applicable for use in developing countries because of the very different sizes of animal in developing country production systems compared with those found in developed countries [200,217,229,233,234]. Country-level estimates of livestock weight when treated is therefore recommended.

Contrary to mg/PCU, which is only recommended for quantifying antibiotics, the mg metrics can be used for both antibiotics and anthelmintics [209,235]. The mg/PCU metric does allow for comparison between different enterprises and systems. Moreover, it also allows a comparison of antibiotic use nationally with global use [227]. However, due to vast differences in the weights of animals in different production stages, the comparison with other countries must be made with caution [236,237] as some country reports consolidate values rather than by enterprises [146].

The estimation of antibiotic use is also strongly influenced by the type of enterprise [29,141,145]. For instance, cattle enterprises have longer production and life span on farms; therefore, the population at risk (PCU) remains the same; however, poultry enterprises' population and production dynamics differ [29,141,145]. The layer birds have longer production and life span; therefore, population adjustments are made based on the numbers of flock in and flock out, birds in the breeding and laying stage, and birds who have retired from laying eggs. Population adjustments are made based on the number of chicks, and birds in the laying to retirement stage [117,135,136,146]. Conversely, the population at risk is quite different in broiler enterprises due to the batch in and batch out practices. In broiler enterprises, birds' life span and production stage are shorter [117,135,136,146]. If antibiotic use is similar in all batches of broiler birds and the restocking batch sizes are identical, antibiotics used (mg/PCU) for a batch would collectively be the same for all batches [117,135,136,146]. Any differences between batches, though, complicates this calculation. This adds obstacles when interpreting antibiotic use in poultry enterprises, noting that the batch cycles, production stages, and population affect the quantification [117,135,136,146,224]. The over and underuse in comparison to the prescribed reference dose as per market authorisation and label is a growing issue; however, it can be only evaluated if the clinical diagnoses, indication and prescription pattern is known [200,217,229,233,234].

Additionally, the process requires prospective farm surveys rather than relying on farm records for information [200,217,229,233,234]. To simplify the process, ESVAC has provided an additional two metrics, which provides an overview on AMU by daily doses and course doses with reference to standard reference daily and course doses [200,217,229,233,234]. The ESVAC has published the reference recommended daily doses and course doses used for quantification; however, their applicability may be disputed in the developing country context [200,217,224,229,233,234]. Given that the ESVAC national reference daily dose and course doses are calculated based on averages from EU member countries, it may confound the quantification, especially when the production systems significantly differ [200,217,224,229,233,234]. The EU have stringent legal

frameworks that govern AMU in EU countries; therefore, using EU reference doses as reference enables establishing the current pattern of use [200,217,229,233,234].
The number of Defined Daily Doses (nDDDvet) and the number of Defined Course Doses (nDCDvet) is calculated by dividing the mg/PCU with the reference defined daily and course dose, respectively [200,217,229,233,234]. The reference doses are indicated by the dosage form and API [233]. The nDDDvet and nDCDvet assists in establishing the patterns of use based on daily doses and course doses, which could further be differentiated by dosage form (oral, parenteral and intramammary) [200,217,229,233,234]. Considering the gaps in ESVAC metrics, non-ESVAC metrics are an essential consideration; additionally, the estimation errors could be mitigated, which may arise using just the ESVAC metrics [200,204,217,224,229,231-234].

The milligrams of antibiotics administered per kg of body weight of animal treated(mg/kg) is calculated by dividing the total mg of antibiotics used with the weight of animal treated. The mg/kg accounts for the weight of animal at treatment rather than the PCU which accounts for the total population weight (herd/flock) at risk and is usually used in human health but is less prevalent in animal studies [224,238,239]. Its applicability has limitations; however, the mg/kg metric helps develop the national reference daily and course doses similar to EU [217,233]. The mg/kg metric also allows establishing patterns of use within systems and enterprises, but the mg/kg metric may be more meaningful if the animals are weighed at the time of treatment [224,225].

The treatment frequency (TF) metric is the only metric that takes into consideration the number of active ingredients of antibiotics used per pharmaceutical formulation adjusted by the population [232]; however, it discounts the milligrams of active ingredient used by bodyweight, therefore, does not provide a clear picture of the amounts of antibiotics used. It does, however, provide a pattern of the number of active antibiotic ingredients used [224,232]. The TF requires a two-stage calculation where the number of used daily doses (nUDDs) are first calculated by multiplying the number of animals administered, with duration, and the number of API in the pharmaceutical formulation, for instance, if there are two active ingredients in a parenteral injection, it will be counted as two treatments rather than one although it is one formulation/ dosage form [232]. Following the calculation of nUDDs, the TF is calculated by dividing the nUDDs by the total animal population on the farm [232]. The TF has been used to quantify AMU in Germany [232].

The percentage treated (% treated) has also been used, especially in the cattle sector in the UK [204]. Its use in other enterprises has also been advocated by RUMA [204]. The % metric considers all animals treated, including the dead animals, which is discounted when using the ESVAC mg/PCU metric; It is calculated by dividing the total number of animals treated with antibiotics divided by the total farm population [204]. The % metric indicates the proportion of animals exposed to antibiotics in an environmental context [204].

Dismissing the dead animals from the evaluation has not been given much consideration, although, in developing countries, animal carcasses may be left to rot in fields [240]. From an environmental perspective, the risks of transmission of resistant microorganisms through dead animal carcasses need further consideration in the research domain [240]. The number of doses per animal per day (dose-animal per day) metric has been used in the UK poultry sector, and the metric has been suggested for use in the non-poultry sector [204]. The dose-animal per day metric ignores the amounts of antibiotics used adjusted by live weight and is calculated by dividing the total number of doses of antibiotics per day divided by the total number of animals in the flock/herd per day [204]. It allows comparison of antibiotic doses used; however, attention must be taken when calculating, interpreting, and comparing AMU in this way, because antibiotics are administered in poultry at flock level in drinking in drinking water. In such cases, where flocks in a particular drinking line are administered antibiotics, the whole flock is treated whereas antibiotic use in cattle is individual animal-based, unlike flock level in poultry [29,136,145]. The various metrics that have been used for quantifying AMU is summarised in Table 2.1. There is still no golden standard for collecting AMU data in developing countries. Information can be obtained using cross-sectional surveys and information can be collected from farm records or using longitudinal studies [209,217,228,229]. The data source required for quantification and extrapolation has limitations [200,217,229,233,234]. Additionally, the accuracy of the farm's records or farmers' recollections of antibiotic use cannot be guaranteed [228,234].

The mg/PCU metric has been used widely to report antibiotic use [200,217,229,233,234]. On this basis, global antibiotic use in livestock is estimated to be 118 mg/PCU [219,227]. However, in Oceania regions, antibiotic use is estimated to be somewhat lower, being around 43.9 mg/PCU in the Solomon Islands, 44.1 mg/PCU in Papua New Guinea and 10.2mg/PCU in New Zealand [227,235]. However, estimated antibiotic use in the South

Pacific Oceania region is scarce and outdated and so quantification of AMU is necessary to establish the patterns of AMU [227,235]. Therefore, metrics outlined in Table 2.1 below will be considered for quantification of AMU.

Table 2.1 Metrics and parameters for quantification of antimicrobial use.

Metric	**Calculation**	**Requirements**
milligrams (mg)	=Total volume or amount ×strength Total mg per enterprise= total mg (oral) + total mg (parenteral, injection) + total mg (intramammary)	Volume or amount of active antimicrobial used per dose, duration of use, number of animals administered.
mg per population at risk (mg/PCU)	= Total mg / total weight of population at risk (kg)	Standardised estimated live weight of the animal at treatment, live, and slaughtered animals were only included in calculating population correction units (PCU), the weight of dead animals during the survey, total mg of antibiotic used.
Number of Defined Daily Dose(nDDDvet)	= Total mg / (DDDesvac (mg/kg) ×PCU (kg))	The total mg of antibiotic used, total PCU, ESVAC standards defined daily dose for antibiotics.
Number of Defined Course Dose (nDCDvet)	= Total mg/ (DCDesvac (mg/kg) ×PCU (kg))	total mg of antibiotic used, total PCU, ESVAC standards defined course dose for antibiotics.
mg per kilograms (mg/kg)	= Total mg / total body weight of animals administered (kg)	Total mg of antibiotic used, total live body weights of animals administered antibiotics only, standardised liveweight assigned to animals.

Treatment Frequency (TF) per day	= (nUDD/ total farm animal population)/ 90 days nUDD = Number of animals × duration × number of active ingredients per formulation	Total number of animals administered antibiotics, duration of treatment, number of active antibiotic ingredients per formulation used, total farm population during survey period.
Percentage treated (%)	= (number of animal treatment /farm animal population) x 100	The total number of animals administered antibiotics, the total number of animals on-farm during the survey period including dead animals.
Dose - animal per day	= (Total number of daily doses / total number of animal-day) / 90 days	Poultry- total number of birds, duration of treatment, Cattle -total number of daily doses, duration, number of animals administered antibiotics.

2.6 Drivers of AMU behaviour

AMU surveillance and quantification studies in livestock production systems have demonstrated the patterns of AMU and practice in developing countries [53,104]. However, there is a need for a clear understanding of socio-psychological motivations and contextual drivers behind the patterns of use [237]. The motivations of AMU behaviour can be better understood once the AMU behaviour is explored in-depth [157,241-243]. More importantly, farmers' and veterinary professionals' knowledge, attitudes, perceptions and behaviour towards AMU and AMR need to be explored [157,241-243].

2.6.1 Psychological and contextual drivers of AMU behaviour amongst farmer and veterinary professionals and their relationship

Farmers lacking knowledge and understanding of antimicrobials has been attributed to the recorded imprudent AMU practice reported in developing countries such as Cameroon, Ghana, Ethiopia, Nigeria, Uganda, Bangladesh, Indonesia, Malaysia, Thailand, and Vietnam [3,244]. Although farmers in developed countries like the UK are perceived to understand antimicrobials, they were unable to identify them [3,244]. Farmers with experience tend to understand antimicrobials and AMU better [238,239].

Knowledge on livestock management is usually passed on through generation to generation in households; however, studies in developing countries such as Tanzania, Kenya, Zimbabwe, Zambia, and Ghana have demonstrated that through experience, the knowledge and attitude towards prudent AMU improve [245,246]. In developing countries, farmers with lower socio-economic status tend to have less access to education [132,147]; hence they usually rely on their social networks for information and guidance [247]. Farmers who lack education are believed to have less knowledge of antimicrobials; thus, they engage in AMU behaviour, which may contravene standard practices [132,245,248,249]. Subsequently, the farmers engage in behaviour that may exacerbate inappropriate AMU practices [250,251].

Additionally, farmers administer antimicrobials (therapeutically and prophylactically) based on their judgement to protect mortality as loss of livestock would affect their income source [250,251]. Studies have demonstrated that improving farmers' knowledge by education optimises the responsible use of antimicrobials, but there are still misconceptions about AMU and AMR globally [3,244]

Unequivocally, veterinary professionals serve as knowledge hubs for the livestock farmers because farmers usually consult veterinary professionals when they face challenges that they cannot manage on farms [177,252]. Therefore, providing advice to farmers, veterinarians, and para-veterinarians influences AMU behaviour; however, actual AMU behaviour is based on farmers' intention and social capability [253-255]. For instance, veterinary professionals may prescribe the antimicrobials, but farmers administer them based on their ability to purchase and administer [158,244,248]. Studies have also reported that veterinary professionals find it challenging to share prescribing practices when farmers generally lack knowledge [250,251].

Para-veterinarians generally lack the training and knowledge that veterinarians hold; therefore, the risks of unwitting use of antimicrobials can be substantial [177,180,184]. Despite not having professional qualifications, para-veterinarians tend to prescribe and dispense antimicrobials in developing countries [256]. It is critically important to provide veterinary services to livestock farmers; however, the quality of services offered by para-veterinarians cannot be compared to the veterinarian [53,180,182,257,258]. Additionally, developing countries where para-veterinarians provide veterinary service tend to lack an understanding of AMU and AMR [172,179,181]. Studies have also reported a mixed level of knowledge and understanding of risks associated with imprudent AMU amongst veterinarians [252].

Nonetheless, improving knowledge of para-veterinarians have resulted in enhanced veterinary service delivery in developing countries [259]. Although farmers self-prescribe and imprudently use antimicrobials in developing countries, they generally perceive that the responsibility for promoting the responsible use of antimicrobials did not lie with them, and AMR was not an issue on their farms [159,260,261]. Additionally, farmers also believed that using antimicrobials was appropriate as it helps in improving production and prevents livestock from disease [38,159,260-262]. Farmers generally use medicines based on their experiences and usually rely on other farmers' advice in selecting and using medicines [158]. The lived experiences of the farmers shape their attitude towards risk management, including the use of antimicrobials as a risk mitigation measure [237,244]. Farmers also rely on their social network for other livestock advice [183]. Livestock farmers seek advice from other sources such as feed and medicine vendors [248,250,263]. Imprudent AMU practice influenced by the non-veterinarians is considered socially acceptable in developing countries [132,262,264].

Farmers in developing countries are of low socio-economic status; therefore, it affects their ability to access and afford resources, including antimicrobials, veterinary services, and farm infrastructure, affecting their risk management capability [54,132,245]. Additionally, in developing countries, large scale farmers tend to be better positioned and have capacity for on-farm biosecurity risk management compared to smallholder farmers [244,250]. Farmers in this cohort take steps to safeguard their livestock from risks as it provides an income source for their livelihoods [132,147].

Due to the lack of restrictions and guidance on AMU in legislation, farmers seek advice on livestock production and management from all sources possible and request antimicrobials without clinical need [53,104,132,147,179,245,263]. Therefore, due to social obligations, veterinary professionals are subjected to prescribing antimicrobials even though AMU is not justified [179,265]. Additionally, in resource-deprived developing countries, the veterinary professionals are usually unable to carry out farm visits to examine the animals; therefore, they mostly rely on the farmers' diagnoses and decisions [178,250,266].

Antimicrobial shortages and the high cost of medicines also affects the access and prescribing of medicines [158,159]. Additionally, due to easy access and lack of policies on regulating AMU, hoarding of antimicrobials have become of grave concern in developing countries [132,162,244,248,267,268]. Hoarding of medicines, including antimicrobials, promotes the self-prescribing of antimicrobials on farms [132,244]. Therefore, overall rational use of antimicrobials may be jeopardised, especially when hoarding farmers have more leverage of using antimicrobials compared to farmers who are unable to afford antimicrobials [158,195,268,269].

The drivers of AMU, including the information on knowledge, attitude, and behaviour of farmers and veterinarians, are available in developed countries, but there is still limited information in developing countries. In the Oceania region, a lot is known about the drivers of AMU and AMR in Australia and New Zealand [28,176,270]; however, the attitude, knowledge and behaviour towards AMU and AMR of Fijian farmers and veterinary professionals are unknown.

2.6.2 AMU behaviour change using AMS programmes

AMS programmes incorporating behavioural change interventions that promote the prudent use of antimicrobials can be designed and implemented once there is an understanding of the behavioural factors which drive AMU [8]. Various robust interventions may perhaps be better designed once there is a better understanding of the drivers of AMU and the AMR phenomena at the country level [4,6,271,272]. There is limited information on the socio-psychological drivers of AMU behaviour of livestock farmers in developing countries, which is essential in designing AMS programmes [2,8]. Globally, various AMS programmes have been designed; however, they cannot be implemented in all countries due to vast differences in psychological and contextual factors [236,237]. Therefore, it is imperative to consider the drivers of AMU behaviour at the country level to develop interventions promoting the responsible use of antimicrobials [247]. Studies have demonstrated that farmers expressed their intention to undertake training and awareness programmes which may increase their knowledge and understanding of risks associated with imprudent use of antimicrobials [170,172]. Training and awareness can be part of AMS programmes but identifying the critical stakeholders for implementing the AMS programmes is paramount [273]. The veterinarians and para-veterinarians are the best stakeholders to lead the AMS programmes [8,273,274]; however, it is essential to understand their knowledge and attitude towards AMU and AMR before they take the lead role in implementing these AMS programmes effectively. To understand AMU behaviour, it is necessary to select an appropriate theoretical framework. This is discussed in the next section.

2.7 Use of theoretical framework to understand the AMU behaviour

AMU behaviour can be better understood and explained once there is an understanding of farmers', veterinarians', and para-veterinarians' attitude and knowledge towards AMU and risks associated (AMR) with imprudent AMU [253-255]. Therefore, an understanding of theoretical frameworks which could assist in understanding AMU behaviour is an important consideration.

2.7.1 Theoretical frameworks

To establish and understand the AMU drivers, an important step is to understand the livestock farmers' and veterinary professionals' attitudes and knowledge which shapes their AMU behaviour [263]. Socio-psychological theories such as Theory of Reason Action (TRA) [275], Health Belief Model (HBM) [276] and Theory of Planned Behaviour (TPB) [241,277] have been used as theoretical frameworks to understand and explain people's behaviour. Therefore, adopting a theoretical framework to explore and understand behaviour is an important consideration. TPB, TRA and HBM are some of the most common theoretical frameworks that are used (although there are others). These are the ones that will be explored in detail in section 2.6.1.1 and onwards [157,275,278-281].

2.7.1.1 Theory of Reasoned Action (TRA)

An intention influences behaviour and the intention is the degree to which an individual may engage in a behaviour. The intention is based on the person's will or aim to achieve the behaviour [157,279,280,282].

Attitude, subjective norms, and volitional control influences intention in the theory of reasoned action, which make up the framework of the TRA [157,279,280,282]. A series of beliefs form a person's attitude. The consequence of the behaviour is evaluated based on the outcome of the behaviour, which may be optimistic, valuable, helpful, looked-for, gainful, or something good according to the person. Therefore, these outcomes shape the person's behaviour. Ideologically, there is a greater chance of a person engaging in that behaviour based on the outcome [283,284].

Additionally, subjective norms are perceived social pressures to engage or not to engage in a certain behaviour, which is determined by normative beliefs [281,285]. Certain behaviours are explicitly performed to please people such as family, neighbours, social network or association members, religious figures, veterinarians, or other people we hold in high esteem [283,285,286]. However, the expectations with which a person tries to comply may or may not be based on reality [283,285,286]. Hence, the subjective norms result from behaviour we perceive these important people expect from us and our desire to comply with their perceived expectations [281,283].

The behaviour cannot happen without the person's will; thus, behaviour has to be under volitional control to happen [287]. The behaviour can only result when the person can decide whether to engage or not to engage in a certain behaviour. When there is less volitional control or willingness despite an outstanding overall intention, the TRA is not useful in predicting or explaining a behaviour. However, generally, TRA is useful in identifying where and how to target strategies for behaviour change [275,283,285,286,288].

2.7.1.2 Theory of Planned Behaviour (TPB)

The TPB has been used in social sciences, psychology, education, and human health to explore and understand behaviour [241,275,277,289,290]. Although TPB is an extension of the TRA, TPB supersedes TRA overcoming its limitations [283,285].

The attitude towards behaviour, subjective norms and perceived behavioural control encompasses the central key constructs of TPB. The intention to perform or decide depends on the three factors; however, other factors such as environmental, policy, socioeconomic, and demographic may equally influence the decision-making processes

[275]. Knowledge and physical resources also influence the decision-making process. Moreover, it is believed that a person's behaviour is based more on their personal traits and the surroundings in which the person performs or decides [157,241,275,281,283].
The behavioural control construct is concerned with perceived control over the performance of a behaviour [241]. The control beliefs impact the behavioural control that either assists or obstructs behaviour performance. Moreover, behavioural control is more concerned with how easy or difficult it is to carry out a behaviour [275,279,280]. It is also believed that the more resources and opportunities people think they own, the greater should be their perceived control over their behaviour. Also, it is worth noting that when people believe they have less control over performing the behaviour due to required resources, their intention to perform that behaviour may be low despite the person having a favourable attitude or being socially influenced concerning the performance of that behaviour [285,287].

For instance, a farming strategy used in eastern Europe would be different from the Oceania region due to climatic factors, geography, veterinary services and extension advice, animal health status, socioeconomic status, attitude and access to information, cultural and moral values. The resources required by farmers may therefore differ in different settings, although the overall intent of the farmer in any setting is to ensure sustainable production for economic, social and food security. Hence, understanding the attitude, subjective norms (social influence), and perceived behavioural controls that shape the farmer's behaviour is important in identifying and planning interventions by way of policy and AMS programmes whilst providing the necessary resources to improve compliance to intervention. TPB helps us to understand a person's compliance and support for change and how best new policies could be implemented or adopted in a setting [114].

2.7.1.3 Health Belief Model (HBM)

The HBM is one of the oldest and most widely used value-expectancy theories to explain health-related behaviour alterations and guide health behaviour interventions [291]. The main constructs comprise perceived susceptibility, severity, benefits, barriers, cues to action, and self-efficacy [292]. This model is mainly used to predict why people engage in prevention, screening and controlling health conditions [293]. Perceived susceptibility is the belief about getting a disease or condition, whilst perceived severity is the belief about the seriousness of the situation or the consequences of not treating a condition. Perceived benefits are beliefs about positive aspects of health action, and perceived barriers are beliefs about the potential negative aspects of health action. The cues to action are the factors that trigger action. Self-efficacy is the belief that one can achieve the desired outcome [286,287,289]. HBM is an appropriate framework in situations where risks or health conditions are known. This theory is used to understand why people mitigate the health risk or condition or participate in the screening or control of the disease. However, knowledge is critical in HBM [293]. HBM has been used in human health studies; however, HBM's application in exploring and understanding livestock farmers' AMU behaviour is limited.

2.8 The rationale for the theory of planned behaviour

HBM has been used widely in research and recommended for use in developing educational health programs, although limitation of the model has been widely acknowledged [291]. The HBM was developed to study behaviour that was easy to perform [292]; however, they are not feasible in exploring and understanding barriers and facilitators of performing the behaviour. Contrarily, the perceived behavioural control construct of TPB focuses on those attributes [283,286]. Behaviour that is not under one's volitional control cannot be examined using the HBM; however TPB model acknowledges that intention is the best predictor of the behaviour [276,283]. Self-efficacy construct in HBM is the belief that one can achieve the behaviour required to execute the outcome, which differs from behavioural control in TPB, where behavioural control is based on how easy or difficult it is to perform a behaviour rather than a person's perception of their ability to perform a behaviour [291,294].

The behavioural controls provide further insight into the other factors that may inhibit or facilitate the action or behaviour [276]. Madded et al. (1992) compared the two theories (TRA and TPB) concerning the prediction of behavioural intentions and target behaviour. They demonstrated that intentions and target behaviour could be predicted by assessing the perceived behavioural control over the behaviour. They also demonstrated that if behaviour is not under complete volitional control, then perceived behavioural control can provide valuable information for predicting target behaviour [285]. Nevertheless, studies have demonstrated that HBM effectively improves knowledge to change behaviour [295]. Studies have also demonstrated that TPB, compared to HBM, is effective in understanding the behaviour of interest [276]. However, both TRA and TPB are not behaviour change theories but have been used to explore and understand the attitude and behaviour of farmers and veterinarians towards AMU and AMR [242,243,255,296-305].

Although TPB has been used both in animal and human health studies to explore and understand behaviour and identify and implement interventions promoting prudent use of antimicrobials, these studies have been more predominantly set in developed countries than very limited studies in developing countries [242,243,255,283,296-308]. Moreover, although information on AMU behaviour and knowledge and attitude towards AMU and AMR is slowly becoming accessible in all developed and some developing countries, the knowledge and attitude of Fijian farmers towards AMU and AMR remain unknown. Therefore, the theoretical framework of TPB presented in Figure 2.4 would assist in exploring and understanding the knowledge, attitude and behaviour of the livestock farmers and veterinary professionals, which may assist in developing policies optimising appropriate AMU practices.

Furthermore, TPB has been widely supported and recommended for socio-psychological studies [272,299,309]. However, TPB fails to consider involuntary background drivers, which influences AMU behaviour [310,311]. Additionally, it also fails to account for emotions, which also affects the AMU behaviours [2,312]. Therefore, actual behavioural controls such as environmental, policy, socioeconomic and demographic, livestock production and management factors, which may influence the decision-making processes, need to be considered [275,310]. Although socio-economic and demographic factors influence livestock production systems and management practices [270,313,314], the current Fijian livestock production and management practices are also unknown. Additionally, there are differences in contextual drivers such as legal framework, policies, and procedures relating to livestock production and management globally, therefore understanding such contextual drivers at local level is crucial [236,237]. Nevertheless, the TPB assists in exploring and understanding the knowledge, attitude, and behaviour towards AMU and AMR; however, it does not allow establishing other contextual drivers of AMU; therefore, conceptualisation of these constructs is an important consideration. The findings of the review are synthesised and presented in the next section.

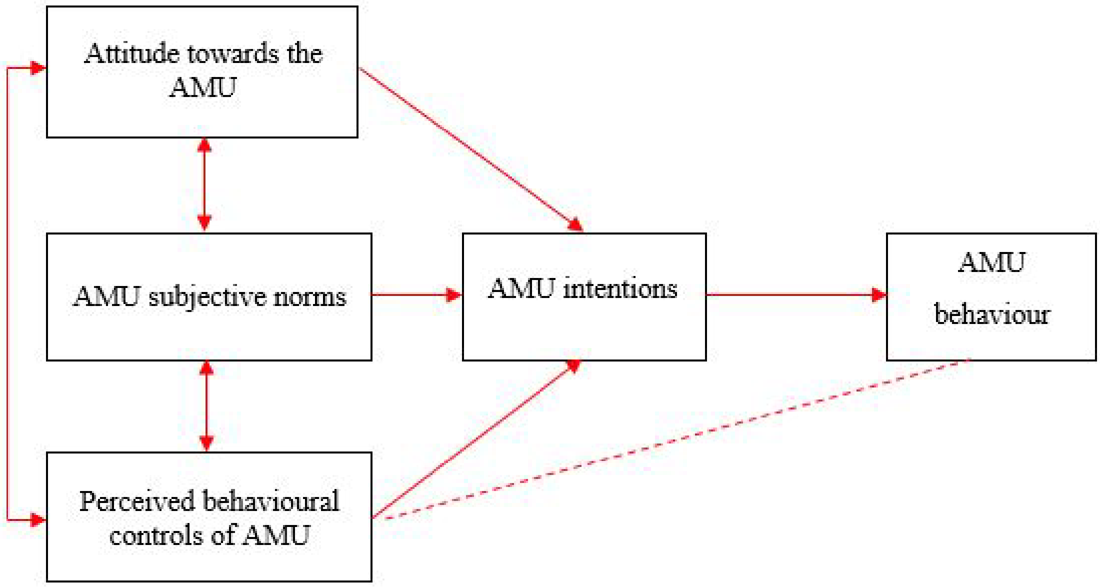


Figure 2.4 Theoretical framework of Theory of planned behaviour (TPB) adopted for understanding AMU behaviour.

2.9 Synthesis

In essence, the above review of relevant literature and theoretical frameworks revealed the contextual and psychological factors that influence AMU and AMR. The review of various metrics reveals various approaches to quantifying AMU in livestock production systems. Several conclusions can be drawn from the literature review relating to the factors influencing AMU and AMR in livestock production systems. First, assessing the transmission pathway of AMR provides an overview of the spread of the AMR through the agri-food value chain and how each sector, i.e. livestock, environment, and humans, are linked. The review also demonstrates the current situation of AMR in the human health sector and the lack of information on AMU and AMR in the Fijian livestock sector.

Additionally, the review demonstrates the limited information about livestock production and management. However, the literature demonstrates the intensification and commercialisation of farming systems, notably the high demand for meat, milk, and eggs globally. The livestock (cattle and poultry) production and management, including farm biosecurity practices, were unknown. Even though animal health epidemiological data is available in developed countries, such critical information seems limited in developing countries. Specifically, the animal health status and the AMU in the Fijian cattle and poultry production remains unknown. Evaluating and understanding the on-farm biosecurity risk management is critically important; therefore, farm biosecurity risk management and feed and medicine used as part of farm biosecurity risk management are important considerations. Veterinary services are essential for livestock production; however, little was known about access to and deliverance of veterinary services in Fiji. The literature review in the above sections highlights the need to evaluate and understand AMU and AMR in livestock production systems from a developing country's perspective.

It also highlights the need to use theoretical frameworks to explore and understand the in-depth knowledge and AMU behaviour by livestock farmers and veterinary professionals in developing countries. Although a body of knowledge is available on AMU and AMR in developed countries [53,104,237,242,243], very little is known about the drivers of AMU and AMR in developing countries.

The surveillance frameworks, quantitative methods and metrics used to quantify AMU in other countries could be considered due to the scarcity of information necessary in the Fijian context. Therefore, ESVAC [200], RUMA [204] and other previously used frameworks used by Cuong et al. [110,136], Mills et al.[234], Redding et al.[145], and Hommerich et al.[232] could be considered in developing the methodology to address quantitative (AMU) objectives discussed in detail in the sections above and outlined in Chapter 3 [217,229,233]. Similarly, the BVA, EPRUMA, ESVAC, and OIE frameworks and human health frameworks for categorising AMU practice could be considered in developing a framework to evaluate the AMU practice, which is discussed in detail in Chapter 3 [20,127,187,199,206]. The psychological (theoretical) based quantitative and qualitative approaches used in exploring and understanding the drivers of AMU were also explored [223,255,315]. The methods used for exploring knowledge and understanding of AMU and AMR amongst farmers and veterinary professionals, which have been mainly conducted in developed countries, were explored, and could be considered for developing frameworks for addressing qualitative research objectives [178,182,183].

The review of theoretical frameworks (sections 2.7 and 2.8) such as TPB [157,283], HBM [276] and TRA [283] demonstrated that the TPB theoretical framework has been used in previous studies in developed countries, but their use in exploring and understanding attitude, knowledge and behaviour towards AMU and AMR amongst livestock farmers and veterinary professions was minimal [253-255,272,316]. Also, literature on veterinary services, a crucial element of livestock production and management in developing countries, was limited [177,271,274]. Therefore, establishing knowledge, attitude and behaviour of livestock farmers and veterinary professionals on AMU and AMR is an important consideration.

The review demonstrates that TPB has been the dominant theoretical framework used in social sciences, psychology, education, agriculture, and human health to explore and understand behaviour. TPB could help explore and understand AMU and AMR because it helps to understand the psycho-social factors that lead to AMU behaviour. TPB assists in constructing an insight into the attitudes towards behaviour, norms, perceived controls, and other barriers to the behaviour [157,283]. TPB can be used in designing and operationalising research exploring behaviour as it helps to understand how individuals behave across different settings, scenarios, and situations [253-255,272,316]. Moreover, TPB also assists in gathering essential socio-psychological information required in developing interventions. Therefore, using TPB as the theoretical framework could be considered to elucidate an insight into the knowledge and understanding would provide a more holistic picture of the AMU and AMR in livestock production systems.

Different methodological approaches, such as focus groups, surveys and interviews, have been used to elucidate people's attitudes and knowledge [317,318]. Focus groups involve specific themes or topics, resulting in different spans or breadth of coverage [319]. It is less time-consuming and more focused on how group members respond to a specific topic area rather than the exploration of an individual's understanding of a topic area [317,318]. For instance, a focus group allows the engagement of many stakeholders, from farmers, veterinary professionals, and other stakeholders such as abattoir staff, farm gate wholesalers, processors, and consumers [85]. However, this may result in some reservation amongst participants whereby they do not speak freely and express their views [317,318]. Such intimidation is usually due to cultural, social, organisational and community-level differences [317,318].

In contrast, individual, semi-structured interviews may be more time-consuming, but they allow exploration of attitude, knowledge, and behaviour at a convenient place of the individual's liking rather than the selection of a location suitable for a focus groups, which may be logistically challenging [317-319]. Developing an explicit, structured question requires a prior understanding of attitude, knowledge and behaviour toward AMU and AMR in the local context to develop a framework to investigate AMU behaviour [317]. Therefore, an established theory with complete constructs needs to be used to guide methodology development [318].

The literature also demonstrates the applicability and suitability of the TPB in exploring and understanding the drivers of AMU behaviour. The role of theoretical frameworks aiding the development of the research framework will be discussed in detail in Chapter 3. The previous sections attest that the various characteristics of farmers (socio-economic and demographic, attitude, knowledge, and behavioural factors) and farms (livestock production, management, farm biosecurity, animal health, and other environmental factors) influence the AMU and AMR in livestock production. An understanding of these factors therefore provides the fundamental concepts which have been conceptualised (Section 2.8). The livestock production and management strategies differ significantly between enterprises, systems, and countries [53,314,320]. Therefore, the farmer and farm factors identified through the review require further investigation in the Fijian context.

The psychological and contextual drivers (such as legal frameworks, policies, and procedures) relating to livestock production and management also differ [53,314,320]. Therefore, the direct application of inferences and policies developed based on these studies may not be practical unless country-level behavioural investigations are conducted [247]. A broader understanding of behaviour is critically important when there is limited knowledge of the area of research in the research setting. Hence, the theoretical framework (TPB, Section 2.7 and 2.8) could be considered to explore psychological and other contextual drivers of AMU behaviour. With the limitations presented in TPB, as discussed in the section above, incorporating the conceptual framework not only addresses the limitations of the theoretical framework (TPB) but also provides an overarching framework for framing and addressing the research questions in this PhD research programme. Hence, further studies are required to evaluate and understand the AMU and drivers of AMU and AMR in the Fijian context to address the knowledge gaps identified through the review. Accordingly, the following section proposes a conceptual framework incorporating the factors identified and the identified hypothesised relationships.

2.10 Conceptualisation of study

TPB as a socio-psychological theoretical framework allows exploring and understanding the attitude, knowledge and behaviour towards AMU and AMR. However, the inclusion of a conceptual framework provides the direction to the study. Further, it adds the background factors such as individual and social factors and environmental factors, usually not addressed in the TPB model [310,311,321]. The TPB authors suggest incorporating background factors which are missed out in the traditional TPB framework [310,311,321]. The present literature review is used to conceptualise the drivers of AMU behaviour which assist in designing the methodological approaches for this thesis discussed in Chapter 3.

2.10.1 The conceptualisation of AMU in livestock farms

Demographic [310,322] and socio-economic factors [52,310,323] such as age, educational level, experience, and geographical location [310,324] influence the livestock production system used and approaches taken in animal health risk management [270,313,314,325]. The backyard farming system dominates in developing countries [60,61,63]. The backyard farmers transit into semi-commercial farming systems when they produce single or multiple livestock for domestic consumption and at times sell to buy plant-based food products; hence this approach benefits farmers directly [59-61]. Although financial returns from the sale of organic animal-based products are usually higher [326,327], the conventional system of farming is standard [156,328], where farm management decisions are influenced by friends and neighbours [114,156,157,241,282]. Therefore, it shapes the attitude and intention of the farmers [114,310,329,330].

Socio-economic status affects farmers' ability to seek veterinary advice on animal health production and improve farm biosecurity infrastructure [60,95-97]. It indirectly impacts livestock production, affecting farmers' income source [98,99,265,331]. The animal health and disease mitigation capability of the farmer is affected by their ability to access resources to mitigate farm biosecurity risks [53,89-93].

The veterinary services impact the decision making relating to AMU as veterinarians serve as a knowledge hub for the farmers [177,332]. The knowledge disseminated by veterinarians to farmers influences the behaviour of the farmers [250,253-255,262,284,306,333,334].

Livestock production systems are intensified and commercialised [56-58], with larger flocks/herds of animals produced in smaller confinements (sheds, cages, and paddocks) and shorter duration than traditional, extensive, and free-range systems to produce milk, meat and eggs [57,335-337]. The challenges to animal health and biosecurity at farms are higher; hence farm risks are managed to sustain production [100-102]. Farmers use antimicrobials, including antibiotics and anthelmintics (as well as other agents such as vaccines, medicated feed, nutraceuticals, and other herbal preparations [103-111]. Farmers use antimicrobials therapeutically on animals [112], prophylactically to prevent diseases [53,104,113-117,315], metaphylactically to treat diseases based on biosecurity intelligence or advice to prevent diseases [113,118] and for growth promotion purposes [110,119-125]. Disease incidence is higher during earlier stages of production [106,140]. Antimicrobials used on farms come from a range of possible sources, such as by prescription from veterinarians [28,272,338], purchased over the counter from pharmacies [339,340], from feed stores, wholesalers, para-veterinarians [53,149,341] or online stores [342].

Antimicrobials may also be kept in the farm medicine cabinet when leftover antimicrobials from incomplete courses are saved for later use [158,244,248]. Farmers then self-prescribe the antimicrobials when the need arises later [343,344]. However, antimicrobials are easily accessible in developing countries [53,99,104,140,345,346].
The farmer makes critical decisions on AMU on the farm, based on the farmers' experience and knowledge, or presenting clinical symptoms in animals, prior veterinary advice, advice from neighbours, or as per the label of the medicine bottle [53,99,104,140,250,331,332,347].

Farmers decide on the AMU, including the class of antimicrobial, dosage form, strength, number of animals administered and duration period and the breeding stages that are treated [117,151-155,231]. These choices affect the treatment outcome [114,156,157].
The feed requirements for different enterprises, types of feed used, and amount of feed used in different livestock production systems differ. The farmer's socio-economic status impacts their ability to procure and use feed on the farm [14]. Feed increases output; however, it may compromise animal health and biosecurity [161,162]. The feed may serve as a medium for administering antimicrobials on-farm, which directly impacts the behaviour, particularly the number and amount of antimicrobials that the farmer mixes in

feed, affecting overall AMU on-farm [163]. Other medicines may also be used as part of farm biosecurity risk management; however, these medicines have implications on production, especially when they are organic compared to conventional farms [103-111,153,164,165]. The overdosing and subtherapeutic administration of antimicrobials will ultimately impact animal health, farm biosecurity risk management effects and antimicrobial residue levels in food from animal origins [116,166].

2.10.2 Visualisation of the conceptual framework

The summary of key constructs identified and rearranged shaped the conceptual framework presented in Figure 2.5.

A. **Socio-economic and demographic factors** include socio-economic and demographic attributes such as geographical location (province, division), age, gender, education level, ethnicity, socio-economic status (gross domestic product per capita), household income from farming and sale of animals for slaughter.
B. **Veterinary services encompass** the veterinarian and para-veterinarian farm extension advisory and visits.
C. **Biosecurity and animal health** include the farm biosecurity risks which affect the livestock production systems. Farm biosecurity risk management strategies include measures to control biosecurity, animal disease risk mitigation and elimination.
D. **Access to antimicrobials** includes access to antimicrobials from veterinarians with prescription, over the counter from retail pharmacists, from feed stores, neighbours, farm medicine cabinets, over the counter from para-veterinarians or contractors.
E. **Feed and other medicines** include medicated feed use, vaccines, feed supplements, antiprotozoal use, antiseptic and disinfectants, agricultural compounds, and herbal remedies.
F. **Livestock farm production and management** is a crucial construct that includes farming system (backyard, semi-commercial, commercial), animal species raised (enterprise type: beef, dairy, broiler, layer, mixed), farm size, farm tenure, production type (conventional, organic), farm ownership, years of experience, farm employees, type of farming, association memberships, livestock population by production stages, commodity produced, farm slaughtering, fencing, animal housing, grazing, poultry housing, feed milling facility and farm records.

G. **Antimicrobial use** in animals based on date, name**,** volume/amount, strength, number of animals administered, dosage form, pack size, duration, and AMU records.

All these constructs connect to the central construct, **farmers' attitudes, behaviour, and knowledge**.

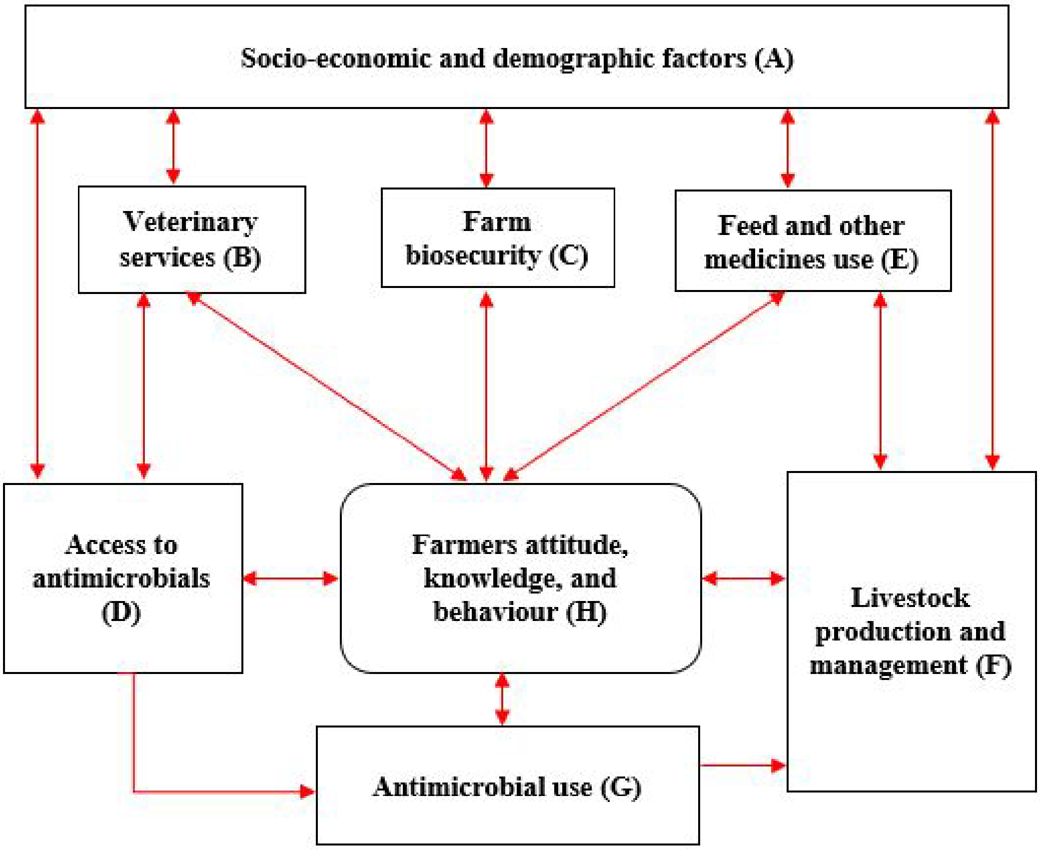


Figure 2.5 Conceptual framework for antimicrobial use in livestock farms (developed using section 2.10)

The AMU can be quantified using ESVAC metrics [200,217,221,222,229,233,234] non ESVAC metrics [200,204,229,231,232] and be guided by the conceptual framework (see Figure 2.5); however, the construct of farmer AMU behaviour encompassing the attitude, knowledge and behaviour cannot be elicited using this conceptual framework alone. Therefore, using the conceptual and theoretical framework, the methodology was designed which is explained in chapter 3 and in-depth in individual chapters (Chapters 4,5,6,7,8).

2.11 Implications of the research

This thesis demonstrates several knowledge gaps, notably in the livestock sector. Although this literature review indicates the presence of AMR in the Fijian human health sector, knowledge on AMU and AMR in the livestock sector remains unknown. Additionally, the AMU practice is also unknown, and the motivation behind the AMU is also unknown. This literature review further demonstrates the justification for the number of studies presented as chapters to address the knowledge gaps.

Although most studies have quantified the AMU, the majority fail to identify the drivers of AMU amongst the livestock farmers and veterinary professionals. The interrelationships are also hardly explored [11,12,304,348,349]. Additionally, either quantitative or qualitative approaches are taken; however, very few studies have used mixed methods [127].

This literature review further demonstrates that information on AMU by different enterprises and systems is also limited, although livestock production is intensifying and commercialising globally.

In addition, very few studies have used TPB as a theoretical framework to understand the attitude and knowledge of farmers and veterinary professionals in developing countries [53,221,350]. The mg/PCU metric is currently used to compare with global antibiotic use; however other metrics (ESVAC and non ESVAC) have hardly been used in developing country contexts. This literature review also demonstrates the different environment and socio-economic and demographic drivers which influence AMU behaviour; however, such conceptual models are limited and have hardly been used to investigate the drivers of AMU in developing countries. Therefore, the current PhD thesis will contribute knowledge on AMU and AMR using various methodological approaches in Fiji, where AMU and AMR in Fijian livestock production systems are unknown.

In conclusion, the outcome of the current thesis is critical in strategizing the mitigation approaches towards curbing the imprudent AMU practices and curbing the growing risks of AMR in Fiji. Although the novelty of this thesis is largely attributed to adding knowledge on AMU and AMR from various aspects such as farm enterprises, farming systems, farmer, veterinary services and livestock production and management, it provides theoretical, conceptual and quantification frameworks which could be used in developing countries where AMU and AMR remain unquantified and unexplored, especially in Oceania countries which share similar geographical and climatic conditions. The conceptual and theoretical framework used in this thesis provides a platform for future research to be conducted in specific areas identified through this thesis.

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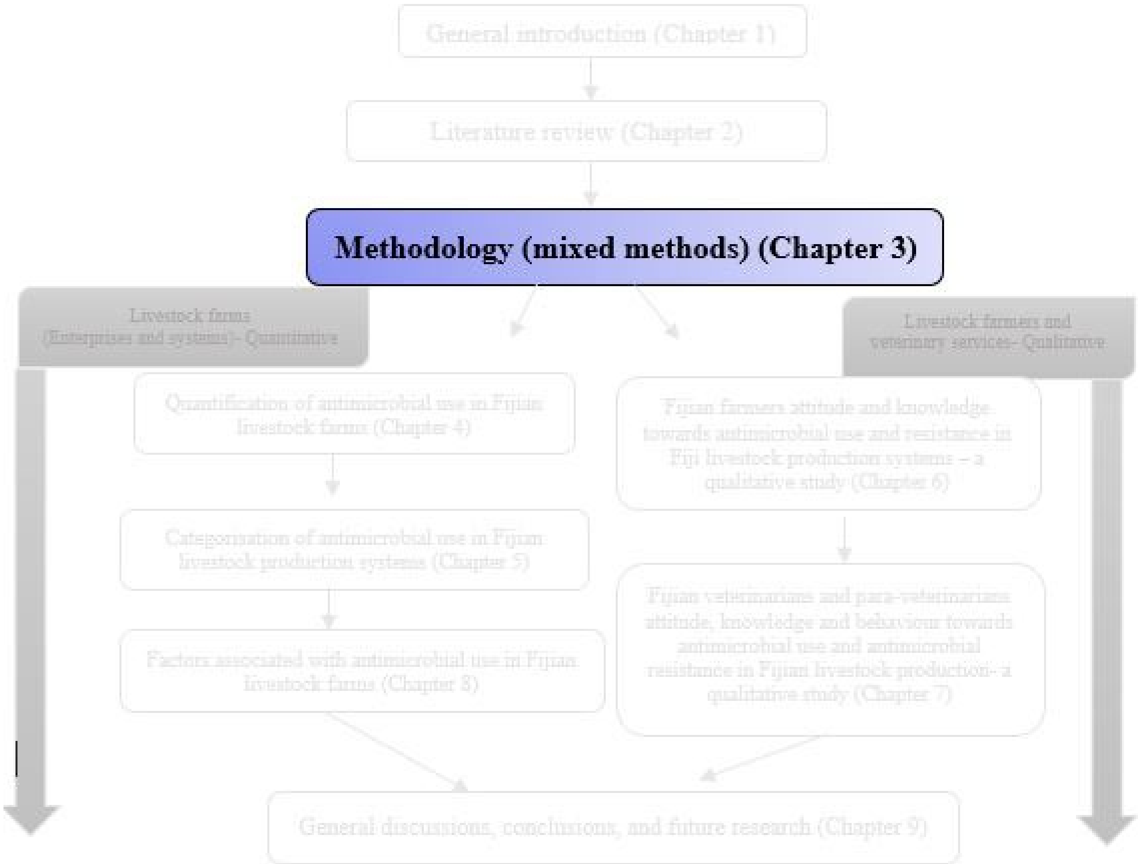
Chapter 3

Methodology

Chapter summary: This chapter describes the methodological approach developed from the theoretical and conceptual frameworks described in chapter 2. The methods to address the research objectives and the philosophical stance taken while conducting the programme of research in this PhD thesis are presented.



3 Methodology

This thesis aimed to quantify AMU, evaluate the AMU practice, and understand the attitude and knowledge of farmers' and veterinary professionals towards AMU and AMR.

3.1 Development of overarching research framework

The literature review was carried out in three phases. Phase one aimed to establish the knowledge gaps in Fiji. The second phase aimed to establish the current knowledge of AMU and AMR in developing countries, and the third phase aimed to inform the design and development of the methodology for the programme of research. The PubMed Central, Medline and Scopus databases and Web of Science gateways were searched for original scientific literature published in English on AMU and AMR in livestock production between 2012 to 2022. Subsequently, the original studies were searched as studies on AMU and AMR got published in developing countries.

The literature was searched using the keywords : ("antimicrobial resistance" and "livestock production ") and/or (AMR and "livestock production") and/or ("antibiotic resistance" and "livestock production") and/or (antimicrobial or antibiotic or anthelmintic) and/or (use or Fiji or "developing countries " or "farming systems"), and/or (knowledge or attitude) and/or (farmers or veterinary or veterinarian), and/or (cattle or dairy or beef or poultry or broiler or layer or cow) and/or (feed or farm or agriculture or biosecurity) and/or (eggs or chicken or layers) and/or ("veterinary medicine", or antibiotics or anthelmintic) and/or (quantify or qualitative or metrics or survey) and/or ("socio-economic" or demographics or "para-veterinarian" or "livestock management") and/or ("farm biosecurity" or "knowledge, attitude and behaviour" or theory) and/or, ("prudent AMU" or "imprudent AMU") and/or ("AMU behaviour" or surveillance or" tropical countries") and/or ("access to antimicrobials" or "prescribing patterns") and/or (pharmacy or "one health approach").

The early review on AMR demonstrated the knowledge of AMR in the human health sector in Fiji; however, AMU and AMR in the livestock sector and livestock management practices were unknown [1-3]. Cattle and poultry were identified as two of the commonly farmed livestock in Fiji [4-7]. The review on AMR in the agri-food value chain demonstrated the interrelationship between humans, livestock, and the environment [8-11]. Therefore, the search was narrowed to cattle and poultry production systems, livestock farmers and veterinary professionals. The FAO, WHO and OIE international standards and ESVAC guidelines were also reviewed [12-14]. The literature surrounding similar studies with a common goal to quantify AMU in livestock production systems and qualitative studies exploring the attitude and knowledge of veterinarians, farmers, para-veterinarians, pharmacists and other professions towards AMU and AMR were retrieved and reviewed [15,16].

Studies focusing on behavioural and contextual drivers of AMU and AMR, veterinary practices, attitude and knowledge of veterinarians, para-veterinarians and farmers were explored [15-17]. However, much emphasis was given to the theoretical frameworks of TRA, TPB and HBM used in understanding attitude, knowledge and behaviour towards AMU and AMR in developing countries. Upon reviewing the different theoretical frameworks and selecting the theoretical framework to develop the research framework, the search was narrowed to studies that used TPB to investigate AMU behaviour amongst livestock farmers and veterinary professionals. The qualitative and quantitative approaches used in investigating AMU behaviour using TPB were reviewed.

The literature on surveillance and quantification of AMU in cattle and poultry production systems was grouped and reviewed. The studies identified through the search were grouped by livestock enterprises (beef, dairy, broiler, and layer). The studies which used ESVAC methodology for quantification were included. Additionally, the RUMA framework was reviewed to identify other metrics used in UK livestock production apart from ESVAC metrics. All studies which did not quantify antimicrobials, particularly antibiotics and anthelmintics, were excluded. Literature on livestock, particularly cattle and poultry production, and management, including farm biosecurity, were included for review. While reviewing the psychological and contextual drivers of AMU and AMR, only original articles from developing countries were included and reviewed. The literature on AMU, AMR, cattle and poultry production and management, and farm biosecurity from Oceania, Asia Pacific, African and Caribbean regions were included. The literature, mainly from UK and Europe, was referred to when there were knowledge gaps on topics in developing countries. Additionally, textbooks were used to identify literature on topics that could not be found otherwise. The literature was grouped by the different constructs, critically reviewed, synthesised, and presented in sections in chapter 2.

A systematic review would be more appropriate with defined inclusion and exclusion criteria in identifying methods and factors and conceptualising the programme of research [18,19]. However, a systematic review was not adopted due to the scarcity of literature on AMU and AMR in Fiji, the Oceania region, and other developing countries[21,22]. Although there is a great body of literature on AMU and AMR in developed countries, corresponding research on AMU and AMR in developing countries is in its infancy [20,21]. Additionally, one of the driving factors for the traditional approach was that there was no attempt to collate the quantitative and qualitative data from the review but rather establish the current knowledge gaps on AMU and AMR in developing countries, enabling the shaping of the programme of research in Fiji [18,19]. Additionally, methodologies used in the developed countries contexts could not be entirely replicated in developing countries due to vast differences in livestock production systems [22,23]. Developing methodologies based on limited information may pose challenges in designing and operationalisation of research programmes, especially when information is not readily available and published in developing countries [15,16,24].

A systematic review methodology was not adopted for this programme of research because of the scarcity of relevant literature. It is acknowledged that this approach would be appropriate once more literature on AMU and AMR is available in developing countries, particularly in Africa, the Caribbean and Oceania regions. The quantitative AMU surveillance framework adopted in addressing research question one could be adopted to quantify AMU in countries where AMU remains unquantified. Similarly, the TPB theoretical framework used in addressing research question two could be adopted in exploring and understanding AMU and AMR in other developing countries. The following section discusses the use of the theoretical framework of TPB in the programme of research.

3.2 Use of theoretical framework of TPB

The literature review in Chapter 2 demonstrates that AMU behaviour can be quantified by computing amounts of AMU using metrics, quantified as AMU practice (used/not used), and explored using qualitative methods. Both quantitative AMU (metrics) and AMU practice (used/not used) can be statistically evaluated. Although the quantitative approach allows drawing inferences, generalising findings, and provides the quantities and patterns of use, it does not explain the drivers of AMU. Additionally, it does not provide an understanding of the drivers and motivations behind AMU practice. Therefore, an understanding of the drivers of AMU requires in-depth investigation. The theoretical framework of TPB has been used where established and tested constructs guide the development of research methodology[25-29].

TPB is one of the most widely used intention and behaviour predicting theories in all disciplines, as demonstrated in the review in Sections 2.6 and 2.7. It has also been used for understanding and exploring peoples' AMU behaviour [25,26]. In particular, the theoretical framework of TPB enables understanding of behaviour by analysing peoples' knowledge, attitude, subjective norms, behavioural controls, motivations, and other factors that affects their decision-making process [26,30]. TPB has been used to understand the behaviour of farmers regarding livestock production and management [31,32]. It has also been used in developing programmes promoting prudent AMU in European farms [33,34]. TPB has been used to explore and understand AMU behaviour in developed countries; however, its application in developing countries has been limited [31-34]. Globally, there are differences in psychological and contextual drivers (such as legal framework, policies, and procedures) relating to livestock production and management [35,36]. Therefore the direct application of existing policies may not be practical. Hence, a country-level understanding of the drivers of AMU behaviour is an essential first step [37].

The review in Chapter 2 also demonstrated that studies had reported a better understanding of AMU and AMR amongst livestock farmers in developed countries compared to developing countries [15,16]. However, some studies have also suggested improving farmers' knowledge through education optimises responsible AMU, but there is a divergence between perceived knowledge, understanding, and practice [15-17]. Therefore, farmers may score the questionnaire based on their desire and knowledge; however, their complete understanding of AMU behaviour cannot be established based on structured questionnaire responses [19,38]. Additionally, other factors such as farmers' age, years of experience, farm and flock size, and access to veterinary services also influence AMU behaviour [15,16]. Hence, other factors can also be scored; probing questions based on structured opening questions informed by TPB enables the elucidation of in-depth knowledge, which cannot be obtained entirely from the structured questions typically employed in a realist approach [26,30,39]. The attitude, knowledge, and personality of individuals are not stable constructs because they are influenced by other social, cultural, and environmental factors; therefore, in-depth investigation allows the generation of thick, rich accounts of knowledge which vary amongst individuals[26,30,39].

Most studies exploring AMU and AMR drivers have been conducted in developed countries [15,16], yet very little is known about AMU and AMR in Oceania, particularly Fiji, except for Australia and New Zealand [15,16,24]. Therefore, understanding the livestock farmers' attitudes and knowledge, which can shape their AMU behaviour, is an important consideration [15,16,40]. The review in Chapter 2 also demonstrated that TPB is not a behaviour change framework but is used to explore and understand behaviour; it is, therefore, a more suitable theoretical framework to address the qualitative objectives of the programme of research [31-34,41-49].

Literature review and theoretical framework in research assist in building a foundation for research, advancing knowledge, conceptualising research, and developing research methodology [19,38,50]. Conceptualising studies based on assumptions and limitations are subjective and based on interpretations in previous studies; however, incorporating a theoretical framework assists in synthesising existing theories and concepts within the research methodology and provides a theoretical lens for investigating psychological drivers [19,38,50,51]. Quantitative studies using a scoring scale to compare farmers' attitudes and knowledge of AMU and AMR can be used to investigate the attitudinal, social, and behavioural controls with other associated socio-demographic factors [17,52,53]. However, it does not provide flexibility in generating in-depth, rich accounts of lived experience, which helps us understand and explain farmers' behaviour that cannot be achieved with surveys alone [19,54-57]. Considering the ontological and epistemological assumptions guiding the study design, the quantitative surveys using predetermined structured questions using the Likert scale do not provide the reality of the farmers' AMU behaviour [50,58]. Additionally, scoring based on self-reporting and responding to structured questions reduces the ability to establish a proper understanding of reality [50,59].

Ajzen (the author of TPB) also recommends using open-ended questions to establish salient beliefs and elucidate important information on the target behaviour [26]. Although it may enable predicting intention to perform a behaviour where information is available, in the Fijian context, such an approach was unfeasible, notably due to significant knowledge gaps on AMU and AMR in the livestock sector. The TPB was used as the theoretical framework, and the hypothesised conceptual framework was used to explore and understand AMU and AMR. Since AMU could be quantified and explored both quantitatively and qualitatively, a hypothesised conceptual framework was adopted for designing quantitative studies, while the theoretical framework of TPB was used for qualitative studies. TPB framework was used to explore and understand AMU behaviour in qualitative studies, as discussed in sections later [16,31,32,60]; however, it specifically informed the design of the interview guide and deductive analysis of interview transcripts.

As acknowledged by Ajzen, there are limitations to using TPB as it does not account for involuntary drivers (socio-economic, demographic, environmental) and the role of emotion [16,61]. Therefore, extending the TPB framework by including other involuntary drivers assists in addressing the limitations of using the TPB framework on its own [16,61]. Therefore, a literature-informed hypothesised conceptual framework was developed to investigate other contextual drivers of AMU. On its own, the conceptual framework enables the addressing of research question one, while the theoretical framework (TPB) enables the addressing of research question two; however, conceptual, and theoretical frameworks collectively provide a better understanding of AMU behaviour from both quantitative and qualitative perspectives. Therefore, the rationale for using mixed methods to address the objectives of this research programme is discussed in the next section.

3.3 Rationale for mixed methods

The objectives of the thesis could not be achieved alone with either quantitative or qualitative methods; therefore, mixed methods were used [18,19,50,55,62]. For instance, the survey approach allows swift administration and quicker evaluation. It enables statistical analysis to draw comparisons; however, these strengths may be the weakness of the approach as characteristics of people, their attitude, perceptions, and beliefs cannot be meaningfully reduced to numbers or understood without referring to the local context where participants live. Surveys cannot provide in-depth understanding of peoples' behaviour, attitude and knowledge which is essential in designing behavioural change interventions [19,54-57]. For generalisation of findings and effective quantitative research, a larger sample size is usually required, which is costly and time-consuming. Quantitative research in the context of a survey provides quantitative numerical data where associations could be ascertained and potential areas for interventions identified. But the reasons for selection may be limited in depth and context for intervention design [19,54-57].

Although a quantitative approach is well-suited to evaluate and investigate relationships between variables, it does not provide an in-depth understanding of the phenomena being investigated. Incorporating a qualitative approach allows exploration and understanding of the meanings individuals or groups ascribe to a social or human problem using emerging questions and procedure [19,55,56]. Qualitative methods are more subjective and reflexive, thus allowing a better understanding of a phenomenon and allowing researchers to have a richer understanding of the complexities and distinctions between participants that quantitative approaches cannot achieve [38,55,63]. Qualitative research methods allow researchers to explore and have an in-depth understanding of perspectives from both homogenous and diverse groups. It allows one to explore and understand values, beliefs, assumptions, and behaviour. The use of open-ended questions allow more flexibility and also allows participants to raise and discuss issues that matter to them [19,54,56,57]. It also allows complex textual descriptions of human experiences to better understand a phenomenon [64]. The major weakness of qualitative research methods are that they are time-consuming, and principal issues could be overlooked and unnoticed. Researcher interpretations are limited, and the data collected is based on the participant as they have more control over the content collected since it uses semi-structured and open-ended questions. The results are not objectively verifiable, and the analysis process is labour intensive. A successful interview also requires skilled interviewers [19,54,56,57,65]. However, by combining mixed methods that use both quantitative and qualitative methods, the limitations of each are mitigated and help generate more valid knowledge and create assurance in outcomes [66].

3.4 Quantitative Study

A quantitative research approach was used to answer Research Question 1 and achieve the first, second and fifth research objectives.

3.4.1 Cross-sectional survey

A survey methodology was used to develop the quantitative cross-sectional study guided by the conceptual framework(see Figure 2.5, Chapter 2) [55,67,68]. Apart from the conceptual framework, the ESVAC framework, and numerous other studies also assisted in designing the cross-sectional survey [69-72]. A sample survey is beneficial, especially in instances where quantitative data are required, and the researcher has prior knowledge of the problems associated with the study setting [73]. The researcher-administered survey also provides an added advantage for the researcher as they can actively observe and interact with the participants [56].

The researcher administered survey was designed to collect farm, farmer, and livestock information and comprised four sections.

- The first section collected information on farmers' socio-economic and demographic status and livestock management practices.
- The second section collected information on livestock production.
- The third section collected information on other medicine use and feed and feeding practices.
- The final last section focussed on AMU.

Information was collected for the last three calendar months from the date of the farm visit [74]. The ESVAC guidelines and other studies recommend a 12-month survey; however, only a 3-month survey was feasible [14,72,75,76] because farmers were unable to recall information beyond the past three months. Farm records were accessed where possible, and general field notes were made during data collection.

The aim was to recruit a sample of at least 100 participants who raised cattle and poultry from Viti Levu Fiji's Western and Central divisions. The majority of Fijians live in this region and raised livestock, and were recruited using the inclusion criteria detailed in Chapter 4. Probability-based sampling was not feasible because information on livestock farmers in the region was unavailable. Although non-probability-based sampling creates bias [19,68], purposive and snowball sampling methods were used to recruit participants as this was the most feasible sampling techniques to ensure diversity in the respondents and include participants from all over Viti Levu. The data were collected from the respondents between May to August 2019. Data were transferred into Microsoft Excel (Microsoft Corporation, Washington, USA) before being organised for specific analyses.

3.4.1.1 Quantification of AMU

The following data were collected:

- Total volume or amount of active antimicrobial used per dose, duration of use, and the number of animals administered.
- Standardised estimated live weight of animals at treatment and the population of live and slaughtered animals on the farm during the survey period.
- Total mg of anthelmintics and antibiotic used.
- Total PCU was calculated at each farm level and by enterprise (dairy, beef, broiler chicken or laying hen). ESVAC standards defined daily dose, and course doses for antibiotics by dosage form were identified from the ESVAC reference.
- Total number of active antibiotic ingredients per formulation, duration of treatment , and total farm population, including mortality figures were calculated.
- Total number of birds treated in the flock, and the total number of daily doses at poultry flock level and individually in cattle were also calculated.

Table 2.1 (Chapter 2) shows the metrics used to quantify AMU and summarised here:

- ESVAC metrics; namely milligrams (mg), milligrams of antibiotics used per population correction unit (mg/PCU), number of Defined Daily Doses (nDDDvet), number of Defined Course Doses (nDCDvet) [13,14,72,75,77].
- Non-ESVAC metrics; mg/kg (milligrams of antibiotics administered per kg of animal treated), Treatment Frequency per day (TF per day), percentage treated (% treated), number of doses per animal per day (dose-animal per day) [14,75,78-80].

The quarterly anthelmintic use was quantified using the 'mg' metric as no other suitable framework was available for quantification [78]. The quarterly AMU was calculated using all metrics; however, the mg/PCU metric was used to extrapolate annual use at aggregated farm level and at the enterprise level for antibiotic use. The ESVAC method of extrapolation was not feasible due to lack of livestock information; hence, the annual mg/PCU of antibiotics was estimated as four times that of quarterly use in cattle enterprises (mg/PCU × 4/1), four times that of quarterly use in broiler enterprises per four batches of the flock (mg/PCU × 4/4) and four times that of quarterly use in layer enterprises per two batches of the flock (mg/PCU × 4/2). The live weight was collected from the survey, and standardised estimated live weight of the animal at treatment was used in calculating PCU (kg); bull calves (80kg), fattening cattle (350kg), breeding cattle (350kg), lactating cows (350kg), dry cows (350kg), heifers (200kg), dairy calves (75kg), broiler breeding birds (1kg), broiler chickens (3kg), layer breeding birds (1kg) and layer hens (2kg).

3.4.1.2 Categorisation of AMU practice

To categorise AMU practice, a seven-step framework was developed using the VMD, BVA, ESVAC and OIE guidelines [14,81-85] which categorised the AMU (antibiotics and anthelmintics) into either prudent or imprudent use (Chapter 5 Table 5). Due to the absence of a Fijian classification system for veterinary antimicrobials and framework for categorising AMU in the livestock sector, the method used in the human health sector was adapted with modification where imprudent use of antibiotics was defined as either using antibiotics without prescription, incomplete course, and non-compliance to instructions of use [86]. The framework presented in Chapter 5, aided in categorising all antimicrobials into prudent/imprudent use. Prescriber of antimicrobials was one of the key criteria; therefore, for classification, all livestock officers, including agriculture veterinary clinic staff and field officers and other non-government livestock officers, were considered suitably qualified persons since they undertook para-veterinarian duties. However, the titles (livestock officer and para veterinarian) were used interchangeably in Fiji due to the lack of prescribed definition and competencies outlined in the current legislative framework.

The antimicrobials were categorised by 1. Antimicrobial type, 2. Antimicrobial class and legal distribution category of antimicrobial, 3. Prescriber of antimicrobials, 4. Target species (authorised as per label or market authorisation), 5. Purpose of administration (metaphylactic, prophylactic, therapeutic, and growth promotion), 6. Antibiotics used under the cascade (use of unauthorised medicines by veterinarians) and 7. Maintenance of farm AMU records. All antimicrobials administered on different occasions were individually evaluated and categorised. However, only antibiotics were considered in Step 6 as antibiotics can only be prescribed under cascade [81,87].

3.4.2 Statistical analysis and software

All descriptive and inferential data analyses were conducted using the SPSS Software V27 (IBM SPSS Statistics for Windows Version 27, Armonk, NY; IBM Corp). Additionally, the ArcGIS Pro (ESRI) was used to map the enterprises surveyed in the Central and Western divisions of Viti Levu, Fiji. In Chapter 4, descriptive and analysis of variance (ANOVA) and Chi-Square analysis were used. Fisher's exact text, Chi-square and binary logistic modelling were used in Chapter 5. Fisher's exact test, Chi-square, and Multinomial logistic modelling were used in Chapter 8.

3.5 Qualitative Study

A qualitative approach was used to address Research Question 2 and achieve the third and fourth research objectives. A brief description of the methodology used is explained in sub-section 3.4.1 and philosophical foundations in section 3.5.

3.5.1 Knowledge, attitude and behaviour of livestock farmers and veterinary professionals towards AMU and AMR

The farmers' and veterinary professionals' attitude and knowledge towards AMU and AMR were explored using qualitative methods, specifically semi-structured interviews to elicit an in-depth understanding. The interpretivist and constructionist epistemological position underpinned the design and conduct of both studies [88].

The TPB assisted in developing semi-structured interview guides [26,89]. Open-ended semi-structured interview questions were used to elicit in-depth knowledge and experience. Although interviews can be conducted face to face one on one, they can also be accomplished using focus groups which allow rich data collection with six to eight participants [55,88].

Focus group is one of the methods for collecting qualitative data where the emphasis is on the specific topic of interest [19,38,50]. The group interaction and dynamics allow the construction of the meaning of topics based on understanding amongst the participants with the moderator's assistance [19,38,50]. Although the topic of interest is discussed in detail amongst the participants, they elevate issues that they think are significant [19,38,50]. This also allows the collection of data from various participants concurrently;

however, due to being more interactive, there are chances of bias in the elevation of a specific topic of interest [19,38,50]. Also, there are chances of participants not fully expressing their views due to fear, whereas the one-to-one interview may allow participants to speak freely without being intimidated by other participants in the room[19,38,50,59,90]. Additionally, there are other operational factors such as suitable time, transportation to the venue, the location of the venue and compensation for time. Cultural factors such as religious taboos and restrictions on congregation are also barriers to participation. In contrast, the one-to-one interview is more convenient for the participants[19,38,50,59,90].

Nevertheless, the one on one semi-structured interview structure was selected to enable participants to speak freely [59,91]. Additionally, due to lack of information on livestock farmers and veterinary professionals, time and resources, the arrangement of focus groups was not feasible; therefore, face to face interviews was considered most suitable.

The fundamental constructs of the TPB (attitude towards AMU, subjective norms (social influence), perceived behavioural controls) were used to design the semi-structured interview guide. The guide included structured and probing questions relating to attitudes toward treating animals, barriers to treating sick animals, the influence of veterinary professionals and other farmers on farmers, and other factors influencing farmers' decisions on using antimicrobials (See Table 3.1 and Table 3.2). Standard structured questions used in other studies conducted in developed countries were not adopted due to the vast difference in livestock production and management systems in developed and developing countries.

Table 3.1 Interview schedule used to guide the one to one semi-structured interview with livestock farmers

Topic	**Questions and Probes (probes in italics)**
Attitude	• What is your view on why the medicine used did not work? *(correct dose? The duration? Right medicine? Type of medicine? Stronger medicine? Didn't follow instructions? Medicine not effective? Antibiotics? antimicrobials?)* • Can you tell me what is antimicrobial resistance?

	(if YES: where have you heard from? What do you know about it? What could be done? If NO: Do you think all medicine, you use is antimicrobials? or are they antibiotics? Where did you hear that from?)
Subjective norms	• What do you do when the medicine you use on animals is not working? *(consultations? Other farmers? Veterinarians or para-veterinarians? Any other medicine used? How do you use them? Do you follow instructions?)*
Perceived behavioural control	• What do you do when your animals are sick? *(Veterinary/ Para-vet consultations? Medicine used? Source? Availability? Cost? Do you record them? How often do you use them? Problems faced?)*
Other factors / motivations	• Can you tell me about your farming experience? *(how long farming for? Years of experience in livestock production? Training? Member of any associations?)* • Can you describe to me a typical working day at your farm? *(what do you do? What do you do with your produce?)* • Are there any other comments you want to make about medicine use or antimicrobial resistance?

Table 3.2 Interview schedule used to guide the one to one semi-structured interview with veterinary professionals

Topic	**Questions and Probes (probes in italics)**
Attitude	• Why do you think antimicrobials or antibiotics don't work? *(correct dose? The duration? Right medicine? Type of medicine? Stronger medicines? Didn't follow instructions? Medicine not effective? Bacteria being resistant? Antibiotics? antimicrobials?)* • Can you tell me what antimicrobial resistance is? (*Note: if antimicrobial resistance is unknown,* what is drug resistance? *If not, then* What is antibiotic resistance? *If not, then* what is microorganism resistant to antibiotics? *If not,* what is drug resistance, (*if YES: where have you heard from? What do you know about it? View on why medicines don't work? Right dose? The duration? Right medicine? Type of medicine? Stronger medicines? Didn't follow*

	instructions? Medicine not effective? Antibiotics? Antimicrobials? What could be done?
Subjective norms	• What do you do when you find the antimicrobials or antibiotics you prescribed on animals is not working? *(Do farmers call back? Consultations undertaken? Check on Dose and Duration farmer used? Consult other Veterinarians or para-veterinarians? Any other medicines used? Usage? Instructions? Medicine substitution?)*
Perceived behavioural control	• What do you do when you attend sick animals? *(how and when do you decide to prescribe? Antimicrobials or antibiotics prescribed? How often do you use them? How often do farmers call? How much interaction do you have with farmers? In what stage of animals' sickness, do the farmers ask for intervention? How do you select the antimicrobial or antibiotics? How do you decide on the dose? Availability? Cost? Problems/ challenges faced?)*
Other factors / motivations	• Can you tell me about yourself? *(Age, qualifications, years of experience, experience in livestock production? Training? Type of practice?)* • Could you describe a typical working day in the clinic/ field? *(what do you do? What type of farmers or complaints do you attend to?)* • Are there any other comments you want to make about medicine use or antimicrobial resistance?

For instance, farmers were asked explicit opening questions such as *" Can you describe to me your typical working day at your farm?*" where attempts were made to establish conversation and establish what other factors influenced activities the farmer carried out on the farm. The follow-up probing questions such as "*What do you do with your produce?"* was used to establish the driver or the motivations for livestock production.

The following explicit question, *" What do you do when your animals are sick?"* was asked to explore the farmers' barriers and facilitators (perceived behavioural controls) towards treating animals. Following probing questions, *" source, availability, cost ?"* were asked to establish the barriers or perceived behavioural control and other factors influencing the AMU. Follow-up structured question *" What do you when the medicine you use on animals is not working?"* and follow up probing questions such as " *consultations, other farmers, veterinarians or para-veterinarians"* were asked to establish how the livestock was managed when they were sick and to explore social influence or societal influence.

Additionally, the structured question *" what do you do when the medicine you use on animals is not working?"* was used to explore their attitude towards AMU and knowledge of AMU. Concurrently, other probing questions, such as *"right medicine? Stronger medicine?Didnt follow instructions?*" were used to explore their knowledge of advantages and disadvantages of using antimicrobials and other factors influencing the AMU. Follow-up probing questions *"antibiotics? antimicrobials?"* were asked to explore farmers' general knowledge of antibiotics or antimicrobials. Subsequently, the explicit question " *can you tell me what antimicrobial resistance is?"* was asked to explore farmers' attitude and knowledge of AMR.

The opening questions were on farmers' socio-economic status and demographic characteristics to establish an understanding of the characteristics of the farmers. All structured and probing questions in Box 2, Chapters 6 and 7 encapsulate all three TPB constructs and further explore the motivations and the other actual behavioural controls. The interview guide was drafted and framed logically so that the interview questions and interview flowed as naturally as possible. Additionally, the interview guide with minor modification was used for interviewing veterinary professionals.

There is no sample size rule in qualitative studies, and the concept of data saturation or information redundancy is usually used as a stopping rule. However, a sample size of 20 to 30 is believed to provide comprehensive information from diverse perspectives whilst in a homogenous group, 3 to 5 participants may be sufficient if numerous groups are being interviewed [19,56,92,93]. Additionally, theoretically informed study designs usually suggest a sample size of around 15 to 25 participants [94]. Some studies have demonstrated that a sample size of at least 10 participants with diversity may provide more in-depth data [95]. Time, available resources, funding, the aim of the study and the quality of data required plays a critical role in determining the sample size [96].

Studies exploring and understanding attitude and behaviour of veterinarians' towards AMU and AMR have used at least 21 participants [97], attitudes towards disease risk management with 15 livestock farmers [98], and exploration and understanding the perception towards AMU in farms has been reported with 29 participants (16 commercial farmers, 4 feed retailers and 9 veterinarians) [99]. The criterion of information saturation was used mainly while a sample size of between 15 and 30 individual interviews was typical [50]. Therefore, a sample of 20 livestock farmers and 10 veterinary professionals were targeted who could share their insights on AMU and AMR.

Purposive and snowball sampling methods have been commonly used in qualitative research methods to recruit participants [92,100]. The purposive sampling method was used to allow diversity in participants by recruiting farmers from different systems and enterprises to the study [41]. The veterinary professionals from the public sector who provided services to farmers were also recruited. Participants recruited were engaged in livestock production and management[92,101,102]. Additionally, purposive sampling tends to be cost-effective, non-probability based and focuses on particular characteristics of the population that are of interest, thus allowing the selection of participants who would be able to provide rich, in-depth information [103]. The snowball sampling method usually helps identify at least two key informants, which assist in recruiting other participants [19,56]. Several studies like the current thesis have demonstrated the use of purposive and snowball sampling to understand the attitude and behaviour of farmers and veterinarians [45,104-106].

Reflexive thematic analysis was used as the analytic approach [59,91]. Since the reflexive thematic analytic method is not underpinned by any theoretical framework, it allows flexibility in the analysis process, leading to the generation of in-depth knowledge on drivers of AMU that a theoretical deductive analytical approach may overshadow [59]. Reflexive thematic analysis was used as the primary analytic approach; however, to mitigate potential gaps in the analytic approach, data was also analysed deductively using the predetermined topics developed using the TPB framework (see Figure 2.4, Chapter 2).The same methodology was used for both qualitative studies that explored farmers' and veterinary professionals' attitude, knowledge, and behaviour, as reported in Chapter 6 and 7, respectively.

3.6 Philosophical underpinnings

Different knowledge is generated by quantitative and qualitative methods. The latter is mainly conducted not to generalise whilst the former, through statistical analysis, does generalise findings[38,107]. From an epistemological standpoint, it is critically important to acknowledge the methods used by the researcher in generating knowledge; a positivist/realist approach is usually aligned to quantitative methods whilst relativist/interpretivist in qualitative methods [38,50,90]. The quantitative deductive analysis is associated with a positivist approach, while qualitative inductive analysis is a constructivist approach [59]. Therefore, my philosophical stance and methodological viewpoints are discussed in the next paragraphs.

3.6.1 Quantitative study

The AMU was quantified using various metrics, and parameters required for quantification were collected. The literature driven conceptual framework provided direction to the quantitative study. Additionally, AMU practice was categorised using the literature driven AMU categorisation framework. The aim was to elucidate the patterns of use and establish the current AMU status, which was computed using the data collected. Additionally, findings were reported objectively. From an ontological position, a realist/ positivist approach described as, reality is independent of human ways of knowing about it, and valid knowledge could be elucidated using appropriate quantitative methods [38,50,90]. Therefore, I took a realist/positivist approach to collect the data on AMU at the farm level and quantified it using different metrics by systems and enterprises. Also, deductive analysis investigated whether the AMU was affected by the farming system or the enterprise type.

However, although I used a framework for categorising AMU practice, my ontology differed from the above. For this study, AMU practice was categorised based on what the farmers reported; however, the actual reality of the antimicrobials being used was unknown since I had no access to the consultation process that occurred before the antimicrobials were used in farms. Although there was enough data and information provided to categorise the AMU practice, there was a degree of subjectivity or bias in what the farmer reported during the survey. There may be chances of farmers not saying the exact reasons the AMU was used. I had made observations and analysed them based on the observations. Therefore, for this study, I took a critical realist position. The study involved realist and relativist approaches where the categorisation component was subjective while the analysis was objective. Critical realism is a position between realism and relativism where true knowledge can be obtained through appropriate methods; however, knowledge generation is socially influenced [38,50,59,90]. Relativism assumes that knowledge obtained is not an actual reality as the knowledge generation is socially influenced, and the fact cannot be asserted by a single approach [38,50,59,90]. In the context of the study, the quantitative studies address the first, second and fifth objectives of the thesis; however, the patterns of AMU cannot explain the drivers of AMU. Although TPB underpinned as the theoretical framework for this PhD thesis, there are limitations in the TPB as presented in Chapter 2. Therefore, a conceptual framework was developed to investigate the drivers of AMU. However, the quantitative approach does not allow me to address the third and fourth objectives, which was an in-depth understanding of the motivations behind AMU behaviour. Hence, a qualitative approach was warranted.

3.6.2 Qualitative study

Semi-structured interviews were used to explore in-depth, rich accounts and explanations on AMU and AMR. The knowledge generation in qualitative studies involves interpretivist epistemological approach, which is subjective due to the researcher being the instrument in the study [38,50,59,90]. The interpretativist approach acknowledges that the reality or actual knowledge cannot be elucidated but constructed by the researcher, and knowledge constructed is influenced by the researcher's social, cultural, theoretical, and subjective assumptions [38,50,59,90]. Additionally, with the interpretivist approach, the researcher is the instrument who transcribes and understands the data from social and cultural perspectives before inductively analyses data using thematic analysis to generate themes. Therefore, the entire process was subjective as my personal experiences in pharmacy, agrosecurity, food security and one health provided me added advantage in understanding the transcripts and generating the topics and themes in both studies involving farmers and veterinary professionals (Chapter 6 and 7). Although the process was iterative, I led the knowledge generation process.

Thematic analysis is not rooted to any ontological, epistemological and theoretical positions; therefore was used as it allowed flexibility in the analysis [59].

Knowledge generation is bound to subjectivity due to the interpretivist epistemological stance however, it yields insights and understandings of phenomena from an individual's perspective, including historical and cultural contexts. Additionally, interpretivist methodology generates knowledge that has limited transferability due to knowledge construction influenced by the researcher [38,50,59,65,90]. Ideally, knowledge generation is influenced by the language in which the information is collected and analysed. Participants' interpretations from their native language to English may have shortfalls [108,109]. Additionally, the thematic analysis does not allow the researcher to make claims about language use, and the flexibility can lead to inconsistencies and coherence in developing themes from the data collected [110-112]. Therefore, I used deductive analysis guided by TPB-informed predetermined topics to mitigate shortfalls from inductive reflexive thematic analysis.

3.7 The research team, research reporting guidelines and ethical approval

Ethical approval for the programme of research was granted on 11 October 2018 by School of Agriculture, Policy and Developing Ethics Committee and the PhD thesis was registered with University of Reading (Reference number: 00772P). The Strengthening of Reporting of Observational Studies in Epidemiology (STROBE) Checklist was used to report the quantitative cross sectional study (Chapter 4, 5 and 8) and the Consolidated Criteria for Reporting Qualitative Research (COREQ) was used to report the qualitative studies (Chapter 6 and 7).

The scope of the PhD thesis included animal and veterinary sciences and pharmacy. In addition to the male doctoral candidate who is a pharmacist with experience in agro-security, food security and one health (Xavier Khan), the PhD supervisory team consisted of a female animal scientist with a doctoral degree and extensive experience in animal sciences (poultry) (Dr Caroline Rymer), one female academic pharmacist with a doctoral degree in medicine use and safety and extensive experience in qualitative research (Dr Rosemary Lim), and a male academic veterinarian and animal scientist with a doctoral degree with extensive experience in animal sciences (cattle) (Dr Partha Ray).Their background added quality and clarity to the discussions and analyses of the data.

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Chapter 4

Quantification of antimicrobial use in Fijian livestock farms

Chapter summary: To evaluate and explain the AMU in Fijian livestock farms, quantification of AMU using various metrics was essential. In this chapter, the patterns of AMU quantified using different metrics are demonstrated in different livestock enterprises (beef, dairy, broiler, and layer) and farming systems (backyard, semi-commercial and commercial).

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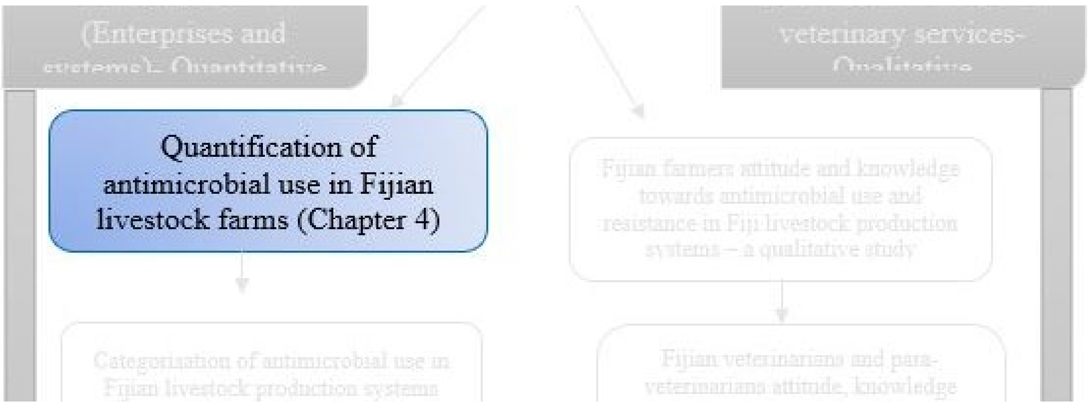

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Quantification of antimicrobial use in Fijian livestock farms

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Fiji

ABSTRACT

Antimicrobial resistance (AMR) is a major threat to humans and animals globally. Antimicrobial stewardship has been acknowledged as a primary strategy to tackle AMR. An important first step for antimicrobial stewardship is to quantify antimicrobial use (AMU). In Fiji, there are currently no data on AMU in livestock farms. This study aimed to quantify AMU in different livestock enterprises (beef, dairy, broiler, and layer) and farming systems (backyard, semi-commercial and commercial) in Central and Western divisions of Viti Levu, Fiji. A survey with 210 livestock farmers and 26 managers representing 276 enterprises was conducted between May and September 2019. The difference in AMU between different livestock enterprises and farming systems was investigated using ANOVA. In Fiji, the estimated annual antibiotic use in livestock was lower than the global average (44 compared with 118 mg/PCU). However, this use was concentrated in 56% of participant farms (the remaining 44% did not use antimicrobials). Total estimated quarterly anthelmintic use (20,797 mg) was not affected by farming systems but was highest ($P < 0.001$) in dairy enterprises (24,120 mg) and lowest in broiler enterprises (4 mg). Quarterly antibiotic use was different between the enterprises regardless of the metrics used to quantify the use ($P < 0.05$). Total estimated quarterly mg/PCU of antibiotic use was highest ($P < 0.001$) in broiler enterprises (12.4 mg/PCU) and lowest in beef enterprises (0.2 mg/PCU). For all other ESVAC metrics, total estimated antibiotic use was higher in poultry and lower in cattle enterprises. Backyard systems used less antibiotics (total mg) than commercial systems, but for other metrics, the trend was reversed. The use of both antibiotics and anthelmintics (rather than antibiotics or anthelmintics alone, or no AMU) was associated with dairy enterprises (X^2 123, $P <$ 0.001). Further studies should be conducted to quantify and evaluate the drivers of AMU in Fijian livestock farms. In addition, differences in AMU between different enterprises and farming systems suggest that strategies to reduce AMU should be tailored to specific settings.

1. Introduction

Antimicrobial Resistance (AMR) is a major threat to human health globally [1,2]. Although a direct link between antimicrobial use (AMU) in livestock and increasing AMR in humans has yet to be established, there is an acknowledgement of the need to reduce the use of antimicrobials in livestock farms [3–7]. Many farm level AMU monitoring studies have highlighted the AMU in livestock such as pigs, broiler flocks and cattle globally [4,5,8–10]. Livestock serve as a major source of protein and essential nutrition for human development and also provide social and economic security to the livelihoods of millions of livestock keepers [11,12]. Livestock are raised for domestic consumption (backyard), domestic consumption and sales (semi-commercial) and for sales only (commercial) [12]. Ensuring the safety of animal-based foods while securing the livelihoods of livestock keepers is therefore an important consideration [13,14].

Globally, the World Health Organization (WHO), World Organization of Animal Health (OIE) and Food and Agricultural Organization of United Nations (FAO) have agreed to promote the prudent use of antimicrobials in livestock through the One Health approach [1,15]. Surveillance systems such as the European Surveillance Veterinary Antimicrobial Consumption (ESVAC) project [16,17], WHO GLASS (Global Antimicrobial Surveillance System) [15] and the OIE surveillance of veterinary medicines use [18] are now in place in many developed countries such as the United States, European Union, Canada, Japan, and United Kingdom. The prudent use of antimicrobials has been

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prioritized to combat the global risks of AMR [1,2] whilst maintaining access to antimicrobials to combat the emerging zoonotic diseases [19].

In the Oceania region, there is surveillance data on AMU in the livestock sector in the Australian [8,20] and New Zealand settings [21], but not in Fiji [22]. In tropical developing countries, the majority of the population depend on backyard farming [11] where multiple species of livestock are kept for domestic use and sold when required [12,23]. In Fiji, the majority of the population live and raise livestock in Viti Levu [24,25] but as yet, information on livestock farmers, enterprises and farming systems is unknown. The relationship between the farming systems (commercial, semi-commercial or backyard) and AMU in Fijian livestock production is unclear.

To date, data on AMR patterns in the Fijian human health sector have been published [26] but there is no equivalent data in the livestock sector. There is currently no data on farm market orientation and livestock production distribution by economic models (farming systems) and antimicrobial sales and use by livestock. At a species level, there is limited information on annual animal census information and livestock performance data; the most recent accessible National Animal Census data is from 2009 [25] and the recently published 2020 Agricultural Census [24]. In addition, the gaps in diagnostic capability and lack of trained professionals in Fijian human health and animal health sectors have been highlighted [22]. There are also policy gaps on the regulation and importation of veterinary medicinal products in Fiji [22].

Globally, antibiotic use in livestock is reported to be 118 mg/PCU [18,27], where PCU is 'population correction unit' and takes into account the size of the animal population and the animal's liveweight at the time of treatment. As global food demand is increasing, it is predicted that livestock production will further intensify both locally and globally, resulting in further increases in AMU in livestock [23,28]. Within species globally, dairy farming systems tend to use more antibiotics than beef farming systems due to the frequent treatment of mammary gland infections [29]. Even though antibiotic use is relatively low in beef farms, anthelmintic use may be high in beef cattle because most beef enterprises rely on extensive grazing, resulting in greater exposure of beef cattle to parasites [30,31]. In terms of mg/PCU, antibiotic use is higher in poultry compared with cattle production because of the higher stocking density of poultry [20]. Furthermore, antibiotic use in poultry enterprises could be expected to be higher compared with cattle production because of flock level rather than individual administration of antibiotics in poultry [21,29,32]. Within poultry enterprises, antibiotic use is higher in commercial broiler enterprises compared with laying hens because the former are young, fast growing birds that are more vulnerable than adult laying hens [33–36]. In a Fijian setting, therefore, it was hypothesized that antibiotic use would be higher in poultry compared with cattle enterprises, and that commercial enterprises would use more antimicrobials than semi-commercial and backyard farming systems. The aim of this study was therefore to quantify AMU on Fijian livestock farms and determine the effect of farming systems (commercial, semi-commercial or backyard) and farm enterprises (beef, dairy, broiler, or layer) on AMU.

2. Material and methods

2.1. Study design, study area, and recruitment

A cross-sectional researcher-administered survey was conducted in livestock farms raising cattle and/or poultry from May to August 2019. The survey was conducted in the Central and Western divisions of Viti Levu, which is the largest island of Fiji. Using purposive and snowball sampling methods, livestock farmers and managers were recruited using the inclusion criterion {farmer or manager >18 years old, raised livestock (dairy, beef, broiler, or layer), located in Central or Western division, farm accessible by road}. Livestock farms were recruited from a list of farms provided by the Animal Health and Production division of the Fijian Ministry of Agriculture, local network of farmers and local markets. The eligibility of participants was assessed using the inclusion criteria by XK. Participants were then contacted via phone or visited in person if their contact details were unknown or unavailable. The purpose and scope of the survey was explained. Informed consent was taken prior to data collection. All collected information was anonymized prior to analysis.

2.2. Data collection

A survey was developed to collect information on farm population and production, AMU, other medicine use and feed and feeding practices. The ESVAC guide and literature review guided the development of the survey [17]. The parameters needed for the quantification of AMU was incorporated in the survey (see Supplementary Table 1). A single researcher (XK) visited participants at their farm and collected data using a paper copy of the survey. All data was collected in a single farm visit. Where available and accessible, farm records were used to collect information on AMU for the last three calendar months [32]. For farms without any records, the farmers and managers were asked to provide their best recall of estimated AMU for the past three calendar months [37]. Information from farm records, medicine labels, and verbal recollections of farmers were recorded directly onto paper copies of the survey. The survey was piloted with 10 farmers. Most of the farm visits lasted approximately 30 min and were conducted in English, however, where participants did not understand English, data collection was conducted in their spoken language (Itaukei, Hindi) and translated back to English by the researcher (XR). Ethical approval was granted by the Ethical Committee (Ref #: 00772P) at School of Agriculture, Policy and Development, University of Reading.

2.3. Data analysis

Data were transferred into Microsoft Excel (Microsoft Corporation, Washington, USA) for analysis. This study reports data relevant to the quantification of antimicrobials (antibiotics and anthelmintics) only. AMU was quantified using ESVAC metrics; namely milligrams (mg), milligrams of antibiotics used per population correction unit (mg/PCU), number of Defined Daily Doses (nDDDvet), number of Defined Course Doses (nDCDvet) [16,17,37,38], and those reported in the current literature; mg/kg (milligrams of antibiotics administered per kg of body surface area of animals treated), Treatment Frequency per day (TF per day), percentage treated (% treated), number of doses per animal per day (dose-animal per day) [17,39–41] (see Supplementary Table 1). Only oral, parenteral and intramammary antimicrobials were included in the quantification. In the absence of a Fijian national reference for DDDvet and DCDvet, the ESVAC DDDvet and DCDvet were used for benchmarking [38]. Since there is little seasonal variation in climate or livestock disease incidence in Fiji, the annual mg/PCU of antibiotics was estimated as four times that of quarterly use in cattle enterprises (mg/PCU $\times$ 4/1), four times that of quarterly use in broiler enterprises per four batches of flock (mg/PCU $\times$ 4/4) and four times that of quarterly use in layer enterprises per two batches of flock (mg/PCU $\times$ 4/2). We considered that cattle herds remained the same over a year, and on average, four batches of broiler were produced, and two batches of layer flocks were raised over a year. The ArcGIS Pro (ESRI) was used for mapping the enterprises on the island of Viti Levu, Fiji.

2.4. Statistical analysis

The SPSS Software V27 (IBM SPSS Statistics for Windows Version 27, Armonk, NY; IBM Corp) was used for descriptive and inferential analysis. Continuous data on AMU were log transformed and categorised into types of antimicrobial use (antibiotics only, anthelmintic only, combination of both, and no antimicrobial used). General linear model was adopted for hypothesis testing and the arithmetic mean of continuous data was reported. A Chi-square test was used for analysis of association between enterprise types and types of antimicrobial use. AMU data were analysed using analysis of variance (ANOVA) to investigate the effect of farming system and farm enterprise on AMU and mean separation was done by Tukey's test. Statistical significance was considered at $P < 0.05$.

3. Results and discussion

3.1. *Farm, enterprises, and farming system characteristics*

A total of 236 farms (94%) of the 250 farms contacted were recruited. Most farms were managed by farmers (89%) rather than farm managers (11%). The majority of participant farms (85%) raised single livestock species (i.e., single enterprise), but a small proportion of farms (15%) had more than one livestock species (i.e., mixed enterprises) (Fig. 1). Therefore, the 236 farms represented 276 enterprises in total, comprising of dairy ($n = 74$, 27%), layer ($n = 73$, 26%), beef ($n = 72$, 26%) and broiler ($n = 57$, 21%). The majority of enterprises were located in the Western division ($n = 174$, 63%) and raised livestock in semi-commercial enterprises ($n = 166$, 60%) (Table 1). Farm records were maintained by 122 farms (52%), but only 38 farms (16%) maintained antimicrobial use records. The median cattle herd size was 70 and 35 for beef (range 2 to 4500 cattle) and dairy (range 6 to 487 cattle) enterprises, respectively. Broiler and layer enterprises had a median flock size of 100 (range 5 to 192,000 chickens) and 160 (range 3 to 195,963 hens), respectively. Participating farms represented 14 and 15% of Fijian cattle herds and poultry flocks, respectively [24].

3.2. *Types of antimicrobials used in different enterprises*

To the best of our knowledge, this study is the first to estimate the

Table 1
Description of enterprises by farming systems in Central and Western divisions of Viti Levu, Fiji.

Enterprises by division	Farming system							
	Backyard		Semi commercial		Commercial		Total	
	n	%	n	%	n	%	n	%
Central division								
Beef	1	4	14	61	8	35	23	100
Dairy	2	6	15	48	14	45	31	100
Broiler	4	19	9	43	8	38	21	100
Layer	3	11	11	41	13	48	27	100
Western division								
Beef	2	4	35	71	12	24	49	100
Dairy	10	23	30	70	3	7	43	100
Broiler	2	6	25	69	9	25	36	100
Layer	11	24	27	59	8	17	46	100
Total								
Beef	3	4	49	68	20	28	72	100
Dairy	12	16	45	61	17	23	74	100
Broiler	6	11	34	60	17	30	57	100
Layer	14	19	38	52	21	29	73	100

The counts(n) and percentage (%) are presented in the columns.

AMU in Fijian livestock enterprises. Antimicrobials were used by a little over half (56%) of the 276 participant livestock enterprises. Of these, 22% of 276 enterprises used antibiotics only, 16% anthelmintics only, and 18% used both antibiotics and anthelmintics (Table 2). The types of antimicrobials used in a livestock enterprise was associated with the enterprise type ($P < 0.001$, Table 2). Relatively large proportions of dairy (84%) and beef (60%) enterprises used antimicrobials, but only 42% of broiler and 36% of layer enterprises used antimicrobials.

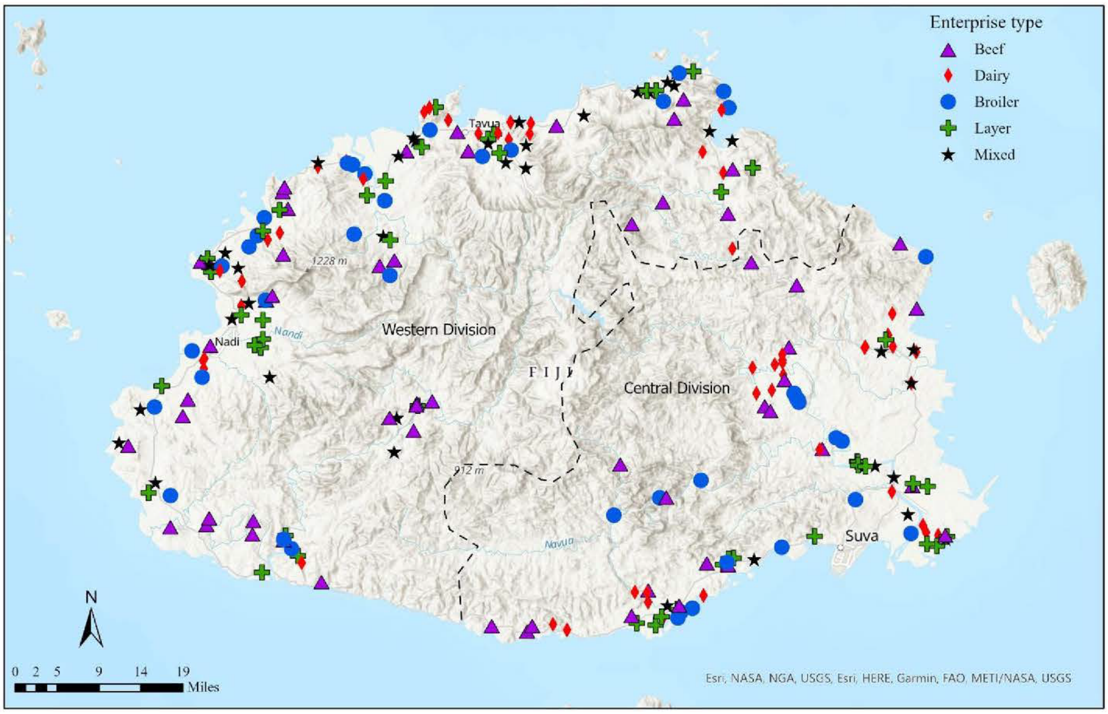

Fig. 1. Distribution of livestock enterprises in Viti Levu, Fiji (*n* 276).Dotted line represents the divisional border.

Table 2
Chi-Square analysis of association of enterprise type and type of antimicrobials used in 276 enterprises located in Central and Western division of Viti Levu, Fiji.

Enterprise type	Antibiotics only			Anthelmintics only			Both[a]			No AMU[b]		
	n	%	X^2	n	%	X^2	n	%	X^2	n	%	X^2
Beef (n = 72)	10	14	2	25	35	16	8	11	2	29	40	0
Dairy (n = 74)	11	15	2	14	19	0	37	50	42	12	16	13
Broiler (n = 57)	23	40	9	0	0	9	1	2	8	33	58	3
Layer (n = 73)	17	23	0	5	7	4	4	5	6	47	64	7

[a] Both denotes both antibiotics and anthelmintics used in enterprises.
[b] No AMU denotes no antimicrobials were used, n denotes the frequency, % denotes percentage observed, X^2 denotes contribution to Chi-square, Chi-square statistics, X^2 123, $p < 0.001$.

Antimicrobials were sourced from agricultural veterinary clinics (85%) and 87% of all AMU were self-prescribed by the farmers or managers. Given that there is higher misuse of antimicrobials when self-prescribed [13], identification of factors that drive AMU in different enterprises is necessary, so that more targeted interventions could be developed. No significant interactions were observed between farming system and enterprise ($P > 0.05$) for any measure of antimicrobial use.

3.3. *Quarterly anthelmintic use*

3.3.1. *Total mg*

The present study is the first study to quantify anthelmintic use in different livestock enterprises and farming systems in Fiji. The quarterly anthelmintic use (mg) was not different between farming systems but was highest in the dairy enterprise followed by beef, layer, and broiler (Table 3). Both beef and dairy enterprises used more anthelmintics compared to broiler and layer enterprises, but the anthelmintic use was not different between the broiler and layer enterprises. As hypothesized above, a larger total amount (mg) of anthelmintic use could be expected in cattle compared with poultry. This is partly because cattle are much bigger than chickens, and partly because grazing cattle would be exposed to a greater helminth burden compared with poultry that are housed some or all of the time. Most interestingly, anthelmintics were not used at all in both backyard and commercial broiler enterprises. Although there are no Fijian past data for meaningful evaluation of anthelmintic use over time, our finding of high anthelmintic use in cattle is consistent with findings reported in other countries [39,42]. Despite lower amounts of anthelmintic use in poultry enterprises participating in the current study, overall anthelmintic use requires further attention due to the growing risks of anthelmintic resistance [30] and the presence

Table 3
Effects of farming systems and enterprises on quarterly antimicrobial use in Fijian livestock farms.

		Enterprise					P		
	Farming system	Beef	Dairy	Broiler	Layer	SEM	FS	E	FS*E
Anthelmintic use (mg)									
	Backyard	900	7158	0	230	5522.1	0.104	< 0.001	0.058
	Semi commercial	32,856	9363	6	701				
	Commercial	112,111	75,157	0	3333				
Antibiotic use: ESVAC metrics									
	Backyard	0	23,065	698	17,278	8877.9	0.017	< 0.001	0.215
mg	Semi commercial	2696	11,702	3571	26,264				
	Commercial	3075	51,073	211,699	80,120				
	Backyard	0	5	10	250	12.5	0.062	< 0.001	0.950
mg/PCU	Semi commercial	<0.1	1	17	9				
	Commercial	<0.1	2	4	72				
	Backyard	0	0.1	0.2	8	0.4	0.001	< 0.001	0.791
nDDDvet	Semi commercial	<0.1	0.1	0.5	0.3				
	Commercial	<0.1	<0.1	0.2	2				
	Backyard	0	0.1	<0.1	1.3	0.1	0.001	0.002	0.770
nDCDvet	Semi commercial	<0.1	<0.1	0.1	<0.1				
	Commercial	<0.1	<0.1	<0.1	0.4				
Antibiotic use: non-ESVAC metrics									
	Backyard	0	14	7	148	9.5	0.640	0.040	0.384
mg/kg administered	Semi commercial	3	7	62	36				
	Commercial	7	18	11	51				
	Backyard	0	<0.1	<0.1	0.1	<0.1	0.025	< 0.001	0.384
Treatment Frequency per day	Semi commercial	<0.1	<0.1	<0.1	<0.1				
	Commercial	<0.1	<0.1	<0.1	<0.1				
	Backyard	0	36	30	27	2.7	0.762	0.002	0.583
Percentage treated (%)	Semi commercial	2	21	26	16				
	Commercial	2	10	38	16				
	Backyard	0	0.2	2.1	3.4	0.1	0.022	< 0.001	0.749
Dose-animal per day	Semi commercial	<0.1	0.3	0.8	0.7				
	Commercial	<0.1	0.2	1.3	0.4				

Note: FS denotes farming systems; E denotes the enterprises. ESVAC denotes European Surveillance of Veterinary antimicrobials consumption, SEM represent the standard error of mean of interaction of FS and E for each metric. 0 indicates no antimicrobials used. <0.1 indicates the number was smaller than 0.1. The arithmetic means are presented, and statistical analysis was conducted using log transformed data. Metrics: mg the amount of antimicrobial use expressed as milligrams, mg/PCU milligrams of antibiotics used per population correction unit of animals at risk (PCU- population correction unit- weight in kilograms of all animals at risk), nDDDvet number of defined daily doses of antibiotics, nDCDvet number of doses of antibiotics per treatment course, mg/kg amount of antibiotics used in milligrams per kilograms weight of animals administered antibiotics per body surface area, TF per day treatment frequency per day, Percentage treated proportions (%) of animals treated with antibiotics, dose-animal per day defined doses per total animal/days at risk (calculated per day).

of residues in animal products [43] and environment (groundwater) [31]. Given that a framework for the quantification of anthelmintic use was unavailable, the 'mg' metric was used [39]. The data from the current study can be used as a reference point for further longitudinal studies to quantify anthelmintic use. To implement anthelmintic stewardship programmes in the Fijian livestock sector similar to those in other countries [39], further studies are required to explore and understand the drivers for anthelmintic use.

3.4. *Annual antibiotic use*

The estimated annual average antibiotic use across all enterprise types (beef, dairy, broiler, and layer) was 44 mg/PCU, which is lower than the global average of annual antibiotic use in livestock (118 mg/PCU) [27]. The antibiotic use estimated in the current study was similar to that reported for Solomon Islands (43.9 mg/PCU) and Papua New Guinea (44.1 mg/PCU) [27], but was considerably higher than that in New Zealand (10.2 mg/PCU in different food enterprises) [44]. Only a small proportion (4.7%) of the 276 enterprises participating in the current study used antibiotics above the global average of 118 mg/PCU. Most interestingly, antibiotic use was not greater than the global average in any beef enterprises (Fig. 2). 7 and 11% of broiler and layer enterprises, respectively, while some dairy enterprises used greater than the global annual average of 118 mg/PCU antibiotics (Fig. 2). Ironically, backyard systems used more antibiotics (mg/PCU) than global average compared to other systems; 14 vs 4 (semi-commercial) vs 1% (commercial). We suggest further studies are needed to quantify antibiotic use in all livestock enterprises as in the case in other countries [7,44] so that a more accurate country level estimation could be achieved, and the types of enterprise associated with higher levels of antibiotic use could be better identified.

3.5. *Quarterly antibiotic use: ESVAC metrics*

3.5.1. *Total mg*

Overall, total antibiotic use (mg) was highest in dairy and broiler with much lower use recorded in layer, and beef enterprises (Table 3). Farming system also affected use, being higher in commercial farming systems but with no significant difference between backyard and semi-commercial farming systems. High antibiotic use in dairy cattle is consistent with the findings from other countries and this trend could be attributed to higher disease prevalence in dairy cows because of environmental [29] and physiological stress [21]. The remarkably high use of antibiotics in broilers reared in commercial farming systems was because of larger flock sizes and higher numbers of production cycles per year. This is one of the limitations of using total 'mg' as a metric of antibiotic use, which has been acknowledged previously [37]. However, the use of this metric requires less effort in data collection and thus could generate useful antibiotic use data especially in countries where the framework for AMU surveillance does not exist. We further recommend studies quantifying antibiotics sold for use in livestock so that assessments could be done based on overall use and by enterprise types as has been done in other countries [7,44].

3.5.2. *Total mg/PCU*

Antibiotic use was higher in poultry (broiler followed by layer) enterprises compared with cattle (dairy followed by beef) enterprises (Table 3), in contrast to the total mg metric (4.5.1), reflecting the greater liveweight of cattle compared with poultry. Use within the cattle (beef vs dairy) or poultry (broiler vs layer) enterprises was not significantly different. There was no significant difference between systems (backyard, semi-commercial and commercial) in antibiotic use, but there was a tendency ($P = 0.062$) for a higher use in backyard systems particularly with laying hens. This is not what was hypothesized, and the reason for the high use in low-intensity, backyard systems is unclear. It may reflect the high value that is attributed to individual animals or birds in a backyard system, with a greater willingness to invest in their health as

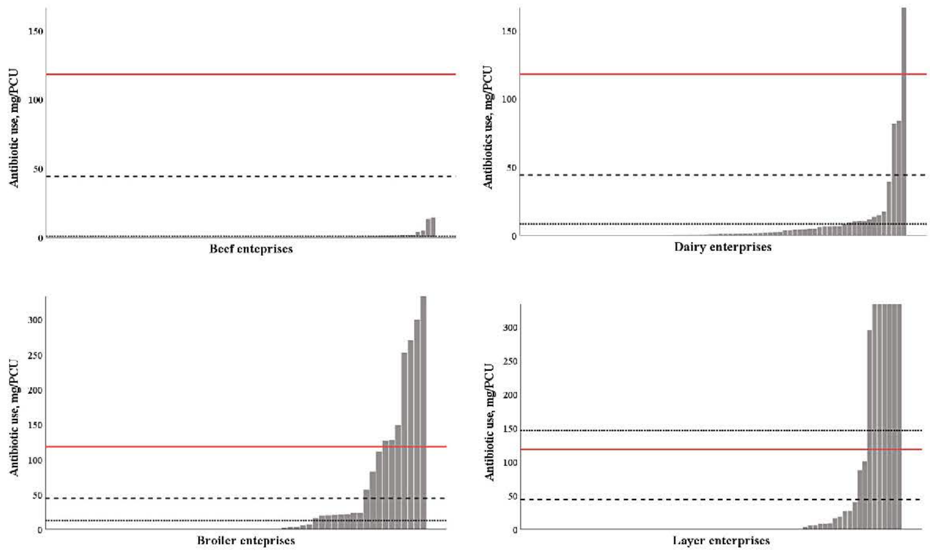

Fig. 2. Distribution of estimated yearly antibiotic use in total mg/PCU in different enterprises in Central and Western divisions of Viti Levu, Fiji. Note solid red line represents the global average of 118 mg/PCU of antibiotics. Dashed black line represents the estimated annual average (all enterprises) of 44 mg/PCU, SEM ± 25.2 mg/PCU) in all Fijian livestock farms. Dotted black line represents the estimated annual average mg/PCU of individual Fijian enterprise. (Beef 0.7 mg/PCU, SEM ± 0.28 mg/PCU), (Dairy 8.3 mg/PCU, SEM ± 3.28 mg/PCU), (Broiler 12.4 mg/PCU. SEM ± 5.43 mg/PCU), (Layer 146.37 mg/PCU, SEM ± 94.62 mg/PCU). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

demonstrated in other studies [36]. It is also worth noting that a high usage was recorded on just four farms, and that the turnover of birds in a backyard system is much lower than in a commercial setting so that the size of PCU is lower (making the calculated mg/PCU higher) in a backyard system. Very limited availability of data on the comparison of antibiotic use between different farming systems makes it difficult to compare our findings with others [9,34–36]. Therefore, we recommend further studies quantifying antibiotic use in different farming systems.

3.5.3. Number of DDDvet and DCDvet

For the remaining two ESVAC metrics (nDDDvet and nDCDvet), antibiotic use was highest in the layer enterprise and lowest in the dairy enterprise. The broiler enterprise was the second highest user of antibiotics with the nDDDvet metric while the beef enterprise, the second highest user of antibiotics with the nDCDvet metric. The number of DDDvet was higher in both broiler and layer enterprises compared with the dairy enterprise and the nDCDvet tended to be higher in the layer enterprise compared with the dairy enterprise. The number of DCDvet was higher in layer and beef enterprises compared with the dairy enterprise, but the broiler and dairy enterprises had similar DCDvet. In the current study, the greater number of DDDvet and DCDvet in poultry compared with cattle is likely a consequence of blanket antibiotic administration via drinking water to the whole poultry flock as opposed to antibiotic treatment of individual cattle for therapeutic purposes [21,32,34]. In addition, the assessment of dose and course of intramammary units is necessary because of non-compliance to instructions noted in developing countries [45]. The reference DDDvet and DCDvet differ greatly between antibiotic classes, the dosage forms, and type of livestock [38] and thus, might have contributed to the difference in the antibiotic use between cattle and poultry enterprises.

Both nDDDvet and nDCDvet were higher in backyard and semi-commercial farming systems compared with commercial farming systems. However, they were not different between backyard and semi-commercial farming systems. These results suggest that there was a higher number of daily doses of antibiotics and a higher number of courses of antibiotics used in smaller herds and flocks (backyard and semi-commercial) compared with larger herds or flocks found in commercial farming systems [35,36]. Therefore, we recommend development of national reference for standardized daily and course doses of antimicrobials and standardized body weight of livestock similar to ESVAC in order to conduct further studies assessing the drivers for high antibiotic use in smaller herds of cattle and flocks of poultry.

3.6. Quarterly antibiotic use: Non-ESVAC metrics

3.6.1. Total mg/kg administered

For the non-ESVAC metric mg/kg administered per unit of body surface area, highest users of antibiotics were dairy enterprises, with much lower use recorded in beef cattle (Table 3). As with mg/PCU, the mg/kg metric may help in estimating and comparing antibiotic use within enterprises and therefore, we recommend the use of mg/PCU and mg/kg metrics to quantify antibiotic use in future studies so that national reference benchmarks could be developed at the enterprise level [16,46].

3.6.2. Treatment frequency (TF)

The treatment frequency per day of antibiotics use was highest in layer followed by broiler, beef, and dairy enterprises. The treatment frequency was presumed to be higher in layers because of administration of antibiotics at flock level compared with administration to individual birds or animals. The smaller herd size might also have contributed to lower use of antibiotics in cattle compared to poultry. Antibiotic use was higher in beef enterprises compared to dairy. However, similar AMU studies in other countries have demonstrated higher antibiotic use in dairy rather than beef enterprises [40]. It is unclear why this difference between Fiji and other countries has arisen, or whether such a difference is real.

3.6.3. Percentage treated (%)

The percentage treated with antibiotics was much lower in beef cattle compared with other enterprises. The flock level administration of antibiotics might explain the higher antibiotic use in poultry enterprises, but not in dairy farms. The likelihood of prophylactic use of antibiotics is higher in poultry [35,46], however, we were unable to establish if prophylactic use contributed to the high use of antibiotics in our study. Therefore, we suggest that future studies should evaluate on-farm practices so that necessary interventions could be developed to promote prudent antibiotic use.

3.6.4. Dose -animal per day

The number of dose-animal per day of antibiotics use was higher in poultry enterprises and in backyard farming systems. For all non-ESVAC metrics, the difference in antibiotic use was greater between cattle and poultry enterprises (being higher in poultry enterprises) than within poultry or cattle enterprises. Antibiotic use was higher in dairy compared with beef enterprises for mg/kg administered and percentage treated metrics. We presume the high antibiotic use in dairy enterprises may be because of the greater susceptibility of dairy cows to bacterial infections associated with lactation and poor hygiene at milking [29]. The use of antibiotics for growth promotion in beef cattle have been reported in other developing countries and therefore, we believe it may have contributed to some of the antibiotic use in beef enterprises in the current study [45]. The high use of antibiotics in poultry may, as has been noted, be in large part a consequence of flock level administration. The high use of antibiotics in backyard systems is of concern because of the large number of small-scale producers in a setting such as Fiji [24,25]. It is very important that the drivers for this high usage in backyard settings is understood, so that appropriate policies and interventions may be developed to address this.

3.7. Overall trends

In the current study, differences in AMU were observed between enterprises and farming systems. Some of these differences arise from the choice of metric and the different parameters used in the quantification of AMU by ESVAC and non-ESVAC metrics (liveweight, reference defined dose, course dose and population) [37]. Anthelmintic use was highest in cattle while antibiotic use was higher in poultry. Although there was no effect of farming system on anthelmintic use, with many of the metrics used to determine antibiotic use there was a significant difference between farming systems. The highest use of antibiotics was associated with backyard systems of production. This is despite these systems having a lower stocking density and, usually, lower levels of performance compared with commercial systems.

The mg/PCU metric has been commonly used for quantification and comparison of AMU in other countries [7] and our results based on the mg/PCU metric suggest that targeted interventions are required in poultry enterprises (both broiler and layer) which had higher antibiotic use than the global average (Fig. 2); many of these enterprises are backyard systems. Overall, Fijian annual antibiotic use is lower than the global average (44 mg/PCU vs 118 mg/PCU). However, anthelmintic and antibiotic use monitoring is required to reduce the use in a small proportion of livestock farm enterprises and promote the prudent use of antimicrobials. It is also important to evaluate and understand the livestock production and management factors which may have contributed to AMU, as studies in other countries have demonstrated [47]. To better explain the data reported in this paper, we suggest further studies are conducted to evaluate, explore, and understand the determinants of antibiotic use practice.

4. Limitations and future research

There was unequal participation per sub-category of farming system and enterprises in our study. We recommend a stratified approach to the recruitment of participant farms with different systems. Nevertheless, the distribution of enterprises across the island of Viti Levu, Fiji gives some confidence that the sample was illustrative of the type and range of farming enterprises and systems in Fiji. The lack of livestock registers, the National Livestock Census data (2020) only being made available in 2021 [24] and the numerous information gaps in the Fiji setting, means we adopted a 3-month survey approach as used in other studies [32]. Although ESVAC guidelines and other studies suggest a 12-month period survey, only a 3-month survey was feasible for our study [17,37,48] because we considered most farmers would not be able to recall information for more than the past 3 months. Data collection period was also constrained by practical consideration of time and resources.

A probability based random sampling method was impossible however inclusion and exclusion criteria were used to reduce bias. Nevertheless, since convenience sampling was done, and the 3-month survey data was extrapolated to annual use (mg/PCU), caution must be taken when extrapolating the data to determine national annual antibiotic use (mg/PCU). We extrapolated assuming that herds of cattle were the same over 12 months, the average of 4 batches of broiler flock were raised with batch in/out approach and 2 batches of layer flocks were raised with batch in/out approach. We also assumed that quarterly antibiotic use practice would be similar over the year and thus multiplying quarterly antibiotic use (mg/PCU) by 4 seemed justified. To enable more accurate estimation of annual AMU, we recommend yearlong studies to consider all seasons since weather could affect AMU as demonstrated in other studies [24,25,29,33,37,49]. The data source for quantification has limitations of its own. The accuracy of the farm's records or recollections of the antibiotic use for the past three months cannot be guaranteed, a limitation that has also been reported in other studies [37,50]. There were no published data or information available on the prescription and sales data of antimicrobials for livestock and therefore, farm record and verbal recollection of AMU by farmers was most feasible, a method which has also been used in other similar studies [32,37]. The sales data would have provided the sales of antimicrobials, however it does not provide an insight into actual use and purpose of AMU. Estimations and accuracy of liveweights of local livestock, required for the calculation of antibiotic use in many of the metrics, is a limitation but a farmer's estimation was considered more reflective of the actual weights of livestock rather than ESVAC estimates (see Supplementary Table 1).

Estimated antibiotic use and its precision cannot be confirmed, but it provides an estimate of relative antibiotic use for different enterprises and farming systems, which could be useful to prioritise the enterprise/system for which interventions need to be developed. Care must be taken when comparing mg/PCU of antibiotic use with other countries since different countries report consolidated values representing different enterprises [33]. There are limited studies that have quantified AMU using non-ESVAC metrics, thus we suggest more studies using a range of metrics for better evaluation and benchmarking of AMU within and between countries. Different studies have used different metrics to calculate the AMU which limits comparisons; however, all metrics assist in explaining relative AMU at the country level. In addition, the AMU in feed was unquantifiable as feed labels lacked information on the formulation and farmers were unaware of the content of feeds. Therefore, we suggest further studies to evaluate and understand the feed use practice so that antibiotic use in feed can be quantified in the future.

5. Conclusions

This study shows that quarterly anthelmintic use (mg) was high in dairy enterprises and antibiotic use (mg/PCU) in broiler enterprises. The overall annual antibiotic use in all enterprises was lower than the global average (44 vs 118 mg/PCU). The current study also shows that a small proportion of poultry and dairy enterprises used more antibiotics than the global average. There was some evidence that AMU was affected by farming system, with AMU being higher in backyard systems compared with commercial ones. This study suggests the need for follow up AMU longitudinal studies in all enterprises and studies evaluating and understanding drivers for AMU so that targeted policy recommendations can be made to reduce AMU in Fijian livestock farms.

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Authors' contribution

XK contributed to conceptualization, methodology, software, data collection, analysis, writing original draft preparation, writing, reviewing, and editing. CR, PR, RL contributed to conceptualization, methodology, analysis, reviewing and editing, interpretation, and supervision. All reviewed and approved the final version of the manuscript.

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Declaration of Competing Interest

None.

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Supplementary information: see Table 2.1 for metrics and parameters for quantification of antimicrobial use.

Chapter 5

Categorisation of antimicrobial use in Fijian livestock production systems

Chapter summary: To evaluate AMU practice in Fijian livestock production systems, categorisation of AMU was crucial. In this chapter, the AMU practice is categorised using international standards and the extent of imprudent AMU practice is investigated. Also, the AMU practices (prudent/imprudent) is investigated in different livestock enterprises (beef, dairy, broiler, and layer) and farming systems (backyard, semi-commercial and commercial).

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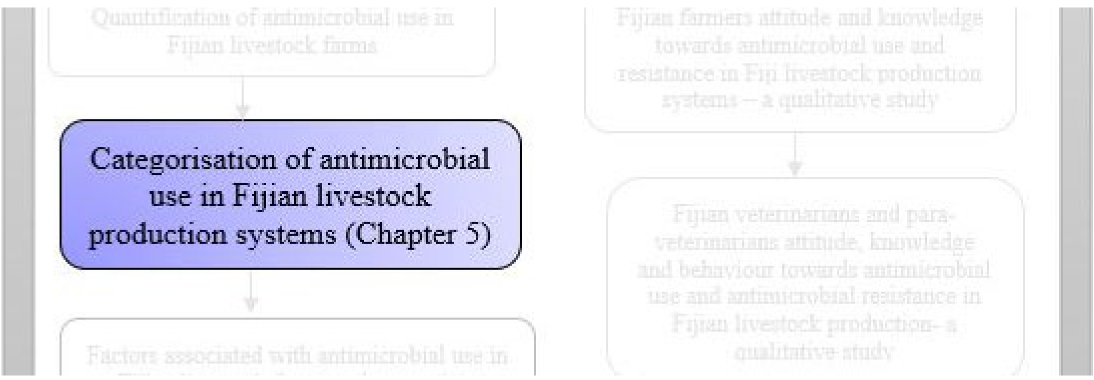

antibiotics

MDPI

Article

Categorisation of Antimicrobial Use in Fijian Livestock Production Systems

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Abstract: Antimicrobial resistance (AMR) is a major global threat to human and animal health. The use of antimicrobials in the livestock sector is considered to contribute to AMR. Therefore, a reduction in and prudent use of antimicrobials in livestock production systems have been advocated. This cross-sectional survey aimed to investigate the extent of imprudent antimicrobial use (AMU) and to determine whether the AMU practice was affected by either the farming system or species of farmed livestock in the largest island (Viti Levu) of Fiji. A total of 276 livestock enterprises were surveyed and antimicrobials were used on 309 occasions over 90 days. Overall, in 298 of 309 (96%) incidents, antimicrobials were used imprudently, comprising antibiotics, 160 of 170 (94%) and anthelmintics, 138 of 139 (99%). Prudent use of antibiotics was associated with commercial farming systems ($X^2 = 13$, $p = 0.001$), but no association was observed with anthelmintic use ($p > 0.05$). Imprudent antibiotic use was associated with dairy (OR = 7.6, CI = 1.41, 41.57, $p = 0.018$) followed by layer and beef ($p > 0.05$) compared to broiler enterprises. Imprudent AMU was more common in the backyard and semi-commercial enterprises compared to commercial broiler enterprises. Policies promoting the prudent use of antimicrobials in Fiji should focus on smaller livestock production systems and enterprises.

Keywords: antibiotics; anthelmintics; prudent use; imprudent use; livestock production systems; Fiji

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1. Introduction

Antimicrobial resistance (AMR) is a significant global threat to human and animal health [1]. Antimicrobial use (AMU) in the livestock sector has been considered to contribute to the AMR issue [1,2]. Therefore, a reduction and a prudent use of antimicrobials in livestock production systems have been advocated [1–3]. Food of animal origin is produced using traditional systems in non-commercial farming settings for food and socio-economic security worldwide [4–6]. However, in recent times, increasing demand for foods of animal origin (meat, milk, and eggs) has contributed to the intensification and commercialisation of livestock production systems locally and globally [7–9]. Larger flocks/herds of animals are produced in smaller confinements (sheds, cages, and paddocks) and in a shorter duration than traditional, extensive and free-range systems [6,8,10]. Backyard farming systems continue to produce livestock for domestic consumption, while semi-commercial farmers who are market-orientated produce livestock for domestic consumption and sale [11,12].

Higher flock/herd density with compromised farm biosecurity infrastructure results in higher chances of transmission of diseases amongst flocks/herds; therefore, striking a balance between increasing production and managing farm biosecurity risks has been a challenge faced by livestock farmers [13,14]. As part of a farm-level biosecurity risk management strategy, antimicrobials including antibiotics and anthelmintics (as well as other agents such as vaccines, medicated feed, nutraceuticals, and other herbal preparations) have been used to reduce the risk of microbial infection in the agri-food value chain [15–23].

Antimicrobials have traditionally been used to treat diseases in livestock; however, antimicrobials have also been used prophylactically in flocks/herds of animals and for growth promotion [16,24,25]. The prophylactic use may be predominant in commercial systems due to higher stock density; however, it is presumed that AMU for growth promotion may be more common in systems that have fewer veterinary interventions [22,26,27]. Unnecessary and imprudent use of antimicrobials in livestock production systems is of grave concern due to the risk of emergence and transmission of antimicrobial resistance (AMR) genes via the agri-food value chains to humans [28,29].

The World Organisation for Animal Health (OIE) discourages unnecessary and long-term use of antimicrobials in farmed livestock and advocate the administration of antimicrobials under the supervision of a qualified veterinarian [30,31]. In addition, the use of World Health Organisation (WHO) classified critically important antimicrobials in livestock production systems is prohibited and considered imprudent [32,33]. The imprudent use of antimicrobials has been reported in developing countries, predominantly in the backyard and semi-commercial farming systems, due to lack of access to veterinarians leading to self-prescribing [5,14,16,24]. However, such AMU practices in Fiji are currently unknown. In the United Kingdom (UK), the Veterinary Medicines Directorate (VMD) produced a code of practice on the responsible use of animal medicines in farm animals for livestock keepers, including guidelines for the access, usage and recording of AMU [34]. At a sectoral level, the Responsible Use of Medicines in Agriculture (RUMA) set guidelines for beef, dairy, broiler, layer and other enterprises [35]. Policies on responsible antibiotic use for farm livestock under cascade were also established in the UK, where veterinarians are permitted to prescribe medicines unauthorised for use in livestock [36], but this has not been the case in Fiji. In Fiji, the shortage of veterinary professionals, lack of legislation restricting AMU in livestock and standard therapeutic guidelines have been reported [37]. In addition, Fijian veterinary legislation is outdated since the current one dates to 1956 [38], while the antibiotics and anthelmintics for use in livestock remain unclassified in the current Medicinal Products Act [39]. On the other hand, the existence of a veterinary authority (a standard-setting authority similar to the VMD and BVA) remains unclear, while the legislation targeting antimicrobial residue levels in animal products only outlines standards on milk and milk products, excluding all other animal products [38–40]. Moreover, AMR in the Fijian health sector has also been reported [37].

In the UK, the BVA, in collaboration with VMD, set good practice guidelines for the use of veterinary medicines to assist veterinarians, pharmacists and suitability qualified personnel [41,42]. The VMD guidelines also include off label and cascade use of antibiotics which is only permitted for use under the supervision of veterinarians [36,42]. Hence, deviation from the set regulatory framework and classification on prescribing and dispensing of the antimicrobials is considered imprudent in the UK [43,44]. Antimicrobial legal categories and classification in other South Pacific countries such as Australia and New Zealand are similar to the UK [43–45]. However, the Fijian jurisdiction does not define such specific legal categories and authorisation of veterinary medicines [39]. Our recent study demonstrated moderately high use of antimicrobials which varied by systems and enterprises; however, the quantity of antimicrobials used does not demonstrate whether the antimicrobials were used prudently [46]; therefore, this study aimed to investigate the extent of imprudent AMU in Fiji, and to determine whether this was affected by either farming system or species of farmed livestock.

2. Results

2.1. Characteristics of Antimicrobials Used

The characteristics of AMU in farm enterprises are presented in Table S1. Veterinary antimicrobials were used in 306 of the 309 (99%) incidents, but on three incidents (1%), human antimicrobials were used, which are prohibited for use in food producing livestock. A little over half of the antimicrobials used were antibiotics (n = 170, 55%). Most of the antimicrobials were administered as an oral solution (n = 227, 73%), while a smaller proportion were administered orally as powders (n = 62, 20%). All powdered formulations for oral use were reconstituted and administered in drinking water. Most antimicrobials contained a single active pharmaceutical ingredient (n = 251, 81%). The majority of administrations were in flocks of poultry or herds of cattle (n = 253, 82%) rather than to an individual bird or cow, and 87% (268 of 309) of all administrations were self-prescribed (prescription and administration of antimicrobials to livestock on the farms) by the farmer or farm manager. Antimicrobials were mainly purchased from agricultural or veterinary clinics (n = 263, 85%) operated by livestock officers (presumably with tropical agriculture qualifications), referred to as para-veterinarians in the Fijian context.

The most commonly used antimicrobial was anthelmintic of the imidazothiazole derivative class (n = 72, 31%) followed by the antibiotic β-lactams (n = 81, 26%) and tetracyclines (n = 58, 19%) while other antibiotic classes were less frequently used (<10%). A larger proportion of antimicrobials were administered to dairy calves (n = 82, 27%) followed by lactating cows (n = 53, 17%), bull calves (n = 42, 14%) laying hens (n = 30, 10%) and broiler breeding birds (n = 25, 8%).

2.2. *Imprudent Antimicrobial Use Categorisation*

The categorisation of AMU practice in livestock enterprises is presented in Table 1. According to the first criterion in the decision-making tree (step 1), all anthelmintics (100%) and almost all antibiotics (98%) passed the step because veterinary antimicrobials were used in 306 of 309 (99%) occasions. The 3 of 309 (1%) uses were imprudent because they were non-veterinary antibiotics. Veterinary anthelmintics were used on 139 of 306 incidents and antibiotics on 167 of 306 incidents (step 2). However, since antibiotics are classified as POM-V and anthelmintics as POM-VPS, antimicrobials were mostly used in an imprudent way, as assessed in step 3 (288 of 306, or 94% of occasions). On this criterion, antibiotics were not prescribed by an authorised prescriber on 156 of 167 (93%) incidents and anthelmintics on 132 of 139 (95%) incidents. In step 4, 18 of 306 (6%) incidents prescribed by the authorised prescriber in step 3 were administered to the target species specified on the label and as per their market authorisation (step 4).

Table 1. Categorisation of 309 incidents where antimicrobials were used in livestock enterprises located in Viti Levu, Fiji.

Steps	AMU Practice	Antimicrobial Type					
		Anthelmintic		Antibiotic		Total	
		n	(%)	n	(%)	n	(%)
1 * (antimicrobial type)	Prudent	139	(100)	167	(98)	306	(99)
	Imprudent	0	(0)	3	(2)	3	(1)
	Total	139	(100)	170	(100)	309	(100)
3 (prescriber)	Prudent	7	(5)	11	(7)	18	(6)
	Imprudent	132	(95)	156	(93)	288	(94)
	Total	139	(100)	167	(100)	306	(100)
4 (target species)	Prudent	7	(100)	11	(100)	18	(100)
	Imprudent	0	(0)	0	(0)	0	(0)
	Total	7	(100)	11	(100)	18	(100)
5 (purpose of administration)	Prudent	5	(71)	7	(64)	12	(67)
	Imprudent	2	(29)	4	(36)	6	(33)
	Total	7	(100)	11	(100)	18	(100)

Table 1. *Cont.*

Steps	AMU Practice	Antimicrobial Type					
		Anthelmintic		Antibiotic		Total	
		n	(%)	*n*	(%)	*n*	(%)
6+ (cascade)	Prudent	n/a	n/a	11	(100)	11	(100)
	Imprudent	n/a	n/a	0	(0)	0	(0)
	Total	n/a	n/a	11	(100)	11	(100)
7 (AMU records)	Prudent	1	(20)	10	(91)	11	(69)
	Imprudent	4	(80)	1	(9)	5	(31)
	Total	5	(100)	11	(100)	16	(100)
Last step **	Prudent	1	(1)	10	(6)	11	(4)
	Imprudent	138 [a]	(99)	160 [b]	(94)	298 [c]	(96)
	Total	139	(100)	170	(100)	309	(100)

Note: - denotes zero *n* (counts) and % (proportion), * denotes steps as per framework (Table 5) where steps 2a and 2b were verification steps, + denotes step 6, which is only applicable to antibiotics, AMU denotes antimicrobial use, ** last step denotes totals of all steps including human antimicrobials used, [a] denotes anthelmintics imprudent sum = step 1 + step 3 + step 4+ step 5 + step 7, [b] denotes antibiotics imprudent sum = step 1 + step 3 + step 6 + step 7 (steps 4 and 5 are not applicable as antibiotics are prescribed in cascade), [c] denotes antimicrobial imprudent total sum = step 1 + step 3 + step 4 + step 5 + step 6 + step 7, less 4 from step 5 (antibiotics used in cascade).

Based on our evaluation, we found that in 6 of 18 incidents, antimicrobials which we classified as imprudent use were prescribed by an authorised prescriber in step 3 and approved target species in step 4, but we were unaware of the pre-existing condition being treated and therefore classified the use as imprudent in step 5. Since antibiotics should only be used in cascade as per our set framework (Table 5), 11 of 167 (7%) incidents (step 3) antibiotics used were categorised as cascade use in step 6.

On 18 occasions, antimicrobials were administered to authorised target species (step 4); however, only in 5 of 7 incidents were anthelmintics used prudently, and in 7 out of 11 incidents, antibiotics were used prudently. Since antibiotics are prescribed in cascade and all 11 of the 167 incidents were prescribed by the authorised prescriber in step 3, we considered all 11 for cascade use. Maintaining AMU records is essential for antimicrobial stewardship (AMS) programmes. Only 1 out of 5 incidents of anthelmintics were recorded (thus used prudently) whilst 10 out of 11 incidents of antibiotic use were recorded (i.e., prudent) (step 7).

Overall, in 298 of 309 (96%) incidents, antimicrobials were used imprudently. Antibiotics on 160 of 170 (94%) incidents and anthelmintics on 138 of 139 (99%) incidents were used imprudently. The practice of AMU (imprudent, prudent) was associated with the antimicrobial type (anthelmintic, antibiotic), $p = 0.026$, with antibiotic use being marginally more prudent compared to anthelmintics (Table 2).

Table 2. The antimicrobial use practice of 309 occasions when antimicrobials were used on 276 enterprises located in Central and Western divisions of Viti Levu, Fiji.

Antimicrobial Type	Antimicrobial Use Practice			
	Imprudent		Prudent	
	n	% Observed	*n*	% Observed
Anthelmintic	138	99	1	1
Antibiotic	160	94	10	6

n denotes frequency, % denotes percentage observed, Fisher's Exact Test, $p = 0.026$.

2.3. Description of the Types of Antimicrobials Used

OIE classified veterinary critically important antimicrobials (antibiotics only) were used on 55% of 309 incidents, while WHO categorised high priority critically important antimicrobials (macrolides, beta-lactams and third and fourth generation cephalosporins) were used on 3% of occasions (refer Table S1). Antimicrobial agents used as antiparasitic agents (45%) and antimicrobial agents for systemic use (38%) dominated the groups of antimicrobials used. According to the VMP classification, 57% of antimicrobials used were POM-V, and 42% were POM-VPS. Almost half of the administrations (48%) were classified as therapeutic use, while the remaining half was for prophylactic purposes (37%) and growth promotion (15%). Although the prescriber was one of the main prerequisites for categorisation of imprudent use, overall, in 36 incidents (12%), AMU was off label or antimicrobials were used in unauthorised target species, and there were only three incidents (1%) when prohibited antimicrobials were used (Table 3).

Table 3. Classification of antimicrobial formulations used in 309 incidents on 276 livestock enterprises located in Viti Levu, Fiji.

Factor	Sub-Categories	*n*	(%)
OIE classification	Veterinary critically important	170	(55)
	Unclassified antimicrobials	139	(45)
WHO classification	Highly important	162	(52)
	Unclassified antimicrobials	139	(45)
	High priority critically important	8	(3)
ATC ESVAC classification	Antiparasitic use	139	(45)
	Systemic use	117	(38)
	Intestinal use	26	(8)
	Intramammary use	24	(8)
	Systemic use (humans)	3	(1)
VMD legal distribution category	POM-V	279	(57)
	POM-VPS	131	(42)
	Human antimicrobial	3	(1)
Purpose of administration	Therapeutic	148	(48)
	Prophylactic	115	(37)
	Growth promotion	46	(15)
	Metaphylactic	-	-
Use on target species *	Authorised	270	(87)
	Unauthorised	36	(12)
	Prohibited +	3	(1)

Note: * denotes classification based on National Office of Animal Health (NOAH), - denotes zero *n* (count) and % (proportion). OIE, World Organization of Animal Health, WHO, World Health Organization, ATC ESVAC, Anatomical therapeutic classification European Surveillance Veterinary Antimicrobial Consumption project, VMD, Veterinary Medicines Directorate, + prohibited use denotes antimicrobials authorised for human use and prohibited for use in livestock raised for food.

In most incidents, farmers self-prescribed anthelmintics (95%) and antibiotics (80%). Para-veterinarians prescribed antibiotics on only 14% of occasions, and veterinarians on only 6% of occasions. There was an association between the type of antimicrobial used and the prescriber, with veterinarians prescribing marginally more antibiotics than anthelmintics ($p < 0.001$) (Figure 1A).

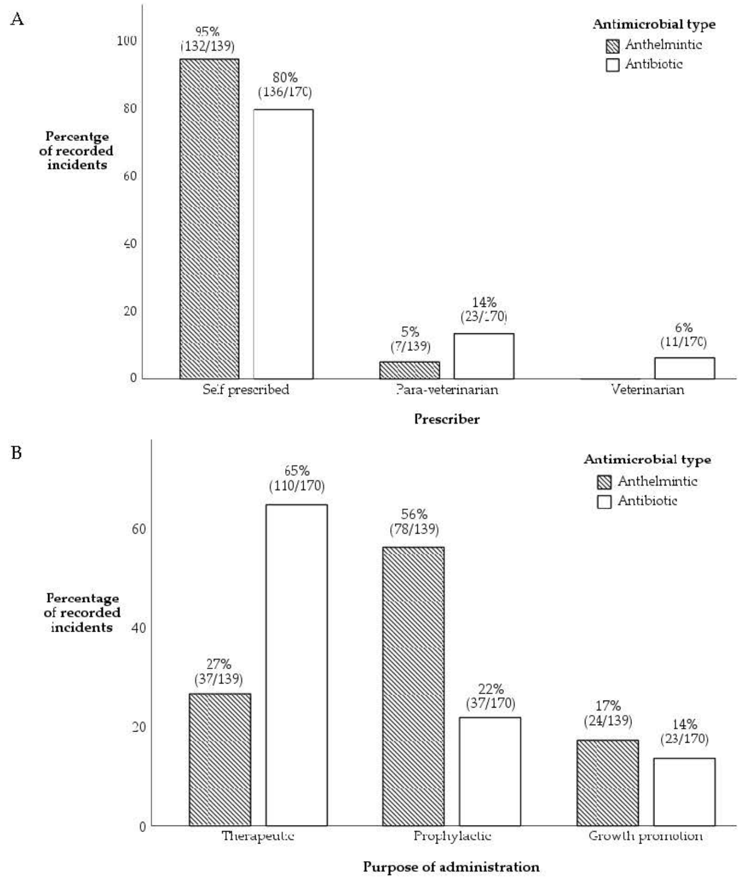

Figure 1. Association of 309 incidents where antimicrobials were used (anthelmintics n = 139, antibiotics n = 170) with (**A**). prescribing pattern (Fisher's exact test, $p < 0.001$), and (**B**). purpose of administration ($X^2 = 48$, $p < 0.001$) in 276 enterprises located in Central and Western division of Viti Levu, Fiji.

Most antibiotics were used therapeutically (65% of occasions), over a fifth (22%) were used prophylactically and 14% as growth promoters. The principal use of anthelmintics was for prophylactic purposes (56%), but on 17% of incidents, anthelmintics were used for growth promotion. There was a significant association between antimicrobial type and purpose of administration type, with greater usage of anthelmintics for prophylaxis ($X^2 = 48$, $p < 0.001$, Figure 1B).

Anthelmintics were used in just over 60% of incidents for parasitic infections, while antibiotics were used in a little over 30% of incidents for growth promotion. Anthelmintic and antibiotics were also used for symptomatic treatment (12% and 26%, respectively). The AMU practice was associated with indications of use, with anthelmintics being mainly used for parasitic infections ($X^2 = 162$, $p < 0.001$, Figure 2).

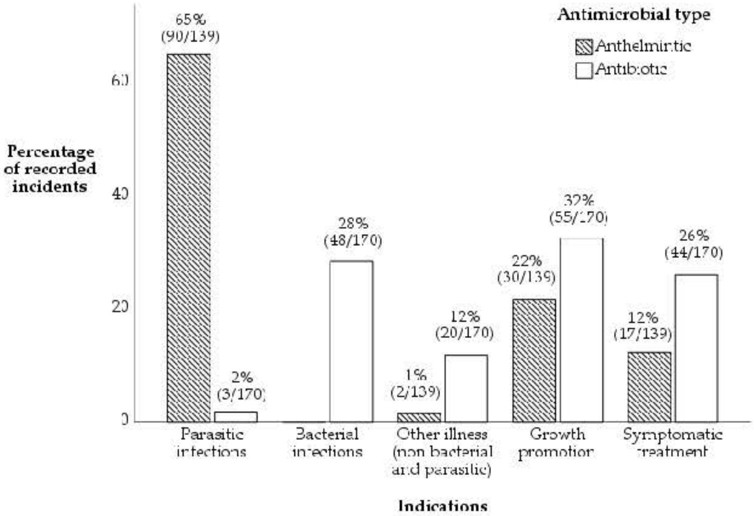

Figure 2. Association between 309 incidents where antimicrobials were used (anthelmintics *n* = 139, antibiotics *n* = 170) and indication of use on 276 enterprises located in the Central and Western division of Viti Levu, Fiji. (Chi-square statistics X^2 = 162, $p < 0.001$).

2.4. Prescription of Antimicrobials in Enterprises and Farming Systems

Antimicrobials were not prescribed by veterinarians (Refer Table S1, 298 of 309 incidents) except in broiler enterprises (100%, 11 of 11 incidents). Para-veterinarians were most likely to be used in dairy enterprises (67%, 20 of 30 incidents) and did not prescribe antimicrobials in poultry enterprises ($p = 0.017$, Figure 3A). Farmers self-prescribed antimicrobials in all enterprises, although this was less common in broiler and layer enterprises (10% and 13%, respectively). Farmers self-prescribed antimicrobials most commonly in dairy enterprises (49%, 132 of 268 incidents).

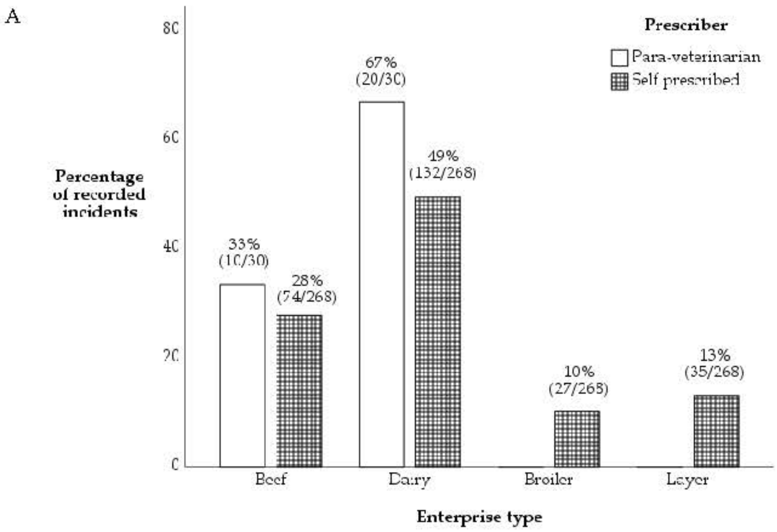

Figure 3. *Cont.*

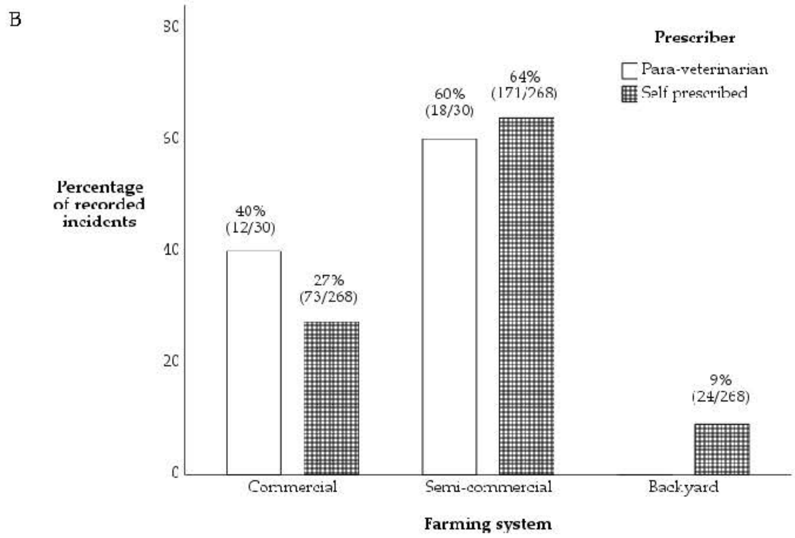

Figure 3. Association between 298 of 309 incidents where antimicrobials were prescribed (para-veterinarians n = 30, self-prescribed n = 268) and (**A**). different enterprises (Fisherman's exact test, p = 0.017) and (**B**). different farming systems (Fisherman's exact test, p = 0.111) located in the Central and Western divisions of Viti Levu, Fiji. Veterinarians only prescribed in commercial broiler enterprises (n = 11 incidents) and were excluded from the analysis.

Veterinarians only prescribed antimicrobials (refer to Table S1, 298 of 309 incidents) in commercial farming systems (100%, 11 of 11 incidents) while para-veterinarians mostly prescribed in semi-commercial farming systems (60%, 18 of 30 incidents). Self-prescribing was also common in semi-commercial systems (64%) and commercial farming systems (40%). Veterinarians and para-veterinarians did not prescribe any antimicrobials for use in backyard farming systems. However, there was no statistically significant association between prescriber and farming system (p = 0.111, Figure 3B).

2.5. Associations and Logistic Regression Modelling of Farming System and Enterprise Type with AMU Practice

Amongst the different farming systems, antibiotics were used imprudently in more incidents in the semi-commercial farming system (98%). The situation was only marginally better in the backyard (92%) and commercial (76%) farming systems. There was an association between farming systems and AMU practice where prudent use mainly was in commercial farming systems (X^2 = 13, p = 0.001).

The antibiotics were administered imprudently on more incidents in dairy (96%) followed by layer (95%) and beef (94%); however, the situation was better in broiler enterprises (75%). There was an association between AMU practice and enterprise type (X^2 = 10, p = 0.022), where broiler enterprises were more likely to use antimicrobials prudently.

All anthelmintics administered in the backyard and semi-commercial farming systems were used imprudently. Anthelmintic use was imprudent in beef, dairy and layer enterprises and only slightly better in broiler enterprises. There was no association between anthelmintic use practice and farming systems and enterprise types (p > 0.05).

Imprudent use was also more likely to be practiced in dairy enterprises (OR = 7.6, CI = 1.41, 41.57, p = 0.018, Table 4) followed by layer enterprises and beef enterprises compared to broiler enterprises; however, our finding was statistically insignificant for layer and beef enterprises (p > 0.05).

Table 4. Summary of association and logistic regression modelling of farming systems and enterprise types with antimicrobial use practice on livestock farms located in Central and Western divisions of Viti Levu, Fiji.

Antimicrobial Type +	Factor	Sub-Categories	*n*	(%)	AMU Practice		Chi-Square Tests		Logistic Regression		
					% Imprudent	% Prudent	χ^2	*p*-Value	*p*-Value	OR	95% CI
Antibiotic	Farming system	Backyard	12	(11)	92	8	13	0.001	-	-	-
		Semi commercial	65	(59)	98	2			-	-	-
		Commercial	34	(31)	76	24			-	-	-
	Enterprise type	Beef	18	(16)	94	6	10	0.022	0.125	5.67	0.62, 52.09
		Dairy	48	(43)	96	4			0.018	7.60	1.41, 41.57
		Broiler	24	(22)	75	25				1	
		Layer	21	(19)	95	5			0.093	6.66	0.73, 60.81
Anthelmintic	Farming system	Backyard	8	(9)	100	0	-	0.248	-	-	-
		Semi commercial	61	(65)	100	0			-	-	-
		Commercial	25	(27)	96	4			-	-	-
	Enterprise type	Beef	33	(35)	100	0	-	0.837	-	-	-
		Dairy	51	(54)	98	2			-	-	-
		Broiler	1	(1)	100	0			-	-	-
		Layer	9	(10)	100	0			-	-	-

Note: reference category is commercial for farming systems, broiler for enterprise type, *n* denotes the frequency, % denotes percentage, AMU, antimicrobial use, OR denotes odds ratio, CI denotes confidence interval. - denotes logistic regression modelling was not executed as there was no association (Fisher's exact test, $p > 0.05$) in the anthelmintic model and unbalanced antibiotic model for the farming system, + denotes two models (antibiotic, anthelmintic).

3. Discussion

The present study, to our knowledge, is the first study categorising AMU in livestock production systems in Fiji. The study revealed that in 96% of incidents (298 of 309), antimicrobials were used imprudently on 276 enterprises. The evaluation revealed that 94% (160 of 170 incidents) of antibiotic (POM-V) use and 99% (138 of 139 incidents) of anthelmintic (POM-VPS) use were categorised as imprudent. Although antimicrobials were purchased from veterinary clinics, presumably operated by para-veterinarians, the prescription and administration of antimicrobials to livestock on the farms were done by the farmers (95% self-prescribed). The results also suggest that most POM-V and POM-VPS were sold to farmers without prescription, concurring with the findings of studies in other developing countries [24,47].

The results also suggest that 12% of antimicrobials were administered to unauthorised target species, thus deviating from the market authorisation and the label. Given that 87% of antimicrobials were used in authorised target species, we presume that these antimicrobials were used correctly; used as per indications given in the market authorisation and the labels of the antimicrobials (see Table 3). The indications for which the antimicrobials were used were at the discretion of the farmers. Nonetheless, the actual administration on the farm depends on the farmers' decision-making process where the farmers' intention, attitude and available resources play a fundamental role in deciding the AMU [48], which differs from the UK, where the antibiotics are only prescribed by the veterinarians while anthelmintics by a pharmacist or suitably qualified person or a veterinarian [49].

On the other hand, the unauthorised prescription and administration of antimicrobials are of grave concern. There is a high chance of incorrect dosing, non-compliance to the correct duration of use, and off-label use resulting in imprudent use similarly reported in studies in other countries [47]. Europe and the UK banned the use of antibiotics for growth promotion [50,51]; however, antibiotics continue to be used for growth promotion in the Asian Pacific region [16,52]. The current study's findings confirmed that antimicrobials were used for growth promotion and were also administered prophylactically in livestock farms in Fiji. We presume there may be chances of justified and right intentions for using the antimicrobials in livestock to mitigate farm biosecurity risks [26]. However, using antimicrobials without consulting veterinary professionals poses a greater chance of antimicrobials being used imprudently [48]. We also believe that some imprudent use may be due to a lack of knowledge and understanding of antimicrobials, as participants reported using anthelmintics and antibiotics to treat similar diseases. In was beyond the scope of this study to explain the motivations behind the AMU practice.

Although antimicrobials were used imprudently in the vast majority of incidents (96%), most of them were used on authorised species (Table 1, Step 4). This finding further infers that although there was easy access to antimicrobials, only 12% of antimicrobials were administered to unauthorised species at the farm level (Table 3). However, we could not elucidate if antimicrobials were under or overdosed; therefore, randomised longitudinal quantitative studies that collect the body weights of animals and the ailments treated at the point of treatment with the antimicrobials would be more appropriate. Subsequently, the individual dose and course doses according to the indication for use could be more accurately estimated so that the under or overuse of antimicrobials in the different enterprises could be evaluated.

In the current study, antimicrobials were usually administered to the flock or herd rather than individual animals, which suggested that antimicrobials might have been used on clinically healthy animals. Prophylactic use of antibiotics in animals has been discouraged by OIE [53], but to maintain biosecurity, prophylactic use may be justifiable for economic and welfare reasons. Nevertheless, the prophylactic use of anthelmintics has been found to be beneficial in reducing the number of macroparasite infections reported in other studies [54]. Some studies have reported that one of the motivations for implementing biosecurity was increasing profit through higher farm production [15,55]. Therefore, we suggest further studies to explore and understand the motivations for implementing biosecurity measures such as prophylactic use of antimicrobials in flocks and herds of cattle and poultry. We further suggest exploring the farm biosecurity risk mitigation strategies employed on farms, reducing the incidence and transmission of diseases, thus reducing the need for antimicrobials. This will enable the development and recommendation of more uniform sectoral and enterprise-level risk management strategies. Exposing clinically healthy herds and flocks of animals to antimicrobials may further contribute to the risk of AMR, as demonstrated in other studies [29]. Therefore, in the Fijian jurisdiction, we suggest that care must be taken when administering antimicrobials at the herd and flock level. In addition, all administrations should be executed in consultation and under the supervision of suitably qualified veterinarians following the guidance of the WHO, OIE and FAO [2,3]. We also found that veterinary critically important antibiotics [33] and antibiotics critically important for human medicine [32], such as tetracyclines and β-lactam penicillin, were commonly used and were similarly reported in other developing countries [22,51,52].

Our results also revealed that antibiotics were used under the cascade, and the record-keeping of AMU was inconsistent. We could not establish a general understanding of the importance of maintaining AMU records amongst the livestock farmers and veterinarians. Evaluating and demonstrating an understanding of the decision-making process for cascade use of antibiotics could not be established; however, the cascade use of antibiotics by farmers, without consultation and supervision of veterinarians, is alarming. Contrarily, in the UK, antibiotics can only be used and prescribed by veterinarians under the cascade, adhering to stringent regulatory requirements [36,49]. Therefore, the development and implementation of regulatory frameworks on the cascade use of antibiotics similar to the UK [41,56] would assist the Fijian livestock production sector. In addition, we were also unable to assess the role of the para-veterinarians in veterinary service delivery and AMU decision-making process; therefore, it is crucial to clearly define the roles of para-veterinarians in the legislative frameworks in Fiji so that all POM-VPS (anthelmintics) are appropriately prescribed by para-veterinarians and other professionals as practiced in the

UK and other countries [30,36,41]. Given that we were unable to precisely evaluate the roles of the para-veterinarians and veterinarians at large in veterinary service delivery and livestock production, we suggest further studies exploring and understanding the knowledge, attitude and behaviour of the veterinarian and para-veterinarian towards antimicrobial prescribing, AMU and veterinary practice so that policy recommendations could be made to improve veterinary services and strengthen AMS programmes.

Based on the indications of use, antibiotics were used most frequently for growth promotion followed by treatment for bacterial infections and symptomatic treatment; however, antibiotics being used for the treatment of other illness (non-bacterial and parasitic) is of grave concern since such use is contraindicated in the market authorisation and label of the antibiotics. The use of antibiotics for bacterial infections may be justified due to its compliance to market authorisation and label; however, all other uses (parasitic infections, growth promotion, symptomatic treatment and non-bacterial and parasitic illness) described in Figure 2 are considered as imprudent use and contribute to the growing risks of AMR as reported in another study [29].

Our findings revealed that antibiotics were used therapeutically (65%) and anthelmintics prophylactically (56%) (Figure 1B), but the indications of use (Figure 2) showed that a higher proportion of anthelmintics were used (correctly) for parasitic infections compared to antibiotics which were used for growth promotion. Our study also revealed that antimicrobials were used mainly in the early phase of livestock production (Table S1), probably to prevent animal mortality which is more prevalent when the animal is younger [5,18] and to ensure the sustainability of production, which would serve as an income source to the household [6]. Our results show that the percentage of imprudent AMU was higher in semi-commercial and backyard systems. The high use of antimicrobials may contribute to the development of AMR [29] and higher chances of antimicrobial residues being found in food of animal origins as reported in other studies [25,57], therefore contributing risks to all in the agri-food value chain. Given that most enterprises raised livestock in the backyard and semi-commercial farming systems (Table 4), there is considerable reliance for Fijians on the semi-commercial and backyard farming systems despite the commercial farming system being the primary source of food in the agri-food chain, similarly demonstrated in other studies [6]. Therefore, further studies investigating antimicrobial residue levels in beef, milk, poultry meat and eggs are required, so that antimicrobial residue limits could be established and unnecessary exposure of antimicrobials to Fijians via the agri-food value chain could be minimised. Furthermore, understanding of the drivers for AMU practice in all farming systems over a prolonged duration is required so that necessary policies targeting behavioural interventions could be recommended for incorporation in AMS programmes.

There was a more prudent use of antimicrobials in commercial farming systems, and we presume that the imprudent use of antimicrobials in the backyard and semi-commercial farming system may be due to lack of accessibility to veterinary services, compromised farm biosecurity infrastructure and lack of knowledge and understanding on antimicrobials and AMR, which have also been reported in other studies [8,10,12,14,48]. Our evaluation of prescribing patterns in farming systems and enterprises revealed that veterinarians only prescribed antimicrobials in commercial farming systems and broiler only enterprises. We believe this is due to the easy access of in-house veterinarians in commercial enterprises. In addition, commercial broiler farmers are financially capable of accessing veterinary services considering the financial investments and mitigating financial losses that can result from compromised farm biosecurity [15,58]. Therefore, improving the veterinary services by recruiting more qualified veterinarians and creating training opportunities locally may improve veterinary services to all farmers resulting in POM-V (antibiotics) only being prescribed by veterinarians. This will also enable easy access of veterinarians by semi-commercial and backyard farming systems as well as other specialists and mixed enterprises. We presume improving veterinary services and engaging farmers and veterinarians in AMS programmes may improve and promote prudent use of antimicrobials.

Since the actual disease or ailments for which antimicrobials were administered was unknown, there may be chances of incorrect interpretation and classification of antimicrobials. However, this present study provides the framework for categorising antimicrobials and can be used in developing countries where information on AMU and AMR is scarce. We were unable to execute the logistic modelling for antibiotic use in different farming systems and anthelmintic use in different farming systems and enterprises due to lack of statistical association and unbalanced model due to unequal representation in all categories; therefore, we suggest equal representation to be considered in the inclusion criteria for future studies so that logistic modelling could be executed.

The high prevalence of imprudent use categorisation may also be due to the framework used, which was based on international standards. In the absence of the Fijian national medicine's directorate and legal classification of veterinary antimicrobials, using the UK, EU and OIE regulatory framework on veterinary antimicrobials use as a reference point was the best available choice. Since the UK and EU's food production systems and standards are a robust encompassing regulatory framework targeting every stage of the agri-food value chain, these standards enabled us to best evaluate AMU practice. Additionally, it was not possible to compare imprudent AMU practice in Fiji with other countries due to limited information regarding the categorisation of AMU practice. Nevertheless, despite vast differences in livestock production between developed and developing countries, AMR is a global threat to all countries. Therefore, the applicability of the international standards is well justified as it helped us establish the current situation on the AMU practice in Fiji.

4. Materials and Methods

4.1. Study Design and Data Collection

A cross-sectional survey was conducted between May and August 2019 on 236 livestock farms comprising 276 enterprises in Fiji's largest island's Western and Central divisions (Viti Levu). Livestock farmers and managers were recruited using a purposive and snowball sampling method. This study's design and data collection method was part of the principal survey published earlier [46]. The AMU dataset from the principal survey was used in this present study for the categorisation of AMU practice.

4.2. Data Management and Analysis

In the absence of a Fijian classification system for veterinary antimicrobials, a seven-step framework was developed using the VMD, BVA, ESVAC and OIE guidelines [36,41,56,59,60] to categorise the AMU (antibiotics and anthelmintics) into either prudent or imprudent use (Table 5). We used a similar approach used in the human health sector where imprudent use of antibiotics was defined as either using antibiotics without prescription, incomplete course and non-compliance to instructions of use [51].

All antimicrobials were classified according to their legal distribution category and market authorisation before being categorised into prudent and imprudent use. While antibiotics were classified as Prescription Only Medicine–Veterinarian (POM–V), anthelmintics were considered Prescription Only Medicine–Veterinarian, Pharmacist, Suitably Qualified Person (POM–VPS). In the current study, Suitably Qualified Persons were livestock officers (agriculture veterinary clinics staff and field officers and other non-government livestock officers) since they undertake para-veterinarian duties. The titles (livestock officer and para veterinarian) are used interchangeably in Fiji as there is no prescribed definition and competencies outlined in the current legislative framework.

Table 5. Framework for categorisation of antimicrobial use practice in livestock farms.

Step	Categories	Description	Procedure
1	Antimicrobial type	Verify if veterinary antimicrobial or human antimicrobial was used.	If veterinary antimicrobial was used, proceed to step 2A; if human antimicrobial was used, use was categorised as imprudent.
2	Antimicrobial class	Classify into class: antibiotics or anthelmintics.	Identify the class of the antimicrobial and then proceed to step 2B.
	Legal distribution categories of veterinary antimicrobials	Classify into either: • Authorised Veterinary Medicine–General Sales List (AVM–GSL), • Non-Food Animal Veterinarian, Pharmacist, a Suitably qualified person (NFA-VPS), • Prescription Only Medicine–Veterinarian, Pharmacist, Suitably Qualified Person (POM–VPS), • Prescription Only Medicine–Veterinarian (POM–V).	Identify and classify the veterinary antimicrobial if antibiotics were used and then proceed to step 3. (NOTE: all antibiotics used orally, parenterally and in-feed were classified as POM-V, anthelmintics as POM-VPS, and suitably qualified person (SQP) was a person trained and registered to sell veterinary medicine from agriculture store)
3	Prescriber	Verify the prescriber; • POM–V can only be prescribed by a Veterinarian, • POM–VPS (Veterinarian, Pharmacist, Suitably qualified person), • NFA–VPS (Veterinarian, Pharmacist, Suitably qualified person), • AVM–GSL (General, Self-prescribed, Other farmers).	If prescribed by the authorised prescriber, then proceed to step 4; if not, the use was categorised as imprudent. (NOTE: for steps 4 to 7, if prescribed not in accordance to step 3, then the use was categorised as imprudent at all steps)
4	Target species	Verify the species administered with approved target species according to market authorisation (MA) and label (authorised, unauthorised).	If deviated from the MA, label and prescribed by the veterinarian, or prescribed as per the MA, label and by the authorised prescriber, then proceed to step 5; if not, the use was categorised as imprudent.
5	Purpose of administration	Verify the purpose and establish the administration type: • Therapeutic, • Prophylactic, • Metaphylactic, • Growth promotion.	If prescribed for growth promotion, then the use was categorised as imprudent. If deviated from the MA, label and prescribed by the veterinarian, or prescribed as per the MA, label and by the authorised prescriber, then proceed to step 6; if not, the use was categorised as imprudent.
6	Cascade use	Verify the use of veterinary antimicrobial and prescriber.	If deviated from the MA, label and prescribed by the veterinarian in steps 4 and 5, then the use was categorised as cascade and then proceed to step 7; if not, the use was categorised as imprudent.
7	Farm AMU records	Verify if records were maintained.	If used under the cascade and maintained the antimicrobial use records, then the use was categorised as prudent; if not, the use was categorised as imprudent.

The seven-step framework included classifying veterinary antimicrobial use into 1. Antimicrobial type, 2. Antimicrobial class and legal distribution category of antimicrobial, 3. Prescriber of antimicrobials, 4. Target species (authorised as per label or market authorisation), 5. Purpose of administration (metaphylactic, prophylactic, therapeutic, and growth promotion), 6. Antibiotics used under the cascade and 7. Maintenance of farm AMU records (Table 5). All antimicrobials administered on different incidents were individually evaluated and categorised into prudent/imprudent use. Since only antibiotics can be prescribed in cascade, Step 6 was only applicable to antibiotics [36,49].

All AMU was categorised into prudent and imprudent use based on the intended therapeutic indications (purpose of use) of use reported by the farmer and farm manager (refer to Box 1).

Box 1. Therapeutic Indication Classification.

- All antimicrobials used for deworming were classified as used to treat/prevent parasitic infections.
- All antimicrobials used for mastitis and other infections were classified as used to treat/prevent bacterial infections.
- All antimicrobials used for other illnesses were classified as used to treat/prevent non-bacterial and parasite infections.
- All antimicrobials used for increasing outputs were classified as used for growth promotion.
- All antimicrobials used for gastrointestinal (diarrhoea), respiratory (flu), and viral illness were classified as symptomatic treatment.

All (n = 309 incidents) intended therapeutic indications of use were individually evaluated and categorised using the framework (Table 5) by the first author, a doctoral candidate and pharmacist with experience in agro security, food security and one health (XK), and verified by co-authors, an animal scientist with a doctoral degree and extensive experience in animal sciences (poultry)(CR), academic veterinarian and animal scientist with a doctoral degree with extensive experience in animal sciences (cattle) (PR) and one female academic pharmacist with a doctoral degree in medicine use and safety and extensive experience in qualitative research (RL).

Descriptive statistics were used to summarise the categorical variables; the pharmaceutical, pharmacological, clinical, legal category, therapeutic indications of use, prescribing pattern, source, and purpose of administration (herd/flock vs individual, prophylactic vs therapeutic, growth promotion). Subsequently, AMU practice (prudent/imprudent use) by the farming system and enterprise types were also summarised. The percentage of imprudent antibiotic and anthelmintic uses per enterprise (antibiotic used, n = 111 and anthelmintics used, n = 94) was calculated using the equation below.

$$\text{Percentage of imprudent use} = \frac{\text{Number of times AM used imprudently}}{\text{Total number of times AM used per enterprise}} \times 100 \quad (1)$$

where AM is antimicrobial, and the number of times is incidents on which antimicrobials were used.

The percentage of imprudent use was binary coded into prudent (0% = prudent, coded 0) and imprudent (>0–100% = imprudent, coded 1) for antibiotics and anthelmintics.

4.3. Statistical Analysis

Data were analysed using IBM SPSS Software V27. The Pearson's chi-square or Fisher's exact test as appropriate was used to investigate the association between the dependent binary-coded variable (prudent = 0 and imprudent = 1) with the antimicrobial types used (antibiotic, anthelmintic), farming system and enterprise type.

To evaluate prescribing patterns, access and use of antimicrobials, the chi-square test or Fisher's exact test as appropriate was also used to investigate the association between antimicrobial types (antibiotic and anthelmintic) and the prescriber of antimicrobials, purpose of administration, and the indication of use (parasitic infections, bacterial infections, other illness, growth promotion, symptomatic treatment). Subsequently, the Fisher's exact test was also used to investigate the association between prescribers of antimicrobials with farming systems and the enterprise type. The veterinarian prescriber category was excluded from the analysis since they only prescribed in commercial broiler enterprises.

The enterprise type (independent variable) was fitted in the binary logistic regression model with the antibiotic use practice (outcome variable). The Hosmer and Lemeshow test was used to evaluate the model fit. From descriptive analysis, the enterprise with the highest percentage of prudent AMU was set as the reference category; thus, broiler enterprises were selected as the reference category in the modelling. The logistic modelling was not executed for antibiotic use practice in different farming systems due to unequal representation of sample, while the anthelmintic use practice modelling was also not performed due to lack of statistical association. For all analyses, $p< 0.05$ was considered statistically significant.

5. Conclusions

This present study suggests that anthelmintics and antibiotics were used imprudently in all enterprises. Imprudent AMU was more common in the backyard and semi-commercial enterprises compared to commercial enterprises. Policies promoting the prudent use of antimicrobials in Fiji should focus on smaller livestock production systems and mixed enterprises. Transformation and improvement of policies on AMU, improving veterinary services and regulating the access, prescribing, and dispensation of antimicrobials is warranted to promote prudent use of antimicrobials at the country level. Concurrently, follow-up studies to understand AMU drivers in Fijian food production systems is essential as information obtained will enable the development of targeted behavioural interventions to promote prudent AMU in livestock production systems.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/antibiotics11030294/s1, Table S1: Characteristics of 309 antimicrobials used in 236 livestock farms comprising of 276, enterprises located in Viti Levu, Fiji.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Supplementary Table

antibiotics MDPI

Article

Categorisation of Antimicrobial Use in Fijian Livestock Production Systems

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Supplementary Materials

Table S1. Characteristics of 309 antimicrobials used in 236 livestock farms comprising of 276. enterprises located in Viti Levu, Fiji

Factor	Sub-Categories	n (%)
Antimicrobial type	Veterinary antimicrobial	306 (99)
	Human antimicrobial	3 (1)
Veterinary antimicrobial class	Antibiotic	170 (55)
	Anthelmintic	139 (45)
Pharmaceutical form	Oral solutions	227 (73)
	Injections	40 (13)
	Long-acting injections	18 (6)
	Intramammary lactating cow	17 (6)
	Intramammary dry cow	7 (2)
Number of API	One	251 (81)
	Two	32 (10)
	Three or more	26 (9)
Type of formulation	Liquid	247 (80)
	Oral powder	62 (20)
Administration type	Group (flock/herd)	253 (82)
	Single animal	56 (18)
Prescriber	Self-prescribed	268 (87)
	Para-veterinarian	30 (10)
	Veterinarian	11 (4)
Source	Para-veterinarians (vet clinics)	263 (85)
	Veterinarian	7 (2)
	Over the Counter	10 (3)
	Veterinary Retail company	2 (1)
	Other farmers	1 (<1)
	Contractor	7 (2)
	Dairy Cooperative	5 (2)
	Farmers farm cabinet	2 (1)
	Feed supplier	9 (3)
	Other sources+	3 (1)
Antimicrobial class	*Anthelmintics*	
	Benzimidazole derivatives	43 (14)

	Imidazothiazole derivatives	96 (31)
	Antibiotics	
	Aminoglycosides*	26 (8)
	β-Lactams	81 (26)
	Tetracyclines	58 (19)
	Sulphonamides and Trimethoprim*	1 (<1)
	Macrolides	4 (1)
	Enterprise and production stage	
	Beef- fattening cattle	4 (1)
	Breeding cattle	37 (12)
	Calves	42 (14)
	Dairy- lactating cow	53 (17)
Livestock type	Dry cow	14 (5)
	Heifers	3 (1)
	Calves	82 (27)
	Layer-breeding birds	5 (2)
	Layer hens	30 (10)
	Broiler-breeding birds	25 (8)
	Meat birds	13 (4)

Note * denotes formulation with a combination of different classes of antimicrobials, + denotes sourced online, - denotes no scores, n denotes frequency, % represents percentage, API means active pharmaceutical ingredient, all percentages were rounded off to the nearest decimal point, contractor – commercial poultry processor.

Chapter 6

Fijian farmers' attitude and knowledge towards antimicrobial use and antimicrobial resistance in livestock production systems - a qualitative study.

Chapter summary: Following from previous chapters in which the data on AMU and AMU practice was presented, the current chapter explores drivers of AMU and AMR amongst livestock farmers. The livestock farmers knowledge and attitude towards AMU and AMR was explored and reported in this current chapter.

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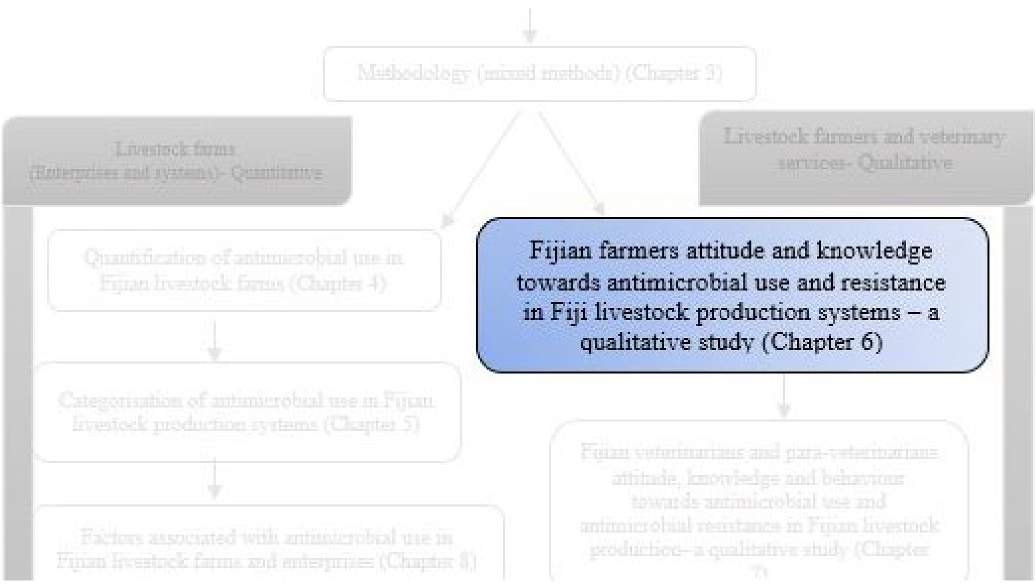
Author Contributions: This study was conceived of and designed by XK, RL, CR and PR. The interview schedule was drafted by (XK), and all (XK, RL, CR and PR) contributed to the development and review. Recruitment, interview, recording and transcription, initial coding of transcripts, higher-order analysis and theme development and drafting of the first manuscript was undertaken by XK. RL, CR and PR provided comments and revisions through several iterations of the manuscript.



Abstract

Antimicrobial resistance (AMR) is a global health issue affecting humans and livestock. To mitigate AMR risks, responsible use of antimicrobials in livestock production systems have been advocated. Studies have reported patterns of antimicrobial use (AMU) in livestock production systems; however, there is limited information on the drivers of AMU and AMR. Therefore, this study aimed to explore and understand the attitude and knowledge of Fijian livestock farmers on AMU and AMR. Livestock farmers and managers from the Central and Western divisions of Viti Levu, Fiji were recruited using purposive and snowball sampling methods. Face-to-face one-to-one semi-structured qualitative interviews were conducted. Interview questions were informed by the Theory of Planned Behaviour (TPB). Interview transcripts were analysed inductively using reflexive thematic analysis and deductively using the TPB framework. A total of 19 cattle and poultry farmers took part. Our analysis generated four themes: 1) Uninformed use of antimicrobials and unaware of AMR, 2) Safeguarding livestock and generating income source as primary motivators for using antimicrobials 3) Medicine shortage results in hoarding and self-prescribing, and 4) Farm decisions on AMU and livestock management influenced by foreign farmers and veterinarians. Livestock farmers used medicines in livestock production; however, they could not differentiate amongst different types of medicine, including antimicrobials. Antimicrobials were used to prevent diseases in livestock and promote production of food and financial security but without any awareness of the risks of AMR. Additionally, farmers hoarded and self-prescribed medicines. Farmers rationed antimicrobials by not completing the entire course of antibiotics to save them for future use. Based on past experiences, farmers expressed dissatisfaction with the veterinary services provided by the government. They sought help online and from foreign farmers and veterinarians. We propose the need for antimicrobial stewardship (AMS) programmes focused on promoting rational use of antimicrobials and awareness of AMR amongst farmers in the Fijian livestock production systems. These programmes need to consider the anthropological, socio-cultural, economic, and environmental factors driving AMU. Future studies are underway to explore the attitude and knowledge of Fijian veterinarians, para-veterinarians and pharmacists on AMU and AMR to gain a broader systems knowledge to inform the design of AMS programmes.

Keywords: attitude, knowledge, livestock farmers, antimicrobial use, antimicrobial resistance, Fiji

Introduction

Antimicrobial resistance (AMR) is a global health issue affecting humans and livestock [1,2]. Although the direct links between antimicrobial use (AMU) in livestock production systems and the increase in AMR in humans have yet to be established, the World Health Organisation (WHO), World Organisation of Animal Health (OIE) and Food and Agricultural Organisation of United Nations (FAO) advocate responsible use of antimicrobials across both human and veterinary medicine [1-4].

Livestock farmers use antimicrobials therapeutically; however, there have been concerns that antimicrobials are used prophylactically in herds/flocks of animals without the supervision of a veterinarian [5] and for growth promotion [6,7] to safeguard livestock production [8], thus maintain food and financial security [9]. The European Union (EU) and the United Kingdom (UK) prohibit the use of antimicrobials for growth promotion in livestock production, but this is not the case in other developed and developing countries [7,10]. There are studies reporting patterns of AMU and practice in developing countries [6,11,12], but few have explored farmers' behavioural drivers for using antimicrobials in developing countries [13-15], which is key in the design and implementation of antimicrobial stewardship (AMS) programmes[4].

Studies have reported better understanding of AMU and AMR amongst farmers in developed countries compared to developing countries [16,17]. Although some studies have suggested improving farmers knowledge through education optimises responsible AMU, there is a mismatch between perceived knowledge and understanding, and practise [16-18]. Other factors such as farmer's age, years of experience, farm and flock size, and access to veterinary services also influence AMU behaviour [16,17]. To date, most studies exploring drivers of AMU and AMR have been conducted in developed and developing countries [16,17] with very little is known about the Oceania region except for Australia and New Zealand [16,17,19]. Hence understanding of the drivers of AMU and AMR in the local context is necessary.

Our current study focuses on the livestock farming systems in Fiji. Our recent study demonstrated the considerably high use of antimicrobials in semi-commercial and backyard farming systems in the largest island of Fiji (Viti Levu) [12], but the drivers for

AMU in this context remain unexplored. An important step is to understand the livestock farmers' attitude and knowledge, which can shape their AMU behaviour [16,17,20]. Socio-psychological theories such as Theory of Reasoned Action (TRA) [21], Health Belief Model (HBM) [22] and Theory of Planned Behaviour (TPB) [23,24] have been used as theoretical frameworks to understand and explain people's behaviour. In particular, TPB enables understanding of behaviour by analysing people's knowledge, attitude and motivation that affects their decision-making process [24,25].

TPB has been used to understand the behaviour of farmers on livestock production and management [14,15]. It has also informed the design and implementation of interventions to promote the prudent use of antimicrobials in farms in Europe [26,27]. There are differences in psychological and contextual drivers (such as legal framework, policies, and procedures) relating to livestock production and management globally [13,28], therefore the direct application of existing AMS policies may not be effective. Hence, it is imperative to consider the drivers of AMU behaviour at the country level to develop interventions promoting the responsible use of antimicrobials [8].

Therefore, this study, informed by TPB, aimed to explore, and understand the attitude and knowledge of Fijian livestock farmers' towards AMU and AMR in the Central and Western division of Viti Levu, Fiji.

Methods

Reflexivity and team

An interdisciplinary research team comprising of two female and two male researchers conducted the study; a male doctoral candidate and pharmacist with experience in agro-security, food security and one health (XK), one female academic pharmacist with a doctoral degree in medicine use and safety and extensive experience in qualitative research (RL), a female animal scientist with a doctoral degree and extensive experience in animal sciences (poultry) (CR) and a male academic veterinarian and animal scientist with a doctoral degree with extensive experience in animal sciences (cattle) (PR). XK undertook all the data collection on the study sites. In preparation, XK undertook qualitative methods research training formally via an accredited course and training 'on the job' with RL and her research team that included XK shadowing another researcher conducting interviews, practical guidance on the analysis of data and mock interviews with RL, CR and PR.

Study design and setting

Face-to-face semi-structured qualitative interviews were conducted between September and November 2019 with Fijian livestock farmers and managers located in the Central and Western divisions of Viti Levu, Fiji. The island of Viti Levu was selected because it is the largest in Fiji, where Fijians lived and raised livestock [29]. An interpretivist epistemological position underpinned the design and conduct of our study [30]. Reflexive thematic analysis was used as our analytic approach [31,32]. The COREQ was used to report this study [33].

Participants and recruitment

Our participants comprised livestock farmers and managers who raised livestock, managed, and directly administered antimicrobials to livestock in their farms. A sample of at least 20 participants from the cattle and poultry production systems (dairy, beef, broiler, and layer) was targeted to generate in-depth, rich accounts and descriptions on AMU and AMR. This study was our follow up study from the earlier published quantitative study which quantified AMU in cattle and poultry production systems [12]. Qualitative studies have no ideal sample size [34,35], and sample sizes of 10-25 have been used in other studies [36,37]. Hence, we presumed 20 participants would be reasonable in our study for generating rich and meaningful insights. Purposive and snowball sampling methods were used to recruit participants. The purposive sampling method allowed diversity in participants and enabled the recruitment of participants who have a direct link, experience and are engaged in the area of interest [38,39]. The participant inclusion criteria are listed in Box 1.

The Fijian Ministry of Agriculture livestock officers and assistants working in the major townships in Central and Western divisions identified potential participants and provided participant contact details to XK. XK contacted potential participants via telephone to introduce them to the study. XK visited all participants who were interested in participating in a face-to-face interview. XK provided the participants with the study participant information sheet and obtained verbal informed consent before starting interviews. No participant had any prior relationship with XK.

Box 1: Participant recruitment criteria

- Located in the Central Division or Western Division of Fiji
- From Naitasiri, Namosi, Rewa, Serua, Tailevu, Ba, Nadroga-Navosa or Ra province
- Located on the mainland of Viti Levu.
- Location was accessible by road.
- Over 18 years old age.
- Raised either poultry (layer, meat bird or both) or cattle (dairy, beef, or both) or raised both poultry and cattle (mixed) farms
- Raised livestock in any type of farming systems (subsistence or semi-commercial, or commercial)

The interview

TPB informed the development of the initial semi-structured interview guide [24,40]. The semi-structured interview guide was structured around the key constructs of TPB (attitude, subjective norms, and perceived behavioural control) and included structured and probing questions relating to attitude towards treating animals, barriers to treating sick animals, the influence of veterinary professionals and other farmers on farmers and other factors which influenced farmers decisions on using antimicrobials were included. The interview guide was piloted with one participant, and minor changes were made to simplify the questions. See Box 2 for the interview schedule. All interviews were conducted in the English language at a time and location convenient to participants. All participants were encouraged to speak freely and were made aware that XK was interviewing them in the capacity of a PhD researcher.

Box 2 Interview topic guide

1. Can you tell me about your farming experience?
(Prompts: how long farming for? Years of experience in livestock production? Training? Member of any associations?)
2. Can you describe to me a typical working day at your farm?
(Prompts: what do you do? What do you do with your produce?)
3. What do you do when your animals are sick?
(Prompts: Veterinary/ Para-vet consultations? Medicine used? Source? Availability? Cost? Do you record them? How often do you use them? Problems faced?)
4. What do you do when the medicine you use on animals is not working?
(Prompts: consultations? Other farmers? Veterinarians or para-veterinarians? Any other medicine used? How do you use them? Do you follow instructions?)
5. What is your view on why the medicine used did not work?
(Prompts: correct dose? The duration? Right medicine? Type of medicine? Stronger medicine? Didn't follow instructions? Medicine not effective? Antibiotics? antimicrobials?)
6. Can you tell me what is antimicrobial resistance?
(Prompts: if YES: where have you heard from? What do you know about it? What could be done? If NO: Do you think all medicine, you use is antimicrobials? or are they antibiotics? Where did you hear that from?)
7. Are there any other comments you want to make about medicine use or antimicrobial resistance?

Data management and analysis

XK transcribed interview recordings verbatim into MS Word and then checked the accuracy of transcriptions against audio recordings. All interview transcripts were anonymised. The data was analysed in NVivo 12 (QSR International Pty Ltd., UK) using Braun and Clarke's approach to reflexive thematic analysis; by exploring and establishing patterns in the dataset, emerging topics, and overarching themes [30,32,41,42] (see Supplementary file 1 for an example of the coding of the interview transcripts). The reflexive thematic analytic approach is not underpinned by any theoretical framework, allowing flexibility in the analysis process, leading to the generation of in-depth knowledge on drivers of AMU that a theoretical deductive analytical approach may overshadow [31].

To mitigate potential gaps in the analytic approach, data was also analysed deductively using predetermined topics developed using the TPB framework shown in Box 3 to clarify and compare findings obtained using both approaches. The analysis process was iterative and involved multiple discussions with the research team that also included the clarification of the technical interpretation of the emerging themes in areas of medicine use, poultry, and cattle production. The demographic data were summarised and reported.

Box 3 Topics

- Attitude towards the AMU
- Social influence (AMU subjective norms)
- Perceived behavioural controls of AMU (Perceived behavioural controls)
- Actual behavioural controls

Results

Participant characteristics

A total of 19 livestock farmers and managers participated in the interviews, which lasted between 45 to 50 minutes (mean 46 minutes). Table 1 summarises the demographic characteristics of the participants. Most participants were male (n=13, 68.4%), and 47.4% were 40-59 years of age. Most participants had attained a secondary school education (68.4%, n=13). The majority of the participants were livestock farmers (n=17, 89.5%) and had 0-5 years of experience in livestock farming (n=7, 38.9%). Most participants were dairy farmers (n=6, 31.6%) and raised livestock in semi-commercial farming system (n= 12, 63.2%). Over 50% of farms were individually owned (n=10, 52.6%). Most participants had no prior training in livestock production (n=12, 63.2%) and were not members of any association (n=11, 57.9%).

Table 1 Demographic characteristics of the livestock farmers (n=19) from Central and Western divisions of Viti Levu*, Fiji.

Category	Sub-category	N	%
Gender	Female	6	31.6%
	Male	13	68.4%
Age	20-39 years	6	31.6%
	40-59 years	9	47.4%
	Over 60 years	4	21.1%
Division	Central	9	47.4%
	Western	10	52.6%
Province	Rewa	1	5.3%
	Tailevu	2	10.5%
	Naitasiri	3	15.8%
	Namosi	1	5.3%
	Serua	2	10.5%
	Nadroga-Navosa	3	15.8%
	Ba	6	31.6%
	Ra	1	5.3%
Level of education	Secondary	13	68.4%
	Tertiary	4	21.1%
	Vocational agricultural school	2	10.5%
Qualifications	Secondary	13	68.4%
	Tertiary	4	21.1%
	Vocational agricultural	2	10.5%
Occupation	Farmer	17	89.5%

	Farm manager	2	10.5%
Years of experience	0-5 years	7	38.9%
	5-10 years	4	22.2%
	10-20 years	3	16.7%
	Over 20 years	4	22.2%
Enterprise type	Beef	1	5.3%
	Dairy	6	31.6%
	Broiler	3	15.8%
	Layer	2	10.5%
	Broiler and Layer	2	10.5%
	Dairy and Layer	2	10.5%
	Beef and Dairy	1	5.3%
	Broiler and Dairy	1	5.3%
	Beef and Layer	1	5.3%
Farming systems	Backyard	1	5.3%
	Semi-commercial	12	63.2%
	Commercial	6	31.6%
Ownership	Individually owned	10	52.6%
	Family owned (generational)	8	42.1%
	Cooperative owned	1	5.3%
Livestock production training	Yes	7	36.8%
	No	12	63.2%
Association memberships	Yes	8	42.1%
	No	11	57.9%

[*]Viti Levu is the largest island in Fiji that is divided into two divisions (Central and

Western) and consists of eight provinces listed in the table.

Interview findings

The analysis enabled the generation of four key themes: 1) Uninformed use of antimicrobials and unaware of AMR, 2) Safeguarding livestock and generating income source as the primary motivator for using the antimicrobials, 3) Medicine shortage resulting in the hoarding and self-prescribing, and 4) Farm decisions on AMU and livestock management influenced by foreign farmers and veterinarians.

Theme 1: Uninformed use of antimicrobials and unaware of AMR in livestock

Overall, most participants lacked general understanding and awareness on AMU and AMR and its mechanism of action. Most of the participants did not differentiate between antimicrobials and other types of medicine. They used the terms 'medicine' or 'drugs' to describe any medicine they used, including antimicrobials. They were also unaware of the names of medicines, including antimicrobials, that they were administering to their livestock. Only a few participants knew the names of the disease they treated using the medicines.

> *"I don't know the name [of] the medicine; it was the injections. [I] inject them and I don't know what's the name of the medicine" Participant 11*

> *"No, we got, um. If we use the, I mean the drugs, there are only two drugs we got, i.e., SA [short acting] and LA [long acting] [penicillin]. Nothing else. And sometimes when they have diarrhoea, we give Scourban [and] nothing else" Participant 5*

Most participants referred to medicines by their packaging, the colour of the medications or the dosage form of medications instead of their generic or brand names. There were a minority of participants who were aware of the type and class of antimicrobials they used. A few participants described antimicrobials they used as a yellow powder but when probed, they were not able to talk about them further.

> *"I used the antibiotic [but I] forgot the name. It [is] some kind of penicillin, I forgot the name written on [that] particular bottle" Participant 7*

> *"Yes! [it is] yellow powder, what you use for the chicken. What [do] you call that. I forgot the name of it. It's an antibiotic, we give that". Participant 2*

According to a few participants, antibiotics were perceived to be a cure for all sicknesses. They used antibiotics on their livestock based on their past experience.

> *"Using antibiotics! Um! [Antibiotics] might cure their [sickness or] whatever the [animals] are facing, sickness. yah!" Participant 2*

The participants also shared that they did not know about the antimicrobials and their use in livestock production. But a few participants were able to explain the risks of using the antimicrobials.

> *"You have to be quite mindful, [that is] how much you use and [for] how long [you] using for [and] not overusing. So continuous use of antibiotics is harmful to the birds [and] production [as well as] harmful to people. Withholding period has to be maintained". Participant 2*

Nonetheless, most participants had never heard of AMR and were unable to provide insight into AMR in livestock and its risks. There were a couple of participants, however, who were able to describe their understanding of AMR as linked to a problem in human health.

> *"Antibiotic resistance! I don't know about it. We don't have [many cases] of sick birds…". Participant 6*

> *"Yah, I heard of but through human [health]. [I] heard [of it] in humans. In humans, the drugs given to them leads [to] drug resistance. The drugs [are] not effective to their immune system, and it [is] like that eh!" Participant 4*

A few participants highlighted the role of the government to address the risks associated with antimicrobial use.

> *"Yeah, they are resistant, but if we just change the medication, then it is ok. If any medication we give every day, it would be like that eh! so we have to change it. If it is harmful, then the government should do something about it". Participant 14*

Theme 2: Safeguarding livestock and generating income source as the primary motivator for using antimicrobials

Most participants inherited their livestock farms from their ancestors, and livestock production was their primary source of income. Hence, the sustainability of livestock production was essential to their livelihoods. Mitigating risks on-farm was crucial, and the use of antimicrobials was perceived to be the first line of defence.

A few participants who were contracted milk suppliers expressed confusion with the actions of milk processor companies. These companies rejected their milk products due to the presence of antimicrobial residues even though participants said they had not used antibiotics prophylactically on their livestock during that period. There was therefore a loss of income. To counter further milk rejection by processing companies, one participant treated animals with antimicrobials.

> *"My whole weeks' milk was rejected by the [dairy processor]. They said [that] there was antibiotic in the milk and [at] that point in time there were no drugs on the farm that we can [use to] inject for the cows' mastitis. I don't know how this farm had the problem [of] antibiotic [use]. I never [received] any money" Participant 5*

> *"I am not sure, but we just give [medicine]. They give the injection for milk if there is milk reject[ion] then they will give the injection, and it will be ok" Participant 14*

Based on past experiences with diseases in their livestock and to mitigate risks introduced from the hatchery and prevent disease transmission on the livestock production, some participants said they will not hesitate to use antimicrobials.

> *"Yes! But for the last 2 or 3 years, we never had any issues. If there [are] hatchery issues, we just use Oxytet, and it sorts itself" Participant 13*

> *"[Sickness] can be prevented. Sometimes like at the moment, I have some medicine down there for them, for diarrhoea [in] young calves, as soon as they get bacteria, I give it to them, and they drink it" Participant 11*

A few participants highlighted that antimicrobial use was necessary due to projected losses resulting from diseases in flocks of chickens from untreated government water supply.

> *"When [government water supply] was tested, there was no chlorine in the water. In government water supply, we have E Coli. [When] all [chickens are] towards the end of the batch [cycle that is] Day 28, 29 and 30, if there is no chlorine [in the water] then the E Coli [infects chickens], then we have to use Oxytet, if not, [we will] bear the loss [of income]". Participant 13*

When using antimicrobials to treat infections in livestock, a few participants said they were selective in the length of treatment. They would monitor the perceived effect of the antimicrobials on their livestock and then act accordingly, whether to continue treatment or to stop.

> *"When I see the mastitis [in udder then], I use it. I keep it for, say, about 48 hours, and then I strip it, separate the milk, and I see if [mastitis is] still [present in udder] than I put another one [intramammary unit]. If the milk is [to be] disposed of, then I use the milk. I don't record anything" Participant 10*

The lack of financial security to invest in improving farm infrastructure, conditions, and livestock feed for a few participants led them to use antimicrobials to prevent disease.

> *" We used to buy the feed, but it was costly, $38 to $40 [for a bag of feed] and [the] mix of the feed [was not of same quality]" Participant 3*

> *"If you properly clean your sheds, then you don't need any medication at all. If your shed is not cleaned properly, then we do have the disease [present in] there "Participant 1*

Theme 3: Medicine shortage resulting in hoarding and self-prescribing

Many participants highlighted that there was a significant shortage of medicines in Fiji. Therefore, they often buy quantities of medicines, including antimicrobials, which exceed their needs, for future use. The costs of antimicrobials were considered exorbitant, and some participants said they rationed medicines by not completing the course of antimicrobials so that they have some to use in the future. They made these decisions based on perceived response to treatment and the availability of medicines at that time.

> *"[For instance,] if the chickens [are] suffering from diarrhoea, we just give them for five days, and it's not like we go and buy [only] one packet. We better buy 4 or 5 packets, so one packet [we] use and the rest of the packets we just keep it for future" Participant 17*

> *"Yes! It is expensive, and it is not available always. Even now, it's not available. We are unable to afford than what we do is, normally [we use] one tube per teat, [and] if [it is] not available then we use half [tube per] teat, [that is]50% of tube in one teat and [the remainder]50% in the other [teat]. But [it] depends on the severity of the disease". Participant 2*

> *"Sometimes [antimicrobials are] available, sometimes [it is] not, we just buy all we can and store it. I use [it] when I [need to]" Participant 10*

A few participants expressed that they injected their animals when they suspected any sickness, and based on treatment response, they adjusted the course of treatments.

> *"I give it myself. Well, I never experience any of that, but whenever they are sick, I just give that medicine and the problem [is] solved". Participant 9*

> *"I inject them, [and]they do improve when I inject them. Also, I give them Vitamin B complex when they are weak, and they get better" Participant 10*

Other participants said they followed the instructions provided by veterinarians, para-veterinarians, and medicine labels, while the majority expressed that they self-prescribed antimicrobials on farms. A few participants used alternate products such as herbal medicines, electrolytes, feed supplements and kerosene on animals to treat their animals when they do not have access to antimicrobials.

> *"I can't because the instructions stated [that] you have to give one per udder, so if I use half, I don't think that it will solve any problem" Participant 12*

> *"I [have] used kerosene most of the time [that is] when I don't get the medicine for foot rot". Participant 10*

Theme 4: Farm decisions on AMU and livestock management influenced by foreign farmers and veterinarians

Most participants did not know that there were livestock associations that they could join to share experiences, access training, and learn about livestock management. They would, however, meet informally with farmers they knew as required, to discuss livestock production and management, including the use of medicines.

> *"I haven't had any poultry experience, but I tried [it]myself, like start with only, only chickens and that's how I learnt each day. It's a learning process for me" Participant 9*

> *"Yah! my brothers, got a farm further up, and then there are few other farmers who always talk. We always talk if there is an issue on the farm [and] we call each other" Participant 13*

Many participants said that they experienced difficulties accessing their local veterinary services due to the unavailability of professionals. There were often slow to respond to requests for advice from participants. When participants did receive advice from veterinary professionals, they were unsure the information provided could be trusted; the advice given was sometimes perceived to show a lack of experience and knowledge on livestock production and extension services.

> *"No! it is very hard. It's no use in calling them because whenever we need them, they are not available there. I don't want to insult anybody, but it does happen that whenever we go to them and try to take advice, they open the book, and they flip the*

pages. So, it should be when they do a degree, and anything should be at their fingertips. So, they start flipping [the] pages, and they want to tell from there what to do" Participant 1

"Service is not good. Sometimes we ring [and they advise] they [will]come tomorrow [however] tomorrow never comes. [I] called [the] veterinarian [and] they never came". Participant 5

The majority of participants expressed that due to gaps in the availability of information on livestock production and management locally from veterinary clinics, they sought advice on livestock production and management from farmers and veterinary professionals based in neigbouring countries via social media and other communication mediums. Some of these farmers and veterinarians would also visit the participant's farm to provide livestock management related advice.

"No, it was just on that spot, the same time we got the information from Mr G, and before calling Mr G, I got into google [and] just typed there " what disease [it] is if we notice red spots in the poo of the chicken" same time the disease came about, coccidiosis and the medicine were given there, but I didn't know where to get it [from so] I contacted Mr G in Australia, messaged him, and he told me" Participant 3

There was also a view from a few participants about the perceived reluctance of some farmers to change their livestock production and management practices.

"The problem [is] the attitude of the farmers. That's the main thing because farmers can't take advice, so if you are a good farmer, you will take every piece of advice you get and try to implement it. So, Fijian farmers have [an] attitude and [also] the accessibility of information is not enough [for farmers] to access information on (farm management) what to do" Participant 12

Discussion

To our knowledge, this is the first study that provided an in-depth insight into the attitude and knowledge of Fijian livestock farmers towards AMU and AMR. Our principal findings were that livestock farmers were uninformed of antimicrobials and were unaware of AMR in livestock. The livestock farmers used medicines to safeguard their livestock, their main source of income to support their livelihoods. Medicine shortage resulted in livestock farmers hoarding medicine, resulting in self-prescribing. Livestock farmers relied on foreign farmers and veterinarians for information and guidance about livestock production, management, and medicine use. They lacked trust in knowledge and advice provided by the local veterinarian and para-veterinarians.

Our findings of livestock farmers lacking knowledge and understanding of AMU and AMR concurs with results demonstrated in studies in other developing countries [43,44]. Low education levels could have led to the lack of knowledge of AMU and AMR [20,43]. However, in our study, the majority of participants had obtained a minimum of secondary school level of qualification (refer to Table 1). Therefore, we believe the lack of awareness and training on medicines in general may have contributed to the lack of knowledge on AMU and AMR amongst participants. The lack of knowledge and understanding of medicine amongst farmers can complicate AMU practice; there are higher chances of incorrect use [45]. The lack of knowledge on risks associated with AMU, such as AMR, is of grave concern. A crucial first step in an AMS programme in Fiji would be to include general training and awareness on medicine, including antimicrobials and the risks associated with AMU and AMR to ensure a baseline local knowledge and understanding on medicine use and safety [1,2]. Terminologies and descriptions of the types of medicine need to be demarcated so that livestock farmers and managers have an understanding and be able to differentiate between 'medicine', 'drugs', 'antimicrobials' and 'antibiotics' and not categorise all as 'medicine' or 'drugs' because evidence shows higher chances of incorrect medicine use, including antimicrobials [46].

Participants in our study use antimicrobials in livestock based on their appearance but different medicines may present in similar dosage form, packaging, and colour. For instance, intramammary units used for treating mastitis are available in similar dosage forms but used for treating different types of mastitis (dry and wet cow) [47]. Similarly, anthelmintic and antibiotic oral powders and solutions are available in the same colour with different indications and contraindications [47]. Therefore, there is a risk of using medicines inappropriately.

The shortage of medicines can impact overall access and AMU [45,48]. Easy access to antimicrobials and a lack of policies on antimicrobial dispensing [43,49] have been reported in other countries [18,50,51]; however, our findings suggest that the medicine shortage in Fiji may have been worsened by livestock farmers hoarding antimicrobials. Additionally, we believe the inconsistent local supply of antimicrobials may have also contributed to a shortage of antimicrobials. However, the hoarding of antimicrobials is of grave concern and have been similarly reported in other studies [52]. Farmers who hoard antimicrobials on farms may have better access, therefore, may unsparingly self-prescribe antimicrobials, as reported in other studies, and is a common problem in developing countries [18,43]. We presume the uninformed use of antimicrobials and all other medicine, in general, may also contribute to the shortage of medicine in local veterinary clinics. Our results suggest that farmers with higher socio-economic status, such as semi-commercial and commercial farmers who have a stable income source, may be better positioned to purchase antimicrobials compared to farmers of lower socio-economic status, such as backyard farmers. These backyard farmers are exposed to food and financial insecurity risks and may be unable to treat the animals when needed [9,53]. The hoarding of antimicrobials worsens medicine access, especially when there is a shortage of antimicrobials; therefore, policies promoting rational use of antimicrobials need to be implemented to ensure accessibility and rational use of antimicrobials in livestock production systems [4,10,48,52,54].

Our results demonstrated that farmers self-prescribed antibiotics and did not complete the full course of antibiotics. The treatment decisions were based on their past experience instead of on the advice of the veterinary professionals, a practice similarly reported in other studies [48]. Imprudent use of antimicrobials resulting from self-prescribing with under and overuse have been reported in developing countries [6,11]. Our results also suggest that incomplete courses of antimicrobials took place due to the high costs of the antimicrobials; thus, farmers used antimicrobial sub-therapeutically and saved the rest for future use, which have been similarly reported in other studies [18,48,49].

Our findings that antimicrobials were used as the first line of defence prophylactically to prevent the loss of animals and promote production were similar to results demonstrated in studies conducted in other developing countries [18,43,49]. Some livestock illnesses can result from a lack of nutrition in feeds, which is common in the backyard and semi-commercial farming systems in developing countries where household refuse is used as feeds for livestock [55]. Due to the high costs of feeds as compared to medicines, antimicrobials were considered the first line approach to manage illness in livestock for some farmers. Therefore, farmers may self-prescribe antimicrobials to safeguard the livestock and prevent the death of animals that provide food and financial security. The chances of imprudent use of antimicrobials have been shown to be higher when used without consulting veterinary professionals, as reported in other studies [20].

The access and use of antimicrobials have been regulated in many developed countries, which farmers and veterinary professionals mostly adhere to [10]; however, the same is not in developing countries [6]. Our results suggest the same where antimicrobials were purchased from veterinary clinics, but the actual use of antimicrobials was based on farmers' past experiences, the advice of foreign farmers and veterinarians, other farmers or from an online source. There seemed to be a general lack of confidence in the local veterinary services provided, which concurs with another study [56]. Therefore, greater engagement of farmers and veterinary professionals is critically important to regain confidence in the quality of local services provided and to establish a working relationship. When advice is given, there may be other anthropological, socio-cultural, economic, and environmental factors that influence farmers' behaviour, as demonstrated in other studies [4,13,16,17,43,57]. Therefore, these factors need to be taken into consideration when developing AMS programmes.

Overall, our results indicate that local veterinarians and para-veterinarians have little influence on the farm decisions on AMU in the Fijian context. Given that pharmacists are experts in medicine use and safety and are readily accessible in the community, it is surprising that the participants in our study did not consult pharmacists for advice. A study also reported similar findings where antimicrobials were accessed from non-professionals and used without consulting pharmacists [58]. The role of the Fijian pharmacist in AMU and AMR is also unknown. Therefore, we suggest further studies exploring the attitude and knowledge of veterinarians and para-veterinarians towards AMU and AMR and studies exploring anthropological, socio-cultural, economic, and environmental factors that may influence AMU behaviour in livestock farmers[16,17]. Studies exploring pharmacists' role in AMU and AMR in the livestock production systems are also suggested.

Limitations and Future research

This study was the first study that explored the attitude and knowledge of livestock farmers and managers in Fiji towards AMU and AMR. Although our study participants were only concentrated in Viti Levu [29], we consider that our participants provided in-depth insights into the current AMU practice. We acknowledge that the views shared by our participants maybe not be the same as the views of all farmers in Fiji. Due to time and logistical reasons, only the island of Viti Levu was included in this present study. We interpreted and conceptualised participants' accounts, acknowledging that our interpretation may not fully encompass the breadth and depth of their experiences and their attitudes and knowledge of AMU and AMR [30,31,41].

TPB was used to explore and understand AMU behaviour in this study [14,15,17,59], specifically, to inform the design of the interview guide and analysis of interview transcripts. We acknowledge that there are also limitations to using TPB. TPB does not consider involuntary drivers and the role of emotion [17,60] as seen in our study where not all themes strongly feature. We therefore also analysed our data inductively to capture our participants' experiences in-depth. Our study focused on cattle and poultry farmers because it is commonly farmed in Fiji [16,29]. However, future studies need to consider the inclusion of other livestock farmers apart from cattle and poultry in all divisions of Fiji.

Conclusion

This study provided the first documented accounts of the Fijian livestock farmers attitude and knowledge on AMU and AMR. The study results suggest that there is a lack of knowledge and understanding of AMU and AMR amongst livestock farmers in Fiji. AMS programmes promoting awareness and rational use of antimicrobials and resistance needs to be implemented to increase awareness amongst farmers. These programmes need to consider the anthropological, socio-cultural, economic, and environmental factors driving the irrational medicine use by farmers. Closer collaboration between farmers, veterinarians, para-veterinarians, and pharmacists needs to be forged for successful AMS programmes. Future studies are required to explore the attitude and knowledge of veterinarians, para-veterinarians and pharmacists on AMU and AMR in Fijian livestock production. Lessons learnt may assist in developing additional AMS programmes targeting behavioural interventions.

Data Availability Statement

The datasets generated for this study will not be made readily available to ensure the confidentiality of participants and may contain potentially identifiable information. The data supporting the conclusions of this study will be available by the authors, upon request, to any qualified researcher. Requests should be made directly to x.r.s.khan@pgr.reading.ac.uk

Ethics Statement

The ethical approval for the study was granted by the University of Readings School of Agriculture Policy and Developments Ethical Committee (Ref #: 00772P).

Conflict of Interests

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

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Supplementary table: Coding of semi-structured interview transcripts

The table S1 below illustrates an extract of the codes and topics for theme.

Different colours were used to represent the codes which lead to the development of the theme. Only codes for the theme are presented in the table.

Interview number	Transcription	Codes	Sub-themes	Theme
Interview 2	I: Did the veterinarian visit the farm to see the calve? P: I didn't go to pick him up and he had improved and there was no need but his coming over tomorrow I: which medicine you gave to the calve? P: ummmm…. I did give him medicine, but I only kept him in shade. So, I tried to avoid letting him move to much…so he needs lots of rest only…. get the mother on time let him suck little and let him rest. Let him suck and rest…. I: Do your give any medicine to these chickens?	• Aware of names of drugs used, • Aware of name of drugs and indications used, • Aware of dosing • Described medicine by its dosage	• *Knowledge on AMU* • *Risks associated with AMU* • *Knowledge on AMR*	***Uninformed use of antimicrobials and unaware of AMR in livestock***

	P: yes! I always have to keep it and give it I: Which medicine you gave and how did you give it? P: yah! yes…yellow powder what you call that for the chicken…what you call that. I forgot the name of it…it's an antibiotic…uh…we give that.	form and colour • Aware of type of antimicrobial • Unaware of antibiotic resistance • Unaware of name of medicine, • Used medicines on farm, • unaware of AMR, • used antimicrobials for incorrect indications		
Interview 4	I: Do you know what is antimicrobial resistance? P: it can be…it can be…. umm.no I: have you ever heard about antibiotic resistance before? P: No! I: have you heard of drug resistance? P: yah I heard if. But through human…. heard in humans…in humans the drugs given to them their drug resistance ...the			

	drugs not effective to their immune system ...and its like that eh but I haven't heard in animals. I: You said earlier that at times you use the medicines for too long and the medicine is not effective. Why do you think like that? P: I think the bacteria is ……. resistant eh! Other than the drug…. I: what do you think can be done about it? P: ok just like you get another drug that can fight that you know the bacteria…because it's just like how we do it in when are dredge the calves… if we keep on using the Nilverm Nilverm Nilverm that Nilverm would be resistant to the ….the bacteria eh…the bacteria that Nilverm would be not useful because the bacteria is like its normal to them for that Nilverm going inside eh…..so that's how ..we change the Nilverm for certain period than we change …if we see know the…if I see that how I use Nilverm for certain period than now the calves still having known that …the worms….than I better change it ..that's how I	• aware of risks associated with drug resistance • unsure of mechanism of action of AMR • aware of anthelmintic resistance • unclear of mechanism of action of anthelmintic resistance • aware of risks to humans via agri-food chain		

	do it. For like 2 years like that …one year …. but I didn't wait until that time.,. I just use the Nilverm not. When I finish the 20litres and I go and change to another I: do you have any other comments? P: lot of antibiotics not good…well because most of the things that we using to animals. same as we using human beings getting from the doctor…the more medicines we use you know it's not it's good for your body same as the animals. The more antibiotics you use and it's not good for the animal health…. rather than if you minimise the use of antibiotics the better to the animal and the better to the human for ...for human consumption that is what I think.			
Interview 5	I: do you record all the medicine you use on the farm? P: no, we got a …. if we use the I mean the drugs there is only two drugs we got SA and LA. nothing else. And sometimes when they have diarrhoea, we give scour ban. nothing else! I: How do you give Scourban?			

	P: Yeah! we give three times…10ml…. I: How do you give it .do you follow instructions? P: Yeah! I: Do you use any injection on the farm? P: Only when the big calve gets sick, we inject SA and LA. I remember back 6 months ago 2 of my cows died just because weakness of these dairy officers in Tailevu one died here one died there and another about to die I have to call Dr P. I have to call Dr S. I am so happy that they were here on time, and they save the cow rather than die I: Do you know what is antimicrobial resistance? P: .NO I: Have you have heard about antibiotic resistance? P: Yeah. about 6 or 7 months later, my whole weeks milk was rejected by FDL and what they said there was antibiotic in the			

	milk and that point of time there was no drug at the farm that we can inject the cow we can the mastitis there was nothing government pharmacy. I mean govt pharmacy or the animal pharmacy there was nothing, but I don't know it was so 3 4 weeks and it was raining, and all place was swampy I don't know myself and this farm we got the same problem antibiotic, and they say there is antibiotic here and that come here 4 am and they come and check for days and for one whole week I never get any money.			
Interview 7	I: Do give medicines yourself? P: yes I: You said that you had an injury on cow, and you used some medicine? Which medicine you used? P: I used the antibiotic…. I forgot the name…. it's its…uh…. some kind of penicillin I forgot the name written on particular bottle I: Did you follow the instruction given by the vet or para-veterinarian?			

	P: yes. umm sometimes I just use what I have I: how much you used? P: I used …. that was 12mls…yah…that's for a 350kg, 16ml for 400kg I: did you record it somewhere? P: no …I didn't I: how often did you give that? P: actually, according to the prescription on the bottle, it supposed to be like today and tomorrow but I. actually antibiotic I didn't use for healing…. it's just to so that it could keep going and prevent from. prevent the. prevent the. Fracture from getting worse. So, I applied after 5 days interval.			
Interview 11	I: what do you do when the medicine you have given doesn't work?			

	P: I call them again. I: Who do you call and what do they do? P: they recheck and sometimes I call them about the medicine …doesn't work for the cows I: do you use any other medicine? P: yah! I: what other medicine you use? P: I don't know the name for the medicine .it was the injections …its put in the …inject them and I don't know what's the name of the medicine			
Interview 14	I: Do you know what is antimicrobial resistance?			

	P: uh no…if it is harmful, than the the…government should do something about it. I: what do you think needs to be done by government? P: it should not be used on the animals so that if it does harm for us, should not use that one. I: Is there any other comments you want to make? P: yah. we just need lot of training; farmers should know things like that.			

Chapter 7

Fijian veterinarian and para-veterinarians' behaviour, attitude and knowledge towards antimicrobial use and antimicrobial resistance: A qualitative study

Chapter summary: Linking to previous chapter in which the drivers of AMU and AMR from livestock farmers perspective was explored, the current chapter explores the Fijian veterinarian and para-veterinarians behaviour, attitude and knowledge towards AMU and AMR was explored and reported in this chapter.

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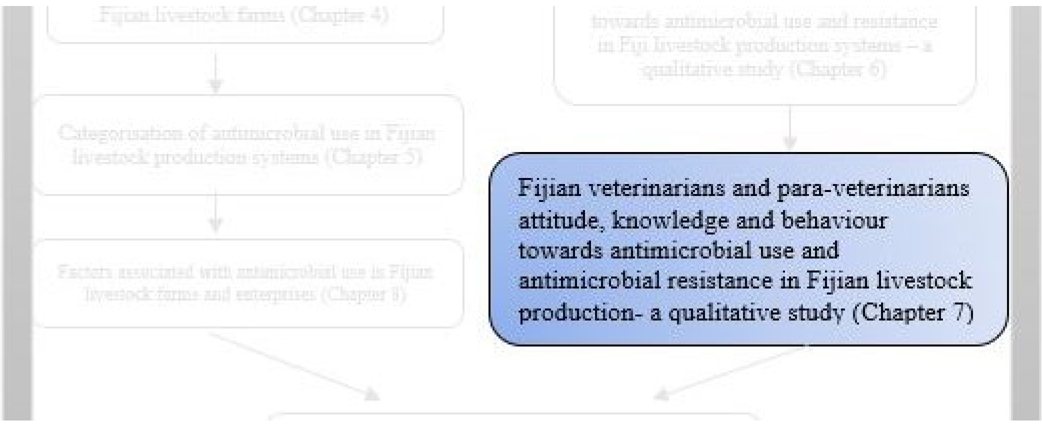

Abstract

Antimicrobial resistance (AMR) is a global health issue affecting humans and livestock. Reduction in antimicrobial use (AMU) and appropriate use of antimicrobials in livestock production systems have been encouraged. Lack of access to qualified veterinarians, policies regulating AMU and knowledge of AMU and AMR have been identified as drivers of inappropriate AMU behaviour in developing countries. Hence, para-veterinarians take lead role in providing veterinary services to livestock farmers in developing countries. Our previous work found Fijian farmers lack knowledge and understanding of AMU and AMR. However, the attitude, knowledge, and behaviour of Fijian veterinary professionals towards AMU and AMR is currently unknown. Therefore, this qualitative study used face-to-face, semi-structured interviews to explore and understand Fijian veterinarian and para-veterinarians' attitude, knowledge, and behaviour towards AMU and AMR. A sample of at least ten participants was targeted and recruited from the Central and Western divisions of Viti Levu, Fiji. Theory of Planned Behaviour (TPB) informed the development of the semi-structured interview guide. The interviews were audio-recorded and analysed using reflexive thematic analysis and deductively using the TPB framework. Our analysis generated three key themes: 1) Antimicrobials prescribed and used based on availability and cost rather than clinical need, 2) Para-veterinarians awareness and knowledge of AMR influence treatment decisions, and 3) Limited resources impede effective consultation and veterinary service delivery. This study demonstrated para-veterinarians (not veterinarians) lacked knowledge and understanding of AMU and AMR. The availability and cost of antimicrobials rather than clinical justification drove antimicrobial prescribing amongst the para-veterinarians. Veterinarians did not visit farms to provide veterinary services; therefore, para-veterinarians provided the veterinary services to the livestock farmers. Lack of human resources, antimicrobials, and physical resources incapacitated veterinary service delivery, where services to farmers' were delayed or not provided at all. Terms of reference for veterinary service delivery and para-veterinarian training framework targeting prescribing, dispensing, use of antimicrobials and risks associated with inappropriate AMU are recommended as part of antimicrobial stewardship (AMS) programme. Allocation of physical and human resources to Fijian veterinary services should be considered part of AMS programme to improve veterinary service delivery to livestock farmers and optimise the AMU at the country level.

Keywords: attitude; knowledge; behaviour; veterinarians; para-veterinarians; antimicrobial use; antimicrobial resistance; Fiji.

Introduction

Antimicrobial resistance (AMR) is a global health issue affecting humans and livestock [1,2]. International organisations such as the World Health Organisation (WHO), World Organisation of Animal Health (OIE) and Food and Agricultural organisation of United Nations (FAO) advocate reduction in antimicrobial use (AMU) and promote appropriate use of antimicrobials in livestock production [1-3]. Antimicrobials have been used to mitigate farm biosecurity risks in livestock production systems; however, inappropriate use (growth promotion and prophylactic use) have been reported in developing countries [4-7]. A lack of policies regulating antimicrobial prescribing, dispensing and easy access to antimicrobials have been reported as reasons for inappropriate use in developing countries [7-11]. The lack of therapeutic guidelines and veterinary legislative frameworks that guide veterinary service professionals have also been reported [5,9,11-14]. Self-prescribing of antimicrobials by farmers has also been reported in developing countries [6,12,15-17]. Additionally, in developing countries, investments in animal health and veterinary services have been given less priority compared to human health [2,13].

Veterinary services in developing countries lack access to qualified veterinarians [18-23]. Consequently, para-veterinarians take a lead role in delivering veterinary services, including prescribing antibiotics [5,9,11]. According to international standards advocated by OIE, only veterinarians (not para-veterinarians) are authorised to prescribe antibiotics [5,22,24,25]. Therefore, the prescription of antibiotics by para-veterinarians contradicts international standards [2,26]. However, to combat the growing risks of farmers self-prescribing antimicrobials in livestock farms, para-veterinarians have stepped in to provide veterinary services to farmers to mitigate the risks of uninformed prescribing of antimicrobials [1-3,6,12,15,18]. The OIE competency guidelines mandates veterinarians to receive training and knowledge on antimicrobial prescribing and livestock management [12,19]. The level of training and the legal access to antimicrobials place veterinarians as important guardians of antimicrobials and AMR in livestock production [27]. This is contrasted with para-veterinarians where very limited is known about their training and knowledge on AMU and livestock management despite serving as the first line knowledge hubs for livestock farmers [19].

In Fiji, there is limited knowledge about the veterinary services and veterinary professionals apart from the shortage of veterinarians, lack of legislation regulating AMU in livestock production and lack of detailed scope of practice for para-veterinarians particularly relating to prescribing and dispensing of antimicrobials in the Fijian veterinary legislation (current one dates to 1956) [28,29]. Our recent study found Fijian farmers lack knowledge and understanding of AMU and AMR, driving inappropriate AMU [16]. Additionally, our study demonstrated that farmers lacked confidence in the local provision of veterinary services, and livestock farmers themselves mitigated farm biosecurity risks including prescribing of antimicrobials [16]. However, psychological (attitude and knowledge), including other contextual drivers of AMU and AMR in livestock production from Fijian veterinary services professionals perspectives are unknown [11,13,30].

Veterinary service professionals are critical partners in livestock production as they interact and provide veterinary services to livestock farmers on daily basis [19,20,31]. Therefore, the attitude and knowledge of veterinarians and para-veterinarians must be well understood so that antimicrobial stewardship (AMS) programmes can be tailor-made to the Fijian livestock production systems enabling more effective policy implementation [31,32].

Behavioural frameworks such as Theory of Reasoned Action (TRA) [33], Health Belief Model (HBM) [34] and Theory of Planned Behaviour (TPB) [33,35] have been used as socio-psychological frameworks to explore and understand people's behaviour. More specifically, several studies using the TPB have demonstrated that veterinarians and para-veterinarians attitude and knowledge influence their AMU behaviour [36-38]. TPB can help to explore and understand the motivations and barriers of AMU behaviour in the context of prescribing, dispensing, and administering [39,40].

Therefore, this study aimed to explore and understand the behaviour, attitude and knowledge of Fijian veterinarians and para-veterinarians towards AMU and AMR in the Central and Western division of Viti Levu, Fiji.

Methods

Study design

A qualitative research design using face to face one-to-one, semi-structured interviews were used. An interpretative epistemological position was taken to analyse the accounts from para-veterinarians and veterinarians [41]. AMU in the context of prescribing, dispensing and use in livestock production systems was explored.

Participants, recruitment, and setting

We contacted and recruited para-veterinarians and veterinarians who worked in the livestock production systems located in the Central and Western division of Viti Levu, Fiji. The Central and Western divisions were selected because most Fijians lived and raised livestock in Viti Levu [42]. Participants were recruited based on the inclusion criteria in Box 1. We aimed to recruit at least 10 participants to provide in-depth information on their experiences on AMU and AMR. Given that there is no ideal sample size for qualitative studies [43,44], we presumed at least 10 participants would provide in-depth information to address our study aims. Purposive and snowball sampling methods were used to recruit participants. Our key contacts, the principal agricultural officers in Central and Western divisions, identified potential participants. XK contacted potential participants via telephone and introduced the study to them. XK visited all participants who agreed to participate in a face-to-face interview at a location of their choosing, usually at their clinic or field offices. XK provided the participants with the participant information sheet and obtained verbal consent before the interview. No participant had any prior relationship with XK.

Box 1: Participant recruitment criteria

- Located in the Central Division or Western Division of Fiji
- From Naitasiri, Namosi, Rewa, Serua, Tailevu, Ba, Nadroga-Navosa or Ra province
- Located on the mainland of Viti Levu.
- Location was accessible by road.
- Over 18 years old age.
- A practising veterinarian or para-veterinarian
- Actively working or had worked in cattle and poultry sector
- Worked in government or non-government organisations
- Experience in the veterinary extension services
- Experience in prescribing, dispensing and administration of antimicrobials

The interview

TPB informed the development of the semi-structured interview guide [33,35]. The interview guide in Box 2 was piloted with one participant, and minor modification were made simplify the questions. The interviews were conducted in English at a convenient location to all participants. All interviews were conducted between September and November 2019. All participants were encouraged to speak freely and made aware that XK was interviewing in the capacity of a PhD researcher and was not a veterinarian by profession. An interdisciplinary research team comprising; a male doctoral candidate and pharmacist with experience in agro security, food security and one health (XK), one female academic pharmacist with a doctoral degree in medicine use and safety and extensive experience in qualitative research (RL), a female animal scientist with a doctoral degree and extensive experience in animal sciences (poultry) (CR) and a male academic veterinarian and animal scientist with a doctoral degree with extensive experience in animal sciences (cattle) (PR). XK undertook all the data collection on the study sites. In preparation, XK undertook qualitative methods research training formally via an accredited course and training 'on the job' with RL and her research team that included XK shadowing another researcher conducting interviews, practical guidance on the analysis of data and mock interviews with RL, CR and PR.

Box 2 Interview topic guide

1. Can you tell me about yourself?
   (Prompts: Age, qualifications, years of experience, experience in livestock production? Training? Type of practice?)
2. Could you describe a typical working day in the clinic/ field?
   (Prompts: what do you do? What type of farmers or complaints do you attend to?)
3. What do you do when you attend sick animals?
   (Prompts: how and when do you decide to prescribe? Antimicrobials or antibiotics prescribed? How often do you use them? How often do farmers call? How much interaction do you have with farmers? In what stage of animals' sickness, do the farmers ask for intervention? How do you select the antimicrobial or antibiotics? How do you decide on the dose? Availability? Cost? Problems/ challenges faced?)

4. What do you do when you find the antimicrobials or antibiotics you prescribed on animals is not working?
   (Prompts: Do farmers call back? Consultations undertaken? Check on Dose and Duration farmer used? Consult other Veterinarians or para-veterinarians? Any other medicines used? Usage? Instructions? Medicine substitution?)
5. Why do you think antimicrobials or antibiotics don't work?
   (Prompts: correct dose? The duration? Right medicine? Type of medicine? Stronger medicines? Didn't follow instructions? Medicine not effective? Bacteria being resistant? Antibiotics? antimicrobials?)
6. Can you tell me what antimicrobial resistance is? (*Note: if antimicrobial resistance is unknown,* what is drug resistance? *If not, then* What is antibiotic resistance? *If not, then* what is microorganism resistant to antibiotics? *If not,* what is drug resistance, (*Prompts: if YES: where have you heard from? What do you know about it? View on why medicines don't work? Right dose? The duration? Right medicine? Type of medicine? Stronger medicines? Didn't follow instructions? Medicine not effective? Antibiotics? Antimicrobials? What could be done?*
7. Are there any other comments you want to make about medicine use or antimicrobial resistance?

Data management and analysis

XK transcribed interview recordings verbatim into MS Word and then double checked the correctness of transcriptions against audio recordings. All interview transcripts were anonymised. NVivo 12 was used to analyse the data (QSR International Pty Ltd., UK). XK explored patterns in the dataset, emerging topics, and overarching themes using Braun and Clarke's approach of reflexive thematic analysis [41,45-47]. The data was also deductively analysed utilising the TPB informed predetermined topics in Box 3. The analysis process was iterative, involving multiple discussions with the research team, as well as the interpretation of emergent themes in areas of medicine use, livestock production and management. The demographic information was descriptively analysed and reported. This study was reported using the Consolidated Criteria for Reporting Qualitative research(COREQ) [48].

Box 3 Topics

- Attitude towards the AMU
- Social influence (AMU subjective norms)
- Perceived behavioural controls of AMU (Perceived behavioural controls)
- Actual behavioural controls

Results

Participant characteristics

A total of 12 participants were contacted and consented to take part however, only ten were interviewed. Two consented participants became unavailable to take part. The majority of participants were male (n=7, 70%) and between the age of 20-39 years old (n =6, 60%). Over 50% of the participants were from the Western division (n=6, 60%) and from Ba province (n= 4, 40%). Most participants had attained a tropical agriculture qualification (n=6, 60%) from a tertiary agriculture university (n=6, 60%) and practised as para-veterinarians (n=6, 60%). The majority had around 10-20 years of experience in their role (n=4, 40%) and worked in government funded veterinary services departments (n=8, 80%). The participants were mostly engaged in providing clinical services from the veterinary clinics and farm advisory services (clinic and fieldwork) (n=5, 50%), and all reported they had training in livestock production (100%) (see Table 1).

Table 1 Demographic characteristics of the participants (n= 10)

Category	Sub-category	N (%)
Gender	Male	7 (70)
	Female	3 (30)
Age	20-39years	6 (60)
	40-59years	4 (40)
Division	Western	6 (60)
	Central	4 (40)
Province	Ba	4 (40)
	Tailevu	2 (20)

	Rewa	1 (10)
	Naitasiri	1 (10)
	Nadroga-Navosa	1 (10)
	Ra	1 (10)
Level of education	Tertiary agricultural university	6 (60)
	Tertiary veterinary university	2 (20)
	Vocational agricultural school	2 (20)
Qualifications	Tropical agriculture	6 (60)
	Veterinary sciences	2 (20)
	Vocational agricultural	2 (20)
Occupation	Para-veterinarian	6 (60)
	Veterinarian	2 (20)
	Para-veterinarian/manager	1 (10)
	Para-veterinarian/Feed mixer	1 (10)
Years of experience	0-5years	2 (20)
	5-10years	3 (30)
	10-20years	4 (40)
	Over 20 years	1 (10)
Type of operations/ Business model	Government funded veterinary services	8 (80)
	Business	1 (10)
	Cooperative	1 (10)
Practice (area of work) *	Clinic and field	5 (50)
	Clinic, field, and administration	2 (20)
	Field	2 (20)
	Clinic	1 (10)
Livestock production training	Yes	10 (100)
	No	-

*Practice or area of work included providing clinical services from the veterinary clinics (clinic), farm advisory services (field) and operational administrative duties (administration)

Interview findings

The reflexive thematic analysis enabled the generation of three key themes: 1) Antimicrobials prescribed and used based on availability and cost rather than clinical need, 2) Para-veterinarians awareness and knowledge of AMR influence treatment decisions, and 3) Limited resources impede effective consultation and veterinary service delivery.

Theme 1: Antimicrobials prescribed and used based on availability and cost rather than clinical need

All veterinary clinic and farm prescribing were done by agriculture assistants or livestock officers who worked as para-veterinarians. Although most of them had attained tropical agriculture qualifications, they said they prescribed whichever antimicrobials were available in their clinic as opposed to following specific prescribing guidelines or making a clear diagnosis before recommending treatment.

> *"Yah! There is unavailability of the drugs [and supply is] very [poor]". Para-veterinarian 3*

> *"Well! We only got two kinds of antibiotics in the clinic. [At the moment] we got properacillin [which] we only use now. We [have] not [been] supplied with the Norocillin, so we [use] only [what we have]. We [prescribe antibiotics] based on the supply, give what is available [at that] particular [point in] time. For example, if I have [short acting penicillin's] SA and [long-acting penicillin's] LA so I will use the SA first, so if there is no SA available, I will use the one we have" Para-veterinarian 7*

The participants also shared that there was an inconsistent supply of antimicrobials and there were instances where they were aware that the antimicrobials prescribed were not indicated for the animal disease being treated but they treated the animals anyway to safeguard any potential losses. A few participants said they used human medicines if they were out of stock of antimicrobials licensed for animals.

> *"Yeah! I just remember[ed] of a farmer. There [was] no medications and we used the alternate antibiotic medication that was [an] injection, and not used normally to treat those kinds of animals" Para-veterinarian 2*

"Um! [The] clinic ran short of the antiseptic powder, dusting powder and antibiotics. In order to heal the open wound, I went to the pharmacy, the one which human beings use, so I got that [medicine], I advise[d] the farmer, [and the] farmer used it. After a week, he came back [and] said it work[ed]" Para-veterinarian 5

The veterinarians expressed that the para-veterinarians only consulted them when needed and typically showed pictures taken of diseased animals to obtain advice. Although veterinarians said they were confident in para-veterinarians delivering veterinary services they doubted para-veterinarians' competence with regards to treating and prescribing antimicrobials.

"Antibiotics use, and resistance is for the extension officers to fully understand when to use and how to use. Otherwise, they will overuse it because [of] lack of knowledge. They do not know what to do, what to use and how to use [it]. They don't know [then] they just pretend they know it, so they inject penicillin anyway anyhow" Veterinarian 2

Additionally, some para-veterinarian participants also shared that they prescribed medicines based on their experience, and they had not received any formal training in antimicrobial use and prescribing

"The major challenge that we face in the field is like trainings. When I joined [the] ministry, I leant from my seniors, so I give medicines from my experience" Para-veterinarian 7

"Since last year, I have not received any training, the last qualification was my para-veterinary, and I didn't receive any [training] in antimicrobial and using medicines" Para-veterinary 2

Some participants also expressed that the farmers do not follow instructions given by the para-veterinarians and usually return complaining about the medicines prescribed to treat sick animals not working. With estimating weight and dosing of medicines, a few participants said that most farmers' were unable to estimate weights; therefore, farmers' estimated doses of all medicines they administered to animals. The participants shared that farmers' usually do not give a complete course of treatment to their animals due to the inflated cost of antimicrobials.

> *"Yeah! it is common. [The farmers] do not follow instructions. Most of them, they do not follow instructions" Para-veterinarian 6*

> *"Whatever we advise farmers, they do not follow it. They do things wrongly, and then they come back blaming us". Para-veterinarian 3*

The para-veterinarian participants expressed that there were instances where antibiotics were not needed; however, due to farmers' persistence, participants administered antibiotics to the animals. The participants also shared that they administered antibiotics due to fear of farmers getting aggressive and complaining to higher authorities about veterinary services rather than consider the risks associated.

> *"We are giving antibiotics every time we are going out to the field like I said earlier, if you don't give injections to that animal the farmer will create a fuss, [insist to] at least give one injection" Para-veterinarian 7*

In addition, the veterinarians expressed that procurement hurdles delay the supply of the medicines; therefore, the veterinarians said that advance pre-orders were taken from farmers, and medicines were dispatched to farmers once medicines were imported and made available. The veterinarians expressed that those advance orders of medicines were taken from farmers to prevent complains about shortage of medicines to higher government authorities.

> *"Oh! This is where it becomes tricky, because farmers complain right up to the Minister, PM's Office, and we take down their names, the numbers and number of drugs and when it comes in you call them to collect the drugs" Veterinarian 2*

Theme 2: Para-veterinarians' awareness and knowledge of AMR influence treatment decisions

The majority of para-veterinarian participants were unaware of the risks associated with AMU. They could not explain and were unaware of AMR. There veterinarian participants were aware of AMU and AMR; however, two participants particularly the para-veterinarians said that they heard of AMR but were unsure of the mechanism of action. However, prescribing and dispensation of antimicrobials in farms were done by para-veterinarians. The majority of participants expressed they rotated the anthelmintics used in cattle and poultry but shared that antibiotics' remained the same all along. Therefore, the para-veterinarian participants shared they prescribed and dispensed the same antibiotics for all illness all year round. The participants shared that they heard of anthelmintic resistance and the purpose of rotating anthelmintics in cattle and poultry; however, most were unaware of antibiotic resistance. Para-veterinarians consistently administering antibiotics in the field on farmers' request was said to be one of the reasons for antibiotic resistance by one participant. Based on past experience with antibiotic prescribing and dispensing, a para-veterinarian participant said the government can address antibiotic resistance by increasing the range of antibiotics.

> *"Antimicrobial resistance! I am not really sure what it is. I don't know" Para-veterinarian 2*

> *"I think the antibiotics [are] not working because, from my view, I think [animals are becoming] resistance to the antibiotics. We are giving antibiotics every time we are going out to the field" Para-veterinarian 7*

The veterinarians highlighted that para-veterinarians lacked understanding of antimicrobials and incorrectly treated animals in some cases due to a lack of knowledge.

> *"Para-veterinarians here, some actually got experience from past because they were trained by previous old veterinarians but there are some you know lack the knowledge and skills, and sometimes, they make things worse than us. I [have] come across those cases, and I have also received complaints" Veterinarian 2*

The participants (para-veterinarians) shared that they injected antibiotics for mastitis; however, there were varying accounts on how mastitis was treated. Some participants used intramammary units first, while some used injectable penicillin (Norocillin). However, the majority shared that they administered antibiotics as a preventative measure.

"Antibiotic injection is given as a preventive measure to prevent further infections" Para-veterinarian 4

"If the intramammary [is used and it] is has improved [then] there [is] no need [for] a revisit, so we just give antibiotic and then after six milking, farmers can start supplying so for example if we treat a cow with intramammary and then it has improved, so the last thing is we give antibiotic injectable and that's it" Para-veterinarian 3

Most participants (para-veterinarians and veterinarians) said that treatments decisions were based on their convenience. For instance, if they had to revisit farms, they would use short-acting and long-acting injections in severe cases of infections. The batches of antibiotics received from major stores were short and long; therefore, most participants said they will always use all the short-acting injections first and then the long-acting for the rest of the cases.

"Mostly [used] for [our] convenience. Yes, because you know long-acting, it's for convenience because you can't just go every day to the farm and inject the same cow, so you know long-acting would last 3 to 5 days might as well just give them LA [long acting] injection and sort of keep in contact [with] the farmer, but you don't have to visit every day" Veterinarian 2

"When we receive [stock], we receive short-acting, long-acting and the oxytetracycline but sometimes because we [have] plenty of cases where we use short-acting and long-acting, so it finishes and only thing, we mostly left with the oxytetracycline" Para-veterinarian 6

Some participants shared that they treated all quarters while some treated only infected quarters of cows. Moreover, some used three intramammary per quarter while some used two per quarter, mainly due to the high costs of the intramammary antibiotics. Interestingly, some injected oxytetracycline injection on day one and day three as they perceived it was better to give oxytetracycline injection. The participants also expressed that injecting antibiotics' was necessary in cases of mastitis due to bacterial infection. A few participants said they used expired antibiotics from the clinics and shared that farmers' also used expired left-over antibiotics.

> *"Yeah! [So]if they have mastitis [and] if it is severe, so we prescribe injectables. If it is not that severe, we just prescribe the [intramammary] tubes, the antibiotic tubes; we just insert it in the udder" Para-veterinarian 3*

> *"Well, sometimes they have their own expired stock of antibiotics, like intramammary they purchase[d] maybe 4 to 5 years ago. They still keep them in stock, and they use those drugs. And then you also got the para-veterinarians who have the expired drugs in the clinic [who] just give them out to them, which is not the good thing, but it happens. I know it happens" Veterinarian 2*

Most participants shared that they used available oral and injectable antibiotics as the first line of treatment in fields irrespective of the disease. A participant expressed that oxytetracycline and chlortetracycline were used to treat coccidiosis and other bacterial infections in poultry. Participants usually switch to the next available antibiotics once treatment does not work.

> *"[The number of tubes] depends [on] how many teats are being affected, and then I have to sometimes take estimate. I usually give two [tubes]" Para-veterinarian 5*

> *"Oxymav, CTC and it is used for [the] treatment of coccidiosis and other bacterial diseases [in] the poultry" Para-veterinarian 3*

> *"If [drugs] doesn't work, [then] we switch to whatever other cheap drugs available" Para-veterinarian 1*

A few participants expressed risks of not following the withholding period after antibiotics use. However, they expressed that farmers' do not follow the withholding period and continue supplying milk despite being advised not to.

> "*[The]large farmers, [with] large [herd]of cows, [for] example, with 100 cows, [the]farmers treat majority of [the cows] on farm. [Farmers] don't separate or mark the cows. We have found sometimes, not sometimes may be many times, [we have] seen farmers [and] the laborers don't [follow the] with[holding] period. They milk the cow[s] and supply the milk to [the] factory. The milk [gets] rejected,*

and we get feedback from the factory. The farmers complain [to us] about milk rejection" Para-veterinarian 8

Theme 3: Limited resources impede effective consultation and veterinary service delivery

The majority of the participants shared their role involved managing the government funded veterinary clinics and carrying out farm visits, which involved consultation and livestock production and management advisory services. There were only two divisional veterinarians (one in central division and one in western division) who were only consulted by para-veterinarians when they required assistance on animal disease management on the farms. The participants expressed that they could not attend to all farmer calls or complaints due to a lack of workforce, transportation, and time. The participants shared that the high costs of medicines also affected their prescribing decisions and scope of veterinary service delivery.

"Right now, we are running short of staff and only two staff [unlike] before [we had] four staff in a district. The working activities [are] bigger [than] before. So, if we are unavailable, the farmers also complain to our head offices" Para-veterinarian 4

"Most [injections are used] for convenience. It is for convenience because you cannot just go every day to the farm. The cost impacts the decision making also". Veterinarian 1

The participants expressed that farmers' usually self-prescribe anthelmintics but only visited and consulted them if they think they needed antibiotics. The participants prescribed and dispensed antibiotics from the clinics based on farmers' own diagnosis of their animals' condition. The participants shared that farmers' requests the quantity of antimicrobials base on what they could afford at that point in time. The participants shared that farmers' only sought veterinarians' advice when previous treatments failed. A few participants expressed that farmers' tend to do their research on the internet before consulting them. The majority of participants shared that farmers' were unaware of the remit of para-veterinary services.

"So, the farmers can easily access a powder, like antibiotics or you know in feed or

water, so usually that's the first thing they do, so they go to the nearby station clinic, and they purchase this from agricultural officers and if it doesn't work and it worsens over time than that's when they start calling us and we normally go and inspect" Veterinarian 2

"Um! Yeah! Like mostly we have some farmers and, but they mostly use the home remedies. They check on [the] internet and then ask us". Para-veterinarian 5

Yeah, farmers too! They need to be educated properly especially on para-veterinary [services]" Para-veterinarian 4

The participants shared that the farmers usually visited them in clinics because they were unable to physically visit the farms; there was a lack of staff to operate the clinic and travel to farms located within a wide geographical distance. Participants therefore provide advice and dispense antimicrobials to farmers in the clinics. The veterinarians highlighted that there were gaps in the overall service delivery, including a lack of diagnostic capabilities. The veterinarians expressed that there was a need for training programmes for para-veterinarians on livestock management including AMU and AMR. Veterinarians also shared that they cannot attend to the farm cases because they are involved in administrative matters rather than clinical work. They also highlighted that the para-veterinarians did not provide information to farmers; instead, they were keen to treat animals than engage farmers and provide extension advice. Additionally, the para-veterinarians expressed that they also lacked knowledge on livestock management and the use of antimicrobials, yet they provided services to livestock farmers.

"[Para-veterinarians] would require a lot more training. Um! Because to be honest, they are not considered para-veterinarians, they are agricultural assistants, but that is not their official job. They are actually extension officers, and yes, they should be dealing with husbandry and management. They need intensive training [and] a lot of learning, like basic things to advise, the farmer needs what is basic. You know that this animal is sick, just telling the farmer to isolate any sick animals, they do not do that. The basic husbandry advice on the farm is missing" Veterinarian 2

"I think [para-veterinarians] like to treat. Yeah! But I think they may give advice, but most of the time, from what I have seen, they do not really. It [is] just like they

want to attend and solve the problem without actually advising the farmer this is what you know he needs to do, the big, big picture" Veterinarian 1

Discussion

To our knowledge, this is the first study to provide an insight into the attitude and knowledge of Fijian para-veterinarians and veterinarians toward AMU and AMR. Our principal findings were that para-veterinarians prescribed and dispensed antimicrobials based on availability and cost rather than clinical need. The para-veterinarians also prescribed antimicrobials without knowing the risks associated with uninformed AMU. There were limited resources such as trained professionals, resources, and time, affecting the quality of consultations and scope of veterinary service delivery.

The antimicrobials, especially antibiotics may perhaps be more inappropriately used when prescribing by para-veterinarians, compared to antibiotics prescribed by veterinarians. This may be due to their lack of training and understanding as compared to veterinarians[9,18,19]. Our findings suggest that livestock officers who performed the duties of para-veterinarians lacked knowledge and understanding of AMU and AMR, which is similar to findings demonstrated in other studies in developing countries [5,12,14]. There are gaps in the veterinary service delivery, which are compounded by factors such as a lack of trained veterinarians and resources required in executing effective service delivery. Hence the livestock officers assume the role of para-veterinarians and fill the gaps, thus playing a fundamental role in livestock production and management. The para-veterinarians were allowed to provide veterinary services although they were unsure of the scope of work particularly relating to prescribing and dispensing of antimicrobials. This was due to lack of veterinarians who could provide veterinary services to livestock farmers. Our findings are similar regarding gaps in veterinary service delivery in developing countries, as demonstrated in other studies[7-11].

As compared to developed countries, veterinary access, and delivery in developing countries such as Fiji is limited[19]. Therefore, veterinary services delivered by para-veterinarians may ease the workload of the Fijian veterinarians', but the uninformed advice and service provided by para-veterinarians may inadvertently compound AMR issues in the livestock farms, as also demonstrated in other studies [21-23]. Taken together, the findings of this and the previous study that focused on Fijian farmers' practise are of grave concern; not only do farmers use antimicrobials inappropriately, the prescribing and dispensing of antimicrobials were also found to be inappropriate. The lack of adequate numbers of personnel meant that para-veterinarians and veterinarians were unable to visit farms. This situation is of concern because the reliance was on farmers' own diagnosis of their sick animals and fulfilments of possibly inappropriate requests for specific types of antimicrobials. There is therefore a greater chance of incorrect clinical diagnosis and use of antimicrobials when compared to clinical diagnosis and treatment by a veterinarian in the field [30]. The current approach could set a precedence that self-diagnosis and self-prescribing of antimicrobials by Fijian livestock farmers was acceptable and the norm in everyday livestock production and management despite findings from our previous study demonstrating that farmers lacked knowledge and understanding of AMU and AMR [16]. These practices may further aggravate and create obstacles for the implementation of behavioural interventions to safeguard AMU. Therefore, more awareness is required amongst Fijian farmers and para-veterinarians regarding the use of antimicrobials and risks associated with AMU.

Similar to results reported in other studies, our study revealed that some livestock farmers placed pressure (such as threats of reports to government authorities) and heavily influenced para-veterinarians' farm biosecurity risk management strategy such as prescribing and dispensing of antimicrobials [49,50]. In the absence of clinical guidelines [51,52], para-veterinarians were subjected to a compromised position leading to prescribing antimicrobials even though they may not be indicated, which have been similarly reported in other studies [4-7,23,50]. We believe the para-veterinarians, including veterinarians, should always practice and provide veterinary services, including prescribing and dispensing antimicrobials, without intimidation and in the most transparent manner [23]. The OIE advocates transparency in the management of animal health diseases and veterinary services [18]; therefore, we suggest awareness programmes educating all critical Fijian stakeholders in the agri-food value chain on the roles of each stakeholder on prescribing, dispensing and using antimicrobials in livestock production systems. Also, there is a need to develop terms of reference so that para-veterinarians and veterinarians can execute veterinary services without fear [19,23]. All decisions made about livestock management should also consider animal welfare issues where animals should not be exposed to antimicrobials unnecessarily [18].

The availability of antimicrobials further exacerbates the situation as there are greater chances of inappropriate prescribing due to gaps in the supply chain [13,53]. Our results indicate that para-veterinarians prescribed antimicrobials based on what is available rather than triaging and consulting veterinarians. The para-veterinarians also prescribed the antimicrobials, not following any clinical guidelines. Given that there are different classes and dosage forms of antibiotics that can be used to treat mastitis, there was no clinically agreed approach to treat mastitis. The single-use full syringe is used per infected quarter every 12 hours to treat mastitis [49]; however, our results suggest that either half syringes were used, or the entire course of antibiotics was not completed. Our results also indicated that antibiotics such as tetracyclines were used to treat coccidiosis when contraindicated for the treatment of non-bacterial infections [54]. We believe the para-veterinarians were unaware of the indications and contraindications; therefore, they prescribed inappropriately based on what was available at the time of treatment and their experience, which has been similarly reported in other studies [6,12,15].

Interestingly, the para-veterinarians were open about their lack of awareness of AMR. Therefore, they continued prescribing and dispensing as they perceived no issues in prescribing antibiotics. Moreover, the para-veterinarians perceived the services they provided complied with best practices and provided services to livestock farmers to avoid complaints that may jeopardise their job. We presume the fear and reticence to challenge and clarify potentially inappropriate practices may be compounded based on age and cultural difference, which was not explored in this present study. Therefore, we suggest further similar qualitative studies exploring other drivers of AMU such as socio-economic, demographic, and cultural contexts.

This present study and our earlier study also alluded to the supply chain issue related to medicines where only a limited range of antimicrobials was available for use [16]. The findings are consistent with those reported by Dione et al. (2021) in Uganda where supply chain constrains were identified as potential drivers of inappropriate AMU [55]. Therefore, we suggest a critical review of the procurement processes so that an informed forecast and procurement of veterinary medicines, including antimicrobials can take place to ensure a sustainable supply of veterinary medicines in the Fijian veterinary clinics. Additionally, the risks of inappropriate may be further mitigated by improving the supply chain of antimicrobials [55]. Our finding is similar to results reported in other developing countries where procurement and inconsistent supply of antimicrobials is an ongoing obstacle faced by livestock farmers and veterinary professionals [56,57]. We believe that pharmacists who are experts in medicine inventory management and forecasting may benefit resource-deprived developing countries [56,58]; therefore, consulting and utilising pharmacist expertise may ease the burdens of procurement. In other developing countries, pharmacists are involved in medicine supply chain management [59]. Consequently, we consider adopting a similar approach for the Fijian livestock sector.

Our results suggest that veterinarians were aware of the gaps and inappropriate decisions made by the para-veterinarians in the field, primarily due to the lack of knowledge and training in AMU and AMR. But the para-veterinarians were allowed to continue to be engaged in services delivery because the veterinarians were unable to provide the range of services due to there being only 2-3 (at the time the study was conducted) local veterinarians engaged in livestock production and management in the entire Fijian government veterinary services. The shortage of veterinarians is a widespread problem in developing countries; therefore, the para-veterinarians fill the gaps [7-11]. Our findings on the scope of para-veterinarians practise in the agri-food value chain is similar to other developing countries [13,18,19]. There are very limited studies that have explored the attitude and knowledge of para-veterinarians and veterinarians in developing countries; therefore, it was hard to compare our findings with other studies; however, the limited studies demonstrated that generally, there was a lack of knowledge on AMU and AMR amongst the para-veterinarians or livestock officers, yet they executed services out of necessity [11-13,30].

The access to veterinary services and utilising the local knowledge is quite similar as other studies have demonstrated that farmers only access para-veterinarians if they perceive that para-veterinarians have better training; therefore, there is a general perception of lack of expertise, knowledge and expectation of compromised serviced delivered by the local para-veterinarians [60]. Therefore, farmers opt for information and advice from other sources, which may associate a high chance of inappropriate AMU on farms due to being influenced by non-veterinary experts [16,30].

Our findings implicate the need for a more collaborative approach amongst farmers, para-veterinarians and veterinarians when designing and implementing AMS programmes, based on a clear understanding of each other's roles in livestock production and management [61,62]. Our results indicate that there is currently a standalone approach where veterinary services, including prescribing, dispensing and use of antimicrobials, are farmer-driven rather than clinically based. Therefore, a complete review of Fijian veterinary services delivery is recommended. The OIE performance of veterinary services technical assistance could be explored to guide efforts to address current gaps in the Fijian veterinary services [18].

In addition, the resource gaps require closer consideration by the government, where more policies and funds need to be allocated to fill the gaps in government veterinary services [13,62]. Increasing the number of veterinarian and para-veterinarians are required so that the veterinarians can take the lead clinical role in the field as opposed to spending most of their time with administrative functions. There is also a need to prioritise and provide all resources to the government veterinary services department so that the veterinarians and para-veterinarians are able to execute services fairly, transparently, and without fear [13,23]. Policies and critical competencies empowering veterinarians and para-veterinarians are essential to implement AMS programmes [9,18,19]. There are immediate measures required to make rational prescribing and dispensing of antimicrobials in veterinary clinics. Antimicrobials should only be prescribed once there is a need for the use of antimicrobials and not based on farmers' demand, which has also been reported in other studies [14]. Therefore, we suggest national and sectoral policies promoting the training of more veterinarians and para-veterinarians aligned to the critical competencies stipulated in OIE frameworks and training frameworks for all livestock officers on AMU and AMR [9,18,19].

Given that there were obstacles faced in the government veterinary services, the utilisation of resources from the private sector such as those in the commercial farms where there is the ability to recruit qualified veterinarians; therefore, a public-private partnership may be considered a feasible approach, especially in developing countries where availability of veterinarians is limited [11,13,21].

Nevertheless, policies need to be implemented to promote antibiotic prescribing with supervision and in consultation with veterinarians only. The para-veterinarians should not be permitted to prescribe and dispense antibiotics without a prescription from a veterinarian. The introduction of basic clinical guidelines, which the para-veterinarians can use as a reference point when executing the veterinary services and livestock management is recommended and all decisions made in fields by the para-veterinarians needs to be made in consultation with the veterinarians.

This current study focused on the para-veterinarians and veterinarians, specifically in the livestock sector. However, understanding the attitude and knowledge of livestock officers in non-government services is also required so a more informed AMS programme could be developed [63]. Currently, there is a lack of information on the livestock officers involved in the livestock inspection and abattoir services; therefore, establishing their perspectives on AMU practice is equally important. Understanding the whole agri-food value chain is critically important as it may also help provide essential information needed to develop and implement more targeted AMS programmes. We suggest exploring and establishing dialogues by engaging key actors (such as abattoir meat inspectors, farm gate buyers, commercial processors) in the agri-food value chain to develop constructive discussion as that may generate knowledge that may have been missed in one-to-one semi-structured interviews. Acquainting and sharing knowledge on AMU and AMR of these key actors is equally essential so that critical control points could be implemented in the agri-food value chain that may assist in mitigating risks of inappropriate use of antimicrobials.

Limitations and Future research

This is the first study that explored the attitude and knowledge of para-veterinarians and veterinarians in Fijian livestock production. Although our sample was mainly from the government veterinary services and accounts may not be representative of the entire Fijian veterinary services, we believe the insights provide a current view of veterinary practices because a significant proportion of veterinary services are rendered by the Fijian Ministry of Agriculture [42,64] and most farmers access government veterinary services since it is delivered free of charge. We acknowledge further studies are required, including the inclusion of all other key stakeholders, to fully understand the veterinary services and the attitude and knowledge towards AMU and AMR more holistically.

There are currently limited published studies exploring the attitude and knowledge of the para-veterinarians as compared to veterinarians [36-38]. Para-veterinarians play a fundamental role in the decision-making process and overall farm management in fields, especially in developing countries because of a shortage of veterinarians [19]. Implementing training and developing the skillset of para-veterinarians would be a crucial consideration when developing AMS programmes[20]; therefore, future studies are required, including public and private veterinary services, to better understand the veterinary service delivery and overall understanding towards AMU and AMR so that more targeted behavioural intervention policies could be developed and implemented as part of AMS programme[31].

Conclusion

This study demonstrated the lack of knowledge and understanding of para-veterinarians towards AMU and AMR. The AMU was dictated by availability and not by clinical need. Terms of reference for veterinary service delivery, training framework and awareness programmes need to be implemented to improve awareness on AMU and AMR amongst para-veterinarians as part of AMS programmes. A public-private partnership collaborative approach should be considered to enhance the delivery of veterinary services and implement AMS programmes that promote the appropriate use of antimicrobials. Allocation of physical and human resources needs to be prioritised to improve the Fijian veterinary service delivery to livestock farmers. Future studies exploring drivers of AMU in the agri-food value should be considered for the development of AMS programmes to enhance appropriate use of antimicrobials and reduce AMR risks in the agri-food value chain at the country level.

Conflict of Interests

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

Ethics Statement

The ethical approval for the study was granted by the University of Reading's School of Agriculture Policy and Developments Ethical Committee (Ref #: 00772P).

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Data Availability Statement

The datasets generated for this study will not be made readily available to ensure the confidentiality of participants and may contain potentially identifiable information. The data supporting the conclusions of this study will be available by the authors, upon request, to any qualified researcher. Requests should be made directly to x.r.s.khan@pgr.reading.ac.uk

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Supplementary file 1: Coding of semi-structured interview transcripts

The table S1 below illustrates an extract of the codes and topics for theme.

Different colours were used to represent the codes which lead to the development of the theme. Only codes for the theme are presented in the table.

Interview number	Transcription	Codes	Sub-themes	Theme
Interview 2	I: Do you consult the veterinarian when you have no medicines? P: Yes. We sometimes consult our vet. We don't usually disturb them you know they usually busy. They the one who do all tender things for the medicines and that's the time we consult, and we see what they say. I: What do you do when you have no medicines, that is the tubes you mentioned earlier? P: Yes ...we normally use what we have available and then sometimes we see what the farmers have to say and sometimes what the vet have to say than we prescribe accordingly.	• Substitution of antimicrobials without verification • Procurement processes • Dispensation of antimicrobials in bulk • Nonclinical dispensation	*Prescription of antimicrobials* *Availability of antimicrobials* *Cost of antimicrobials* *Purpose of using antimicrobials*	***Antimicrobials prescribed and used based on availability and cost rather than clinical need***

	I: What do you do when you have no medicines and how you address the situation? P: You know its all about price……and what is available…you know I: How do you deal with farmers when you have no medicines in clinics? P: Yeah! There were farmers!. You know some farmers! They can be dramatic….. I just remember of a farmer he used, like there was no medications and we use the alternate one that was injection, and not used normally to treat those kinds of animals I: Could you further elaborate on that? P: Listen so…sometimes we just have to give the medicine you know…the farmers they want it, and they will make stories…so I just give it. I: What do you do when you find the medicines you gave or prescribed to the animals is not working?	and prescribing • Cost of antimicrobials and prescribing and use • High cost of antimicrobials • Shortage of antimicrobials • Antimicrobial prescribing • Shortage affecting prescribing of antimicrobials • Prescribing antimicrobials with clinical need		

	P: Umm,. you know…funny there was a case, that it's not working, but that medication that is the only medication for that so if it is not working ..i think farmer don't give it right. They always worry about the cost you know…. that this particular farmer is here and he is saying that medication is not working on his farm.. that one always complains about cost you…. know…but yes prices are too expensive. We just give what the farmer says because….ummm they are one paying. Most times I cant go to farm, so I listen to farmer you know...they know it. I: Which medicine was that? P: Like before, farmers used to buy albenol…nilverm.now we don't have nilverm available in clinics, its albenol, replacement, so nilverm was umm…light liquid and this is a thick liquid so most farmers still go for nilverm but we but we here in the ministry we advise them that we want to try practise rotational dredging since nilverm..nilverm ..it will make like…for them to be ..you know. Resistant to that medication so we always try and change the medications so that they have rotational drenching, and they don't build resistant to particular medication, so we advise them you always try this one for this month if it doesn't work you try again for. Next month or maybe we always ask	• Prescribing guidelines • Self-prescribing by farmers • Human medicine use		

	them what the prescription was, or what was the constitution like. How they prescribe what was the measurement or amount they give to that particular calve or cow or what was the weight. Sometime…we come across farmers are not that educated the small scale farmers and they are not educated and they don't. they sometimes give wrong less medication they sacred of the disease …scared of the not disease but scared their animals might die with new medicines they are using so we always tell them what is the weight of them ..if you don't know the weight you just estimate the weight of animals. If it's a big animal estimate 350 to 450kg.if it's a small calve you can estimate that its small. Like 100kg or less…. if they are still not clear we always go to their farm and we always assist them. You know…. Since this year I have not received any training, the last qualification was my para-veterinary, and I didn't receive any in antimicrobial and using medicines…like I do what I can… I: In that case do you always consult farmers first? P: Yes farmers! they give it in farms so have to…you know..or else again.			

	I: How often you come across with this situation where they don't use the right dose, or the right duration of the medicine? P: Yes, plenty cases …this one only I think otherwise before when we prescribe the medicine, we tell them what kind of animals they have sheep goat and cattle. We tell them how to prescribe. Give them medications. I: Are medicines always available? P: No..the medications are not always available with us….out of stock…out of stock…o/s o/s…. I: In that situation when medications are not available, what steps you take? P: No. When the medications are not available in my clinic, I always check other clinics if it is available but usually you now just give the farmer what is available. sometimes I advise the farmer if he or she can refer to that clinic and buy bulk and if not if there is no clinics if none of the clinics have the medications than I refer to them to the stores and check if they have the stocks and I will check the farmer …if its			

	serious is the case, if they genuinely need it if the stores doesn't have medications than I just use what we have man…you know the medications are not always available with us…you it's like that.			
Interview 3	I: What type of complains you usually attend to on the farm? P: Um. main common one at the moment is like the farmers complain about like late arrival of our drugs and unavailability of drugs especially the dredges, antibiotics. if you take it as a dairy farm, mostly we face issues like they have milk rejection on the farm., milk rejection is due to certain reasons there are certain reasons why they having the milk rejection. I: So how do you decide which one to use? P: Normally what we do we use short acting for revisit cases, revisit, and small animals , if it is not that serious we use short acting and if it I serious than we use long acting and then the last one is the oxytet we use. I: Is it always available in the clinic?			

	P: when we receive .we receive short acting, long acting and the oxytet but sometimes because we plenty cases where we use short acting and long acting so it finishes and only thing we left mostly left with the oxytet. I: How do you decide which medicine to prescribe? P: We just make the decision on the farm because its antibiotics any ways and we give what we have. farmers always complain about cost too. I: Are the costs reasonable to the farmers? P: Umm…yah it's reasonable .but not very reasonable..mostly they can't afford I: How do you address the challenges of out-of-stock antibiotics and farmers requests? P: Yah! the only thing we have is the unavailability of drugs very low. And another thing something when we whatever we advise farmers they do not follow it they do not follow it and then they do things			

	wrongly and then they come back blaming us. We even face that kind of issues with the farmers I: Do farmers use other medicines? P: Yes. Like mostly farmers they will want to use mostly the home remedies….so they use any drugs without consulting us, but they will use home remedies which we can't even stop them from using they are more experienced than us sometimes it works. but yes…sometimes whatever we advise they don't follow it you know……they do things wrongly and then they come back blaming us…. i get sick at times.			
Interview 4	I: What types of complains you attend? P: Plenty …. complains coming up now. All the farmers need help right now they need help. Complains are looking at commodity, sheep, and beef and drugs. Help for the fencing materials, fencing, medicines .,medicines are very important the dredged,. The dewormer they need that, but I am sorry to say now it's been out of stock…we can't meet the demands. Sometimes they are very frustrated and are returning back telling us .they are very frustrated …we just give what drugs we have there.			

	I: What is the problem? shortage of medicines or the price of medicine? P: Both problem…drugs are always out and price is high…we sometimes just prescribe like how much what they want…. I: Do you participate in ordering of the drugs? P: Everything we do here, we sell drugs, we have to submit our report, weekly report monthly report ..monthly report, everything is there we selling drugs, the money goes back , than once we put our order for the clinic, but unfortunately there is nothing form there in stores. I: What do you think can be done about it? P: There should be training, refresher course and we can call the awareness and call a meeting for all the farmers its locality… they need to have stocks of drugs. hmmm…. ummm there is slight issues ..but like here in the clinic run short off antiseptic powder, dusting powder in order to heal the open wound so I went to the pharmacy, the			

	one which human beings use so I get that one I advise the farmer so farmer used it after a week he came back he said it is working. I: what else is causing the out of stock? P: Umm….yah..too much use because we have to give drugs when they sicks….farmers don't complete the course…follow the instruction I give just because they ….it expensive…you know….Um! because when it's out of stock …..Suva, no one else even now we try to contact our nearest neighbouring clinics, but they told us same story it is out of stock and end of the day farmer suffers..it's always the case..farmer suffers but you know			
Interview 5	I: How many tubes do you prescribe? P: They should get 3 tubes some of them they only buy 1 and they say they will try this one and if it works and if it doesn't work, they will come back….at times it doesn't works I: Why do antibiotics don't work?			

	P: I think the problem is for the farmers to understand that if they need animals to be good or mastitis that disease to get well than they have to use the treatment that is given like the 3 tubes some of them they use one and that's it…but I think sometimes we are finding it that antibiotics is not really effective on some animals. Mostly animals that have been treated so many times with antibiotics we change it…I don't know the change in drugs around name of the drugs only but the antibiotics is there but some of the animals are not and they getting resistant to antibiotics like it doesn't work in that so we try other we try other vitamins or we just tell the owner to just to leave the cattle free just to see if anything happen to it and could make the cattle to cow to get better…all that. I: Do farmers follow instructions always? please tell me more about that. P: Yah its common…. they don't follow instructions. most of them they don't follow instructions…. some farmers they these are the farmers they have lot of problems on their farm. It's like they come they tell us this is the problem on the farm and they go back they never do what we tell them and then after two days or one or two days they come back and tell the animals about to die but we have given them			

	what is needed to be done. umm…some of them they need us to go with them on the farm we usually go and attend to cases but some of them need us to do it for them like giving drugs, treat some of the wounds, or anything like that so we go but some of the farmers they are they do what we tell them if some of them they don't do it. I: Do you usually substitute medicines, like when antibiotics don't work, do you substitute? P: The only think we ..we have only few drugs with us ah…like antibiotics we usually run out of antibiotics every month and because they give us in less amount and we work what we inject to we give the animals in less amount these what farmers tell us the animals is sick and they tell us ok I have only this amount of money and you have to inject the animal on that amount but the instructions is no there is amount of drugs to be given to that animals but some farmers are different, they can afford everything want for the animals but for substitution on the drugs we have we have less drugs the only drugs that we have mostly is antibiotics in our clinics those are the drugs we have I think its most of the drugs have antibiotics in it but only the names are different.			
Interview 6	I: Can you tell me about your working day?			

	P: Ok in the clinic, for example in the field eh…it depends on the for case in the field it depend on how much cases I been called for the day from last week I didn't receive any cases last week was just normal office work clinic work only ….only selling drugs and ..yah that's it..there is less drugs in the office we can serve the farmers who are after drugs but sometimes we are running out of stocks so we not able to deliver the drugs to the farmers. I: So, you said you running out of drugs or out of stock, so what is it like ongoing issue or is it a something new you facing ? P: Well! For example, we only got two kinds of antibiotics in the clinic, now we got properacillin and we not supplied with the Norocillin so like now we only use. How to say that! We give based on the supply, give what is available particular time. For example, if I have SA and LA so I will use the SA first, so if there is no SA available, I will use the one we have. this issue for this year like it's been ongoing from months for we normally submit our returns first week of every month like supplied by 6th or 5th of every first week of the month so our drugs normally later in the month can be last week of the month so once we are submitting the returns that means most of the			

	drugs are out at that time so for that whole month there are some of the drugs we really requested are not in I: So, you as a paravet what are the challenges you face on the farm or challenges in executing your job on a daily basis? P: Ok….The major challenge that we face in the field is lack training. Again, like for me when I joined the ministry, I never attended a para-veterinary training I have …. based in clinic. Like basic one for clinical and I attended the one on food safety and meat hygiene so what I learnt when I joined from my senior staff from that time and the reading materials that we normally use that's what I am doing and the challenges that we normally face in the clinic like… more knowledge. Some of the farmers keep calling us like they have rapid death on the farm, and they want post-mortem reports and want to know what medicine to give. I can't do a post-mortem, and I don't know all that medicine. So, I tell them … have to wait for those kinds of decisions I: Apart from these issues you have highlighted, are there any other challenges or problems you face?			

	P: At the moment, the manpower for me its I am …. for us, its only two ..like one is manning the clinic and the other one normally sometimes goes out….yes shortage of drugs. I: How often do you have these sorts of situation where farmers call back and complain that antibiotics not working? P: Umm….eh…like only like for diarrhoea, for diarrhoea cases, like we been giving scour ban .that's for diarrhoea. We explain to the farmers the dose rate,, like some of the farmers the come after and still saying that it's not working so can have another one so I normally ask them if you giving the right amount ..they sometimes they say yah..they give very less because cost of the ..because for 120mls its $10.40 may be they give less because it's so expensive I: Why do antibiotics don't work? P: Yah may be…We are giving antibiotics every time we are going out to the field like I said earlier, if you don't give injections to that animal the farmer will create a fuss, at least give one injection			
Interview 7	I: How do you select antimicrobials when you prescribing?			

	P: Umm….again it comes down to I think it's its. Bit different to overseas here it's also there is a time factor involved…. the supplies our currently selection of antimicrobials is not that wide ummmm…say usually you just select broad spectrum and narrow it down but again it's a difficult one to answer ..there is lot of factors involved..yah I: To what extent cost is involved in this? P: I think its $3.40 for a mastitis tube but I think that's about for the cost of it and initially they require like 3 minimum some farmers will kick up the fuss for three so like its $15 my way of convincing them is you spend more like $20 on grog a day ……so fork out. Most farmers I have visited they bought the tubes,,,,some farmers will just buy only one again it won't treat the mastitis and they will come back complaining so I have to just tell them like if you take 3 you have a high chance of treating the mastitis but you know….out of stock and procurement….arrgghhh I: Can you please tell me more about the issue of procurement and out of stock?			

	P: Argh! The government processes! bureaucracy! So, we can prepare request here and say we need this amount, then it goes to our accounts team that would take at least four weeks. Then it goes to [the] economy and then takes another four weeks by the time that they actually finalise the request, the quotations have expired [then] they throw it back like, getting a quotation and by the time companies not willing to provide and most companies we purchase from only want advance payment, so we order from Australia and New Zealand that's the one we regularly order from. So yeah, that's the major hurdle. I: Can you tell me about the role of para-veterinarians? P: Para-veterinarians here! Some actually got experience from past because they were trained by previous old veterinarians, but there are some you know lack the knowledge and skills, and sometimes, they make things worse than us. I come across those cases, and I have also received complaints…some just do it right at all…they don't follow and listen…arrghhh			
Interview 8	I: Can you tell me more about the medicine out of stock issue?			

	P: Oh, very different. You know in Australia they keep to the standards, everything is also available, there resources available, I think for them there Code of conduct is more like, what you say! Um! The way they actually handle their cases, they are much more strict they are here, there is no any form of laws, regulations governing us veterinarians basically you can do whatever we want, and we won't get penalised for it whereas over there it is very tight. They have veterinary councils, board um! So, the standards have to be kept. I: What else is causing the out of stock of antibiotics in clinics? P: A lot of use…. like use…literally… Antibiotics use, and resistance is for the farmers to fully understand when to use and how to use especially the farmers and officers; extension officers, otherwise they will overuse it because lack of knowledge. That's the only thing if they know what to do, what to use and how to use. They don't know they just pretend they know it, so they inject penicillin anyway anyhow. Oh yes…. Oh! Um! This is where it becomes tricky, because with me, from farmers that we don't have the drugs in stock, they will complain right up to the top level, you know, Minister, PM's Office,			

	and the best we can advise them is that while it's going to be here in a week or a month next month or two months, and we take down their names, we take down the numbers and number of drugs and when it comes in you call them to collect the drugs			

Chapter 8

Factors associated with antimicrobial use in Fijian livestock farms

Chapter summary: Following on from previous chapters which quantified AMU, categorised AMU practice and explored drivers of AMU and AMR from Fijian livestock farmers' and veterinarians' perspective, this present chapter investigates the factors associated with AMU in livestock farms informed by conceptual framework.

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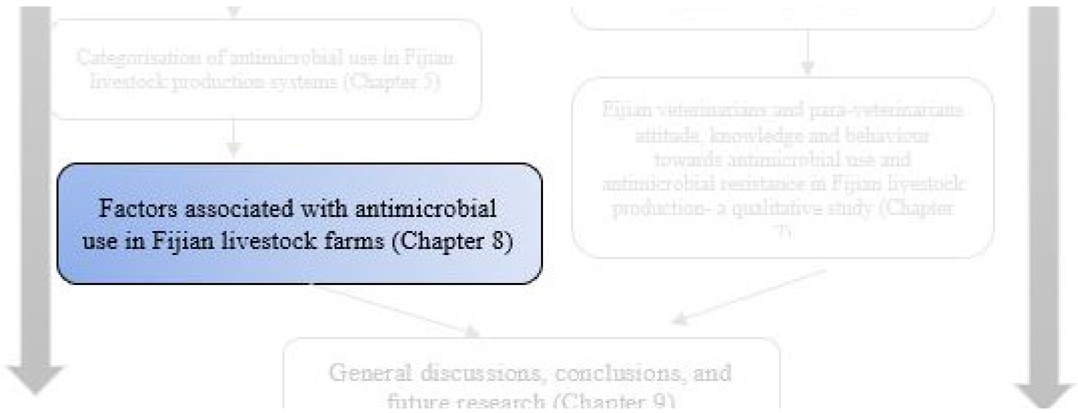

Abstract

Antimicrobial stewardship (AMS) programmes in human health and livestock production are vital to tackling antimicrobial resistance (AMR). Data on antimicrobial use (AMU), resistance, and drivers for AMU in livestock are needed to inform AMS efforts. However, such data is limited in Fiji. Therefore, this study aimed to evaluate the agri-food value chain (farmer and livestock production and management) factors associated with AMU. Socio-economic, demographic, livestock production and management information were collected from 236 livestock farmers and managers located in Central and Western divisions, Viti Levu, Fiji. Purposive and snowball sampling was used to recruit farmers and farm managers. Descriptive and inferential analyses were performed. Multinomial logistic regression was used to determine the factors associated with AMU in livestock farms using aggregated livestock farm model. Farms that raised cattle only for dairy (farm factor) were more likely to use antibiotics and anthelmintics ($p = 0.018$, OR = 22.97, CI 1.713, 308.075). There was a tendency for layer only ($p = 0.917$), broiler only ($p = 0.356$), and layer and broiler mixed farms ($p = 0.698$) to use antibiotics. Farms that maintained AMU records (farm factor) were more likely to use antibiotics ($p = 0.045$, OR = 2.65, CI 1.024, 6.877) and, similarly, anthelmintics only ($p = 0.051$). AMU in livestock farms was not influenced by the socio-economic and demographic characteristics of the farmer. Other livestock production and management factors had no influence on AMU on the livestock farms. Although there was a difference between different livestock enterprises and their management, the lack of association may have been attributed to a lack of knowledge and awareness on AMU and livestock management practices. AMS programmes targeting awareness on AMU and livestock management are required to promote prudent use of antimicrobials. Improving veterinary services by increasing farm visits and advisory services should be incorporated in AMS programmes so that the prudent use of antimicrobials is practised in all livestock farms in the agri-food value chain locally.

Keywords: Antimicrobial use; livestock farms; livestock enterprises; factors; socio-economic; demographic; Fiji

Introduction

Antimicrobial resistance (AMR) is a major global threat to human and animal health [1-3]. International collaborative efforts by the World Organisation of Animal Health (OIE), the World Health Organisation (WHO) and the Food and Agricultural Organisation of United Nations (FAO) have adopted the One Health approach to combat the global risk of AMR [1-3]. In doing so, the prudent use of antimicrobials in livestock production systems have been encouraged [1,2]. Additionally, with the increasing risks of transmission of AMR microbes from livestock farms into the environment and agri-food chain, antimicrobial stewardship (AMS) programmes in the human and animal sector have been advocated[1,2]. Although AMU data are becoming more accessible, the information on drivers of AMU, which are essential in developing AMS programmes, remains unclear.

Socio-economic and demographic factors influence livestock production systems and management practices [4-6]. Backyard farmers produce livestock for domestic consumption and at times sell to buy plant-based food products [7,8]. These backyard and semi-commercial farmers' management practices are also influenced by other farmers, friends, and neighbours, thus shaping the attitude and intention of the farmers [9,10]. Socio-economic status may also affect farmers' ability to seek veterinary advice on animal health, production and improve farm biosecurity infrastructure [7,11-13]. In principle, veterinary services affect farmers' decision-making process since veterinarians may serve as farmers' knowledge hub [14]. The advice disseminated by veterinarians to farmers also shapes the behaviour of the farmers [15,16].

Fiji is a developing tropical country with backyard and semi-commercial enterprises such as beef, dairy, broiler chicken, and laying hens, predominantly providing food and financial security to many Fijian farmers' [17,18]. Shortage in veterinary professionals have been reported in the livestock sector [19] and are similar to other developing countries [20]. In the human health sector, AMR has been reported [19], but AMR in livestock is unknown. Prudent use of antimicrobials has been advocated at global levels using AMS programmes [1-3]. However, implementing mitigation policies surrounding prudent AMU in developing countries such as Fiji is challenging, noting the vast difference in livestock production, management practices, socio-economic and demographic factors [6,20,21]. In developing countries, antimicrobials have been used prophylactically and to increase production [22,23]. Additionally, a lack of knowledge and understanding of AMU and AMR have also been reported [13,24,25].

Contextual and socio-psychological factors influence farmers' attitudes towards farm biosecurity risk management and AMU practice [6,14,26]. However, farm biosecurity risk management strategies differ between farm enterprises [27,28]. Antimicrobials (antibiotics and anthelmintics), nutraceuticals and other medicinal products have been used in livestock production to manage and mitigate farm biosecurity risks [28-30]. Nevertheless, the use of these medicinal and non-medicinal products is substantially different in poultry and cattle [29,31]. For instance, antibiotics are administered in flocks of chickens compared to individual animals in cattle herds [31-33]. The information on-farm biosecurity risk management using medicinal and non-medicinal products, including antimicrobials and effects of contextual drivers on AMU practice in Fijian livestock farms, is largely unknown.

Our earlier studies have demonstrated the AMU and the patterns of use and lack of knowledge and understanding of AMU and AMR amongst farmers and para-veterinarians; however, the contextual farmer and farm factors driving AMU remains unexplained. It was hypothesised that farmers' socio-economic and demographic factors and livestock production and management characteristics influenced the AMU, illustrated in the conceptual framework (see Figure 1).

Therefore, this study aimed to investigate the agri-food value chain factors (farmer and livestock farm production and management) that influence AMU in the Central and Western regions of Viti Levu, Fiji.

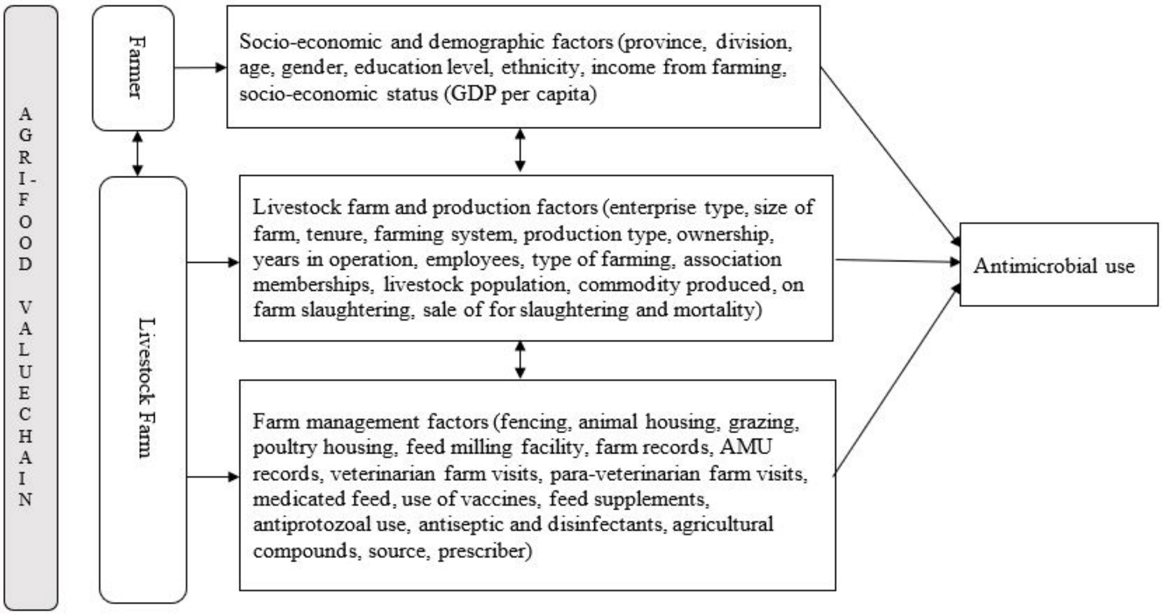

Figure 1 The conceptual framework illustrating the overarching constructs influencing antimicrobial use.

Material and Methods

Data on farmer and farm characteristics, livestock production, feed and feeding practices and medicine use, collected from the cross-sectional survey conducted between May to August 2019 in Central and Western Divisions of Viti Levu, Fiji, previously reported in Khan et al. (2021) [34] was evaluated in this present study. Purposive and snowball sampling was used to recruit farmers and farm managers. A total of 236 livestock farms were investigated [34]. Considering the farmer and livestock farm constructs in the conceptual framework (see Figure 1), factors associated with AMU was assessed using the aggregated livestock farm model (see Figure 1 and supplementary Table 1(farm model) for a detailed description of all factors).

Data management and analysis

Data were analysed using IBM SPSS Software V27. Farmer characteristics (socioeconomic and demographic), livestock farm production and livestock management, including feed and feeding practices, medicinal and non-medicinal product use, and antimicrobial access variables (factors) (see Figure 1 and supplementary Table 1(farm model) for a detailed description of all factors), were descriptively analysed. Frequency and percentages were summarised for categorical factors. Data on other medicines used, excluding antimicrobials administered orally, parenterally and intramammary, were assessed and classified into vaccines, topical antimicrobials, antiprotozoals, multivitamins and minerals, feed supplements, herbal preparations, antiseptics and disinfectants and agricultural compounds [29]. These other categories of medicines used were coded (either used or not used). Continuous factors were reclassified into categories. These were: years of operation (<5yrs, 5-10years, >10years) [12], number of employees (0, 1, ≥2), farm size (smallholder farm = <2 hectares(ha), medium-large = >2 ha) [35], para-veterinary and veterinary visits (no visits, monthly, quarterly) and herd/flock size (as reported in an earlier study [34]) was classified into three categories based on farming system (backyard, semi-commercial = small-medium, commercial = large) [36,37]. From the antimicrobial use data, outcome factor (AMU) was categorised into types of antimicrobial used (antibiotics, anthelmintics, both and none) [34]. Our earlier study demonstrated that antimicrobials were mainly sourced from veterinary clinics and self-prescribed by farmers; hence factors (source and prescriber of antimicrobial) were excluded in this study [38]. A total of 34 variables for the livestock farm model were considered for analysis (see Figure 1 and supplementary Table 1(farm model) for a detailed description of all factors).

Statistical analysis

A livestock farm model was developed using the livestock farm data (see Figure 1 for a detailed description of all factors). Chi-square test or Fisher's exact test as appropriate, were used to investigate the association between hypothesised independent factors (farmer characteristics, farm production and management characteristics) with outcome factor (AMU) [39,40]. Statistically significant independent factors were fitted into multinomial logistic regression models to investigate the relationship between the independent factors and AMU [30,41]. The independent factors with $p < 0.2$ in univariate analysis were retained, and model reduction was done manually with confounding factors eliminated from the model [42,43]. The 'no AMU' outcome category was set as a reference category in livestock farm modelling. Odds ratio with 95% confidence interval (95% CI) were reported, and $p < 0.05$ was considered statistically significant.

Results and discussion

The summary of statistically significant farmer and farm factors associated with AMU are presented in Table 1 (farm model). Refer to supplementary Tables 1(farm model) for a detailed description of all factors.

Table 1 Analysis of associations between farmer and farm characteristics and antimicrobial use in 236 livestock farms located in Central and Western divisions of Viti Levu, Fiji

		Antimicrobial use										
		Total		Antibiotics		Anthelmintics		Both		No AMU		
Factor	Sub-category	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	p-value
Division	Central	93	(39)	27	(47)	12	(33)	25	(52)	29	(31)	0.038*
	Western	143	(61)	30	(53)	24	(67)	23	(48)	66	(69)	
Province	Naitasiri	26	(11)	8	(14)	6	(17)	7	(15)	5	(5)	0.001*
	Namosi	13	(6)	2	(4)	1	(3)	2	(4)	8	(8)	
	Rewa	13	(6)	5	(9)	1	(3)	0	(0)	7	(7)	
	Serua	19	(8)	5	(9)	4	(11)	6	(13)	4	(4)	
	Tailevu	22	(9)	7	(12)	0	(0)	10	(21)	5	(5)	
	Ba	84	(36)	15	(26)	14	(39)	21	(44)	34	(36)	
	Nadroga-Navosa	28	(12)	5	(9)	8	(22)	2	(4)	13	(14)	
	Ra	31	(13)	10	(18)	2	(6)	0	(0)	19	(20)	
Gender	Male	198	(84)	48	(84)	34	(94)	44	(92)	72	(76)	0.021*
	Female	38	(16)	9	(16)	2	(6)	4	(8)	23	(24)	
Association memberships	Yes	60	(25)	10	(18)	14	(39)	22	(46)	14	(15)	<0.001*
	No	176	(75)	47	(82)	22	(61)	26	(54)	81	(85)	
Farm size	Small holder (<2ha)	51	(22)	14	(25)	2	(6)	3	(6)	32	(34)	<0.001*
	Medium-large holder (>2ha)	185	(78)	43	(75)	34	(94)	45	(94)	63	(66)	
Years in operation	< 5years	67	(28)	19	(33)	4	(11)	5	(10)	39	(41)	<0.001*
	5-10years	68	(29)	17	(30)	8	(22)	15	(31)	28	(29)	

	>10years	101	(43)	21(37)	24	(67)	28	(58)	28	(29)	
Fencing	Yes	133	(56)	28(49)	24	(67)	36	(75)	45	(47)	0.005*
	No	103	(44)	29(51)	12	(33)	12	(25)	50	(53)	
Enterprise type	Beef only	57	(24)	10(18)	17	(47)	8	(17)	22	(23)	<0.001*
	Dairy only	52	(22)	9 (16)	11	(31)	29	(60)	3	(3)	
	Beef and dairy	11	(5)	0 (0)	2	(6)	4	(8)	5	(5)	
	Layer only	50	(21)	13(23)	3	(8)	2	(4)	32	(34)	
	Broiler only	38	(16)	18(32)	0	(0)	1	(2)	19	(20)	
	Layer and broiler	12	(5)	4 (7)	0	(0)	1	(2)	7	(7)	
	Other mixed	16	(7)	3 (5)	3	(8)	3	(6)	7	(7)	
Animal housing	Yes	150	(64)	43(75)	13	(36)	22	(46)	72	(76)	<0.001*
	No	86	(36)	14(25)	23	(64)	26	(54)	23	(24)	
Para-veterinarian farm visits	No visits	118	(50)	21(37)	14	(39)	20	(42)	63	(66)	0.004*
	quarterly	74	(31)	20(35)	15	(42)	19	(40)	20	(21)	
	monthly	44	(19)	16(28)	7	(19)	9	(19)	12	(13)	
Veterinarian farm visits	No visits	223	(94)	46(81)	35	(97)	48	(100)	94	(99)	<0.001*
	quarterly	4	(2)	2 (4)	1	(3)	0	(0)	1	(1)	
	monthly	9	(4)	9 (16)	0	(0)	0	(0)	0	(0)	
AMU records	Yes	38	(16)	16(28)	8	(22)	4	(8)	10	(11)	0.010*
	No	198	(84)	41(72)	28	(78)	44	(92)	85	(89)	
Medicated feed used	Not used	125	(53)	22(39)	32	(89)	35	(73)	36	(38)	<0.001*
	Used	111	(47)	35(61)	4	(11)	13	(27)	59	(62)	
Feed supplements	Not used	202	(86)	53(93)	30	(83)	27	(56)	92	(97)	<0.001*
	Used	34	(14)	4 (7)	6	(17)	21	(44)	3	(3)	
Antiseptics and disinfectants	Not used	193	(82)	44(77)	30	(83)	31	(65)	88	(93)	<0.001*
	Used	43	(18)	13(23)	6	(17)	17	(35)	7	(7)	

Note - zero (0) indicates no participant of that category participated, n denotes frequency, and % denotes percentage observed, * Both denotes antibiotics and anthelmintics were used, AMU denotes antimicrobials used and – denotes analysis not executed due to no representation in one sub-category of the factor. p-value denotes the probability of association obtained using the Chi-square test or Fisher's exact test as appropriate between antimicrobial use (antibiotic, anthelmintic, both and no AMU) and factors.

Livestock farm model

Characteristics of Fijian livestock farmers and farms

Supplementary Table 1 shows the characteristics of the 236 livestock farmers and farms. Most participants were farmers (n = 211, 89%) and were from the Western Division of Viti Levu (n = 143, 61%). The majority were from Ba province (n = 84%) and were 40-59 years of age (n = 120, 51%). Most farmers were male (n = 198, 84%) and had obtained secondary education qualifications (n = 142, 60%). Most farmers reported their income from farming comprised between 25-50% of total household income (n = 94, 40%), and their household income was less than gross domestic income per capita (n = 151, 64%). Most respondents were not members of any associations (n = 176, 75%). Most farms were household-owned (n = 162, 69%) with Itaukei Land Trust Board (TLTB) leased tenure (n = 63, 27%). Most farms were medium-large holders with farm sizes greater than 2 ha (n = 185, 78%) raising livestock in semi-commercial farming systems (n = 144, 61%) and classified as organic (n = 101, 43%). Most farms were not mixed (crop and livestock) and raised livestock only (n = 162, 69%) and were in operation for more than 10 years (n = 101, 43%). Most farms employed no farmworkers (n = 134, 57%). The most numerous enterprises were beef, which comprised the only livestock on the farm (n = 57, 24%). Most farms were small-medium sized herds or flocks (n = 171, 72%). Most farms were fenced (n = 133, 56%) and had an animal house (n = 150, 64%). Half the farms had no para-veterinarian farm visits (n = 118, 50%), and the vast majority had no veterinarian visits (n = 223, 94%). Although most farmers' had maintained farm records (n = 122, 52%), very few farms-maintained AMU records (n = 38, 16%). Most farms had no on-farm milling facility (n = 220, 93%) and had not used medicated feed (n = 125, 53%). Most farms had not used any feed supplements (n = 202, 86%). Most farms had not used antiprotozoal (n = 229, 97%) or herbal preparations (n = 211, 89%). However, most had used vitamins and minerals (n =122, 52%). Very few farms had used vaccines (n =11, 5%), and the majority of farms had also not used antiseptics and disinfectants (n = 193, 82%) or other agricultural compounds (poisons) (n = 232, 98%).

Livestock farm modelling

Of the 34 variables presented in Supplementary Table 1, only 15 variables (division, province, gender, association memberships, farm size, years in operations, enterprise type, fencing, animal housing, para-veterinarian farm visits, veterinarian farm visits, AMU records, medicated feed use, feed supplement use, antiseptics and disinfectants use) were associated with AMU ($p < 0.05$) (see Table 1). Farms that raised cattle only for dairy were more likely to use antibiotics and anthelmintics (p = 0.018, OR = 22.97, CI 1.713, 308.075). Dairy farms were more likely to use antibiotics only (p = 0.097) and anthelmintics only (p = 0.594). There was a tendency (p = 0.848) for beef only farms to use both anthelmintics and antibiotics. Farms which had both a beef and dairy enterprise used both antibiotics and anthelmintics (p = 0.467). The layer only (p = 0.917), broiler only (p = 0.356), and layer and broiler mixed farms (p = 0.698) were most likely to use antibiotics. Smallholder farms were less likely to use a combination of both (p = 0.015 OR = 0.15, CI 0.032, 0.689). Interestingly farms that maintained AMU records were more likely to use antibiotics (p = 0.045, OR = 2.65, CI 1.024, 6.877) and similarly anthelmintics only ($p > 0.05$). Farms that had not used medicated feeds were more likely to use anthelmintics only ($p < 0.001$, OR =11.56, CI 3.456,38.604) and a combination of both (anthelmintics and antibiotics) (p = 0.017, OR = 3.10, CI 1.222, 7.882). Farms that had not used feed supplements were also more likely to use anthelmintics only (p = 0.025, OR = 6.37, CI 1.261,32.155) or both (p = <0.001, OR = 30.41, CI 7.277, 127.081). In contrast, farms that had not used antiseptics and disinfectants were less likely to use antimicrobials (see Table 2).

Table 2 Multinomial logistic modelling analysis of factors influencing antimicrobial use in 236 livestock farms in Central and Western divisions of Viti Levu, Fiji (No antimicrobial used as reference category)

Factor	Sub-category	Antimicrobial use					
		Antibiotics		Anthelmintics		Both	
		P value	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)
Enterprise type	Beef only	0.934	0.92(0.131,6.456)	0.428	0.43(0.053,3.472)	0.848	1.27(0.114,13.985)
	Dairy only	0.097	6.67(0.711,62.490)	0.594	1.91(0.176,20.776)	0.018*	22.97(1.713,308.075)
	Beef and dairy	0	0(0)	0.264	0.23(0.017,3.064)	0.467	2.72(0.184,40.117)
	Layer only	0.917	1.09(0.227,5.206)	0.151	0.23(0.030,1.719)	0.217	0.27(0.032,2.177)
	Broiler only	0.356	2.10(0.434,10.154)	0	0(0)	0.057	0.08(0.005,1.080)
	Layer and broiler	0.698	1.46(0.217,9.821)	0	0(0)	0.541	0.43(0.029,6.356)
	Other mixed	Ref		Ref		Ref	
Farm size	Small holder (<2ha)	0.284	0.64(0.282,1.449)	0.104	0.26(0.050,1.319)	0.015*	0.15(0.032,0.689)
	Medium-large holder (>2ha)	Ref		Ref		Ref	
AMU records	Yes	0.045*	2.65(1.024,6.877)	0.051	3.48(0.993,12.166)	0.406	0.53(0.120,2.354)
	No	Ref		Ref		Ref	
Medicated feed used	Not used	0.894	1.05(0.496,2.234)	<0.001*	11.56(3.456,38.604)	0.017*	3.10(1.222,7.882)
	Used	Ref		Ref		Ref	
Feed supplements	Not used	0.247	2.52(0.527,12.003)	0.025*	6.37(1.261,32.155)	<0.001*	30.41(7.277,127.081)
	Used	Ref		Ref		Ref	
Antiseptics and disinfectants	Not used	0.076	0.39(0.136,1.105)	0.283	0.49(0.136,1.789)	0.001*	0.15(0.047,0.456)
	Used	Ref		Ref		Ref	

Note - zero (0) indicates no participant of that category participated, n denotes frequency, and % denotes percentage observed, * used to denote significant results, both denote (antibiotics and anthelmintics used), AMU denotes antimicrobials used and – denotes analysis not executed due to no representation in one sub-category of the factor p-value denotes probability for the association, Ref denotes reference group.

As flock level administration of antimicrobials in poultry is more likely compared to an individual animal in cattle [32,33,44], the chances of antimicrobial use in specialist cattle and poultry and mixed cattle and mixed poultry were higher than other mixes of farms enterprises [6,31]. We believe the higher incidence of mammary infections in dairy cows may be the reason for the increased use of antibiotics in cattle [45]; however, we also believe the use may be for prophylaxis and growth promotion, as demonstrated in our previous study [38]. The chances of antibiotic use were higher in poultry enterprises due to flock level administration, prophylaxis and growth promotion, as demonstrated in our previous study [34]. Our finding of higher chances of using antimicrobials in cattle and poultry enterprises is similar to findings demonstrated in other studies [31,44]. Although flock/herd density is higher in commercial systems than semi-commercial and backyard, there was no influence of the farming system on AMU ($p = 0.430$). We believe that is due to similar AMU practices in all enterprises. Our earlier study also demonstrated that the farming system did not affect AMU when quantified using different metrics [34].

However, we also believe this similar use between farming systems may be due to a lack of knowledge and understanding of AMU, leading in some cases to an unwitting use of antimicrobials. We could not establish statistical significance with the farming systems factor due to modelling inefficiencies. We believe that lower chances of AMU in smallholder farms may be due to a lack of access to antimicrobials [46]. We also believe antimicrobials were used in smallholder farms; however, they were used based on availability compared to the medium to large holders that are financially capable and keep large stores of antimicrobials, as demonstrated in our earlier study [46]. The association between maintenance of AMU records and antibiotic use may be a consequence of farmers producing poultry to contract being required to provide records of AMU to commercial processors [47]. Farmers that were not producing for a contract may be using antimicrobials but have not kept records of AMU because of a lack of knowledge and understanding of the importance of maintaining such records. This has been demonstrated in earlier studies [46,47].

Our earlier study demonstrated that farmers lack general knowledge and understanding of medicines and did not differentiate between different types of medicine [46]. We believe farmers considered medicated feed, feed supplements, antiseptics, and disinfectants also as medicines and used on their livestock [46]. We believe farmers use medicated feed (containing antimicrobials) and feed supplements to prevent animal diseases and promote growth [48] and used antimicrobials as the first line of treatment [38,46]. It was beyond the scope of the current study to explain the motivations behind the use of other medicines (vaccines, topical antimicrobials, antiprotozoals, multivitamins and minerals, feed supplements, herbal preparations, antiseptics and disinfectants and agricultural compounds). Therefore, further studies investigating the drivers of other medicines use are required, so that other medicines use including AMU in Fijian livestock production systems could be better understood. Additionally, these future studies can inform the design of AMS programmes optimising medicines use that currently do not exist in local context.

Overall findings

Our study demonstrated that AMU in livestock farms was not influenced by the socio-economic and demographic characteristics of the farmer but influenced by the livestock production and management factors such as species of farmed livestock (enterprise type), farm management factors (AMU records, medicated feed use and feed supplements) (see Table 2). Despite the differences in farming systems and management, most factors were not associated with AMU. We presume the lack of association may be due to not enough commonality between systems to detect any associations. Given that seasonal effects affect disease burdens in different production systems, the chances of using a type of antimicrobials would be higher; however, the AMU practice was not similar in the livestock farms surveyed [45].

Other studies have demonstrated the effects of livestock management and farm biosecurity systems on AMU practice [27,28]. The lack of association in our study may be because of a lack of statistical power because of the small number of backyard and commercial farms that were included. Other studies have demonstrated that AMU was influenced by socio-economic and demographic factors [7,14,49], and this may have been the case in our study as well, but we were unable to detect it because of an unequal representation of farmers from all socio-economic and demographic groups since most farmers in the present study were of lower socio-economic status (household income less than GDP per capita) [50,51]. Given that the driver for the semi-commercial farming system was income and most farmers in this category are usually on the poverty line or below the poverty line, we believe most farmers raised livestock in the semi-commercial farming system for social, economic and food security [7,49]. The results suggest that most farms raised animals in semi-commercial farming systems, which can be transitional; hence, we suggest future studies need to consider the sampling strategy to ensure equal representation and larger sample size so that modelling could be executed to better predict the AMU practice in different enterprises and systems.

Our study revealed that farmers used antibiotics, anthelmintics, commercial feed, nutraceuticals, herbal medicines, and vaccines, and these may have been used to mitigate farm biosecurity risks or for other purposes [28,29,52]. Farm biosecurity infrastructure was in place in most farms, but farmers with lower socio-economic status do find it challenging to implement farm biosecurity risk mitigation measures because of the associated costs [14,22,52-54]. Nonetheless, our studies showed no association with farm infrastructure factors in most farms.

Maintenance of farm records is another essential part of farm biosecurity assessment [54]. Although most farmers had attained secondary school education, most farms did not maintain farm AMU records. We do not believe that literacy is an issue but understanding the importance of maintaining farm AMU records may be an essential consideration. Hence, we suggest follow up studies exploring attitude and knowledge towards record-keeping and overall biosecurity risk management on farms. Our study revealed that level of education was not associated with AMU practice, but exploring the knowledge and understanding of farmers on AMU and AMR at the enterprise level may be an essential consideration as reported in studies in other settings [24,46]. Additionally, this may inform and assist in developing mitigation strategies adopted as part of AMS programmes.

Veterinarians and para-veterinarians have a critical role in AMS programmes [55], but our study revealed veterinarian and para-veterinarian farm visits were very low. Interaction between farmers with veterinarians and para-veterinarians is therefore low, resulting in imprudent AMU practices as farmers self-prescribe antimicrobials [24,26,51,56]. Also, this may provide a window of opportunity to farmers who may opt to explore other avenues for advice, as is the case in other countries [57]. It must be noted that technical and clinical guidance on managing animal health and farm risks offered by veterinarians are more informed and cannot be compared to other sources [14]; therefore, it is imperative that improving Fijian veterinary services should be considered and incorporated as a critical priority indicator when developing policies in AMS programme so that better farm risk management practices are implemented. Self-prescribing is a common problem in the human health sector; thus, the chances of the same behaviour adopted by farmers in livestock farms is of grave concern as also indicated in our previous studies [38,46,56]; hence such practices need to be further explored [58]. We, therefore, recommend further studies exploring self-prescribing behaviour patterns of farmers so that more informed behavioural change intervention could be recommended.

Strengths and Limitations

This study, to our knowledge, was the first study investigating the factors associated with AMU in Fijian livestock farms. Although participants were unequally represented by gender, our findings are not extraordinary since farm ownership, and farm decisions are traditionally made by the head of household, usually male, consistent with findings in other studies [50]. A higher representation of farms from the Western division may have confounded the results. Nevertheless, the literature review informed our hypothesised conceptual framework (figure 1), which assisted in elucidating valuable information about Fijian livestock production and management practices; AMU practices, the nutraceuticals and herbal medicines used, and the feed and feeding systems which was unknown. Therefore, the conceptual framework provided can be used to elucidate information on livestock production systems in other developing countries like Fiji, where information is limited.

Conclusion

This study suggests that the AMU on livestock farms was not influenced by livestock farmers' socio-economic and demographic characteristics. Antibiotic and anthelmintic use was more likely in dairy only farms and antibiotics in broiler and layer only farms. AMS awareness programmes on the use of antimicrobials, farm biosecurity risk management, and improving veterinary services need to be implemented to promote prudent use of antimicrobials in Fijian livestock production systems. Further studies exploring the social and cultural factors driving the AMU are required to understand better the drivers of AMU practice at the national level.

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Declaration of competing interest

None

Availability of data and materials

The manuscript and supplementary files include all pertinent materials and data supporting findings.

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Supplementary Table

Table S1 Analysis of associations between farmer and farm characteristics and antimicrobial use in 236 livestock farms located in Central and Western divisions of Viti Levu, Fiji

		Antimicrobial use										
		Total		Antibiotics		Anthelmintics		Both		No AMU		
Factor	Sub-category	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	p-value
Participant type	Farmer	211	(89)	51	(89)	35	(97)	44	(92)	81	(85)	0.231
	Farm manager	25	(11)	6	(11)	1	(3)	4	(8)	14	(15)	
Division	Central	93	(39)	27	(47)	12	(33)	25	(52)	29	(31)	0.038*
	Western	143	(61)	30	(53)	24	(67)	23	(48)	66	(69)	
Province	Naitasiri	26	(11)	8	(14)	6	(17)	7	(15)	5	(5)	0.001*
	Namosi	13	(6)	2	(4)	1	(3)	2	(4)	8	(8)	
	Rewa	13	(6)	5	(9)	1	(3)	0	(0)	7	(7)	
	Serua	19	(8)	5	(9)	4	(11)	6	(13)	4	(4)	
	Tailevu	22	(9)	7	(12)	0	(0)	10	(21)	5	(5)	
	Ba	84	(36)	15	(26)	14	(39)	21	(44)	34	(36)	
	Nadroga-Navosa	28	(12)	5	(9)	8	(22)	2	(4)	13	(14)	
	Ra	31	(13)	10	(18)	2	(6)	0	(0)	19	(20)	
Age	10-19years	1	(0)	0	(0)	1	(3)	0	(0)	0	(0)	0.293
	20-39years	49	(21)	11	(19)	7	(19)	6	(13)	25	(26)	

	40-59years	120 (51)	27 (47)	20 (56)	27 (56)	46 (48)	
	Over 60 years	66 (28)	19 (33)	8 (22)	15 (31)	24 (25)	
Gender	Male	198 (84)	48 (84)	34 (94)	44 (92)	72 (76)	0.021*
	Female	38 (16)	9 (16)	2 (6)	4 (8)	23 (24)	
Education level	Primary	31 (13)	10 (18)	7 (19)	3 (6)	11 (12)	0.850
	Secondary	142 (60)	30 (53)	19 (53)	31 (65)	62 (65)	
	Tertiary	39 (17)	10 (18)	6 (17)	9 (19)	14 (15)	
	Agricultural College	21 (9)	6 (11)	4 (11)	4 (8)	7 (7)	
	Never Attended	3 (1)	1 (2)	0 (0)	1 (2)	1 (1)	
Income from farming	<=25%	71 (30)	13 (23)	11 (31)	12 (25)	35 (37)	0.213
	25-50%	94 (40)	21 (37)	12 (33)	21 (44)	40 (42)	
	51-75%	30 (13)	10 (18)	8 (22)	6 (13)	6 (6)	
	>=76%	41 (17)	13 (23)	5 (14)	9 (19)	14 (15)	
Household income > GDP (Gross Domestic Product) per capita	Yes	85 (36)	23 (40)	14 (39)	19 (40)	29 (31)	0.552
	No	151 (64)	34 (60)	22 (61)	29 (60)	66 (69)	
Association memberships	Yes	60 (25)	10 (18)	14 (39)	22 (46)	14 (15)	<0.001*
	No	176 (75)	47 (82)	22 (61)	26 (54)	81 (85)	
Farm ownership	Individual	32 (14)	14 (25)	4 (11)	8 (17)	6 (6)	0.106
	Household	162 (69)	30 (53)	27 (75)	33 (69)	72 (76)	
	Company	32 (14)	10 (18)	3 (8)	6 (13)	13 (14)	
	Cooperative	7 (3)	1 (2)	2 (6)	1 (2)	3 (3)	

	Contract farming	3	(1)	2	(4)	0	(0)	0	(0)	1	(1)	
Farm tenure	Freehold	45	(19)	15	(26)	4	(11)	7	(15)	19	(20)	0.336
	Crown Lease	31	(13)	8	(14)	4	(11)	8	(17)	11	(12)	
	Agriculture Leased	43	(18)	14	(25)	6	(17)	5	(10)	18	(19)	
	TLTB Leased	63	(27)	11	(19)	12	(33)	19	(40)	21	(22)	
	Mataqali	44	(19)	8	(14)	8	(22)	6	(13)	22	(23)	
	Squatter	2	(1)	0	(0)	1	(3)	1	(2)	0	(0)	
	Commercial leased	8	(3)	1	(2)	1	(3)	2	(4)	4	(4)	
Farm size	Small holder (<2ha)	51	(22)	14	(25)	2	(6)	3	(6)	32	(34)	<0.001*
	Medium-large holder (>2ha)	185	(78)	43	(75)	34	(94)	45	(94)	63	(66)	
Farming systems	Backyard	27	(11)	8	(14)	2	(6)	3	(6)	14	(15)	0.430
	Semi commercial	144	(61)	30	(53)	23	(64)	33	(69)	58	(61)	
	Commercial	65	(28)	19	(33)	11	(31)	12	(25)	23	(24)	
Production type	Organic	101	(43)	24	(42)	14	(39)	21	(44)	42	(44)	0.302
	Conventional	70	(30)	22	(39)	7	(19)	13	(27)	28	(29)	
	Prefer not to comment	65	(28)	11	(19)	15	(42)	14	(29)	25	(26)	
Farming type	Livestock only	162	(69)	39	(68)	20	(56)	36	(75)	67	(71)	0.270
	Mixed (Crop and Livestock)	74	(31)	18	(32)	16	(44)	12	(25)	28	(29)	
Years in operation	< 5years	67	(28)	19	(33)	4	(11)	5	(10)	39	(41)	<0.001*

	5-10years	68	(29)	17	(30)	8	(22)	15	(31)	28	(29)	
	>10years	101	(43)	21	(37)	24	(67)	28	(58)	28	(29)	
Employees	0	134	(57)	34	(60)	21	(58)	22	(46)	57	(60)	0.309
	<2	25	(11)	7	(12)	5	(14)	8	(17)	5	(5)	
	>2	77	(33)	16	(28)	10	(28)	18	(38)	33	(35)	
Enterprises type	Beef only	57	(24)	10	(18)	17	(47)	8	(17)	57	(24)	<0.001*
	Dairy only	52	(22)	9	(16)	11	(31)	29	(60)	52	(22)	
	Beef and dairy	11	(5)	0	(0)	2	(6)	4	(8)	11	(5)	
	Layer only	50	(21)	13	(23)	3	(8)	2	(4)	50	(21)	
	Broiler only	38	(16)	18	(32)	0	(0)	1	(2)	38	(16)	
	Broiler and layer	12	(5)	4	(7)	0	(0)	1	(2)	12	(5)	
	Other mixed	16	(7)	3	(5)	3	(8)	3	(6)	16	(7)	
Flock/herd size	Small-medium	171	(72)	38	(67)	25	(69)	36	(75)	72	(76)	0.614
	Large	65	(28)	19	(33)	11	(31)	12	(25)	23	(24)	
Fencing	Yes	133	(56)	28	(49)	24	(67)	36	(75)	45	(47)	0.005*
	No	103	(44)	29	(51)	12	(33)	12	(25)	50	(53)	
Animal housing	Yes	150	(64)	43	(75)	13	(36)	22	(46)	72	(76)	<0.001*
	No	86	(36)	14	(25)	23	(64)	26	(54)	23	(24)	
Para-veterinarian farm visits	No visits	118	(50)	21	(37)	14	(39)	20	(42)	63	(66)	0.004*
	quarterly	74	(31)	20	(35)	15	(42)	19	(40)	20	(21)	
	monthly	44	(19)	16	(28)	7	(19)	9	(19)	12	(13)	
Veterinarian farm visits	No visits	223	(94)	46	(81)	35	(97)	48	(100)	94	(99)	<0.001*

	quarterly	4 (2)	2 (4)	1 (3)	0 (0)	1 (1)	
	monthly	9 (4)	9 (16)	0 (0)	0 (0)	0 (0)	
Farm records	Yes	122 (52)	28 (49)	23 (64)	24 (50)	47 (49)	0.469
	No	114 (48)	29 (51)	13 (36)	24 (50)	48 (51)	
AMU records	Yes	38 (16)	16 (28)	8 (22)	4 (8)	10 (11)	0.010*
	No	198 (84)	41 (72)	28 (78)	44 (92)	85 (89)	
Feed milling on farm	Yes	16 (7)	1 (2)	3 (8)	3 (6)	9 (9)	
	No	220 (93)	56 (98)	33 (92)	45 (94)	86 (91)	0.317
Medicated feed used	Not used	125 (53)	22 (39)	32 (89)	35 (73)	36 (38)	<0.001*
	Used	111 (47)	35 (61)	4 (11)	13 (27)	59 (62)	
Feed supplements	Not used	202 (86)	53 (93)	30 (83)	27 (56)	92 (97)	<0.001*
	Used	34 (14)	4 (7)	6 (17)	21 (44)	3 (3)	
Antiprotozoal	Not used	229 (97)	55 (96)	36 (100)	46 (96)	92 (97)	0.703
	Used	7 (3)	2 (4)	0 (0)	2 (4)	3 (3)	
Herbal preparations	Not used	211 (89)	50 (88)	34 (94)	45 (94)	82 (86)	0.384
	Used	25 (11)	7 (12)	2 (6)	3 (6)	13 (14)	
Vitamins and minerals	Not used	114 (48)	33 (58)	14 (39)	19 (40)	48 (51)	0.170
	Used	122 (52)	24 (42)	22 (61)	29 (60)	47 (49)	
Vaccines	Not used	225 (95)	54 (95)	36 (100)	46 (96)	89 (94)	0.490
	Used	11 (5)	3 (5)	0 (0)	2 (4)	6 (6)	
Antiseptics and	Not used	193 (82)	44 (77)	30 (83)	31 (65)	88 (93)	<0.001*
disinfectants	Used	43 (18)	13 (23)	6 (17)	17 (35)	7 (7)	

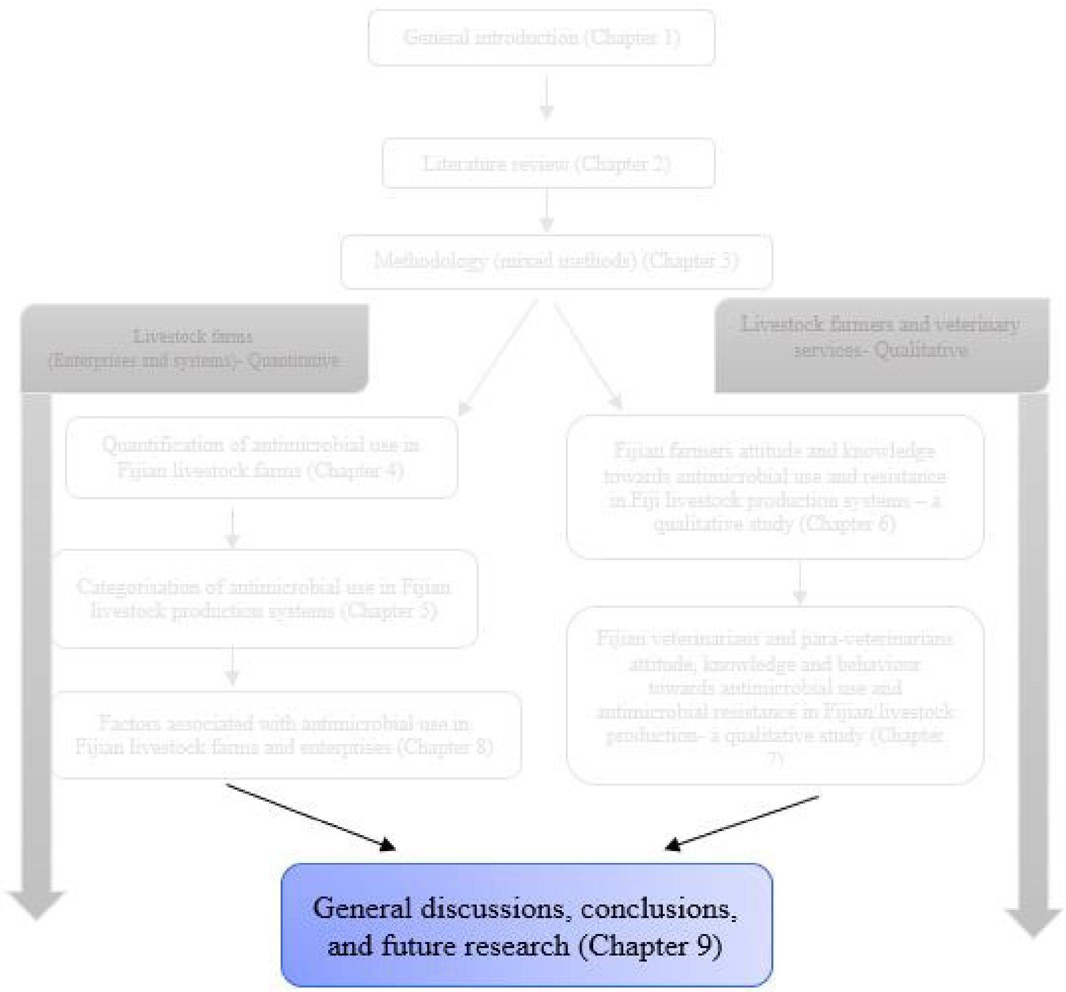
Agricultural compounds	Not used	232	(98)	57	(100)	35	(97)	47	(98)	93	(98)	0.711
(poisons)	Used	4	(2)	0	(0)	1	(3)	1	(2)	2	(2)	

Note - zero (0) indicates no participant of that category participated, n denotes frequency, and % denotes percentage observed, * denote significant results, both denote (antibiotics and anthelmintics used), AMU denotes antimicrobials used and – denotes analysis not executed due to no representation in one sub-category of the factor, p-value denotes probability of association obtained using Chi-square test or Fisher's exact test as appropriate between antimicrobial use (antibiotic, anthelmintic, both and no AMU) and factors.

Chapter 9

General discussion

Chapter summary: This chapter provides an overall view of the PhD programme; the key findings, their implications, along with reflections of methodological rigour and study limitations. In the final part of this chapter and thesis, I propose future work that could help optimise AMU and curb the growing risks of AMR in the Fijian livestock production systems in the short, medium, and long term.



9.1 Introduction

This PhD thesis aimed to quantify the AMU and evaluate the AMU practice in the Fijian livestock production systems. This thesis also aimed to explore and understand Fijian farmers, veterinarians, and para-veterinarians' attitudes and knowledge towards AMU and AMR in livestock production systems. AMR poses a threat to humans and animals in developed and developing countries [1-3]. However, a reduction in AMU and prudent use of antimicrobials in livestock production systems have been considered as mitigation measures [1,2]. Information is scarce on AMU and AMR in developing countries, especially in the Oceania region, particularly Fiji. Like other developing countries, AMR has been reported in Fiji [4,5]; however, the AMU and AMR in the livestock sector is unknown. Therefore, novel findings from this PhD work programme contribute to the existing knowledge gap specific to AMU and AMR in the Fijian livestock sector. Moreover, this thesis is also timely as Fiji adopted the national AMR action plan in 2015 [6]; therefore, empirical information on AMU and AMR can be used to inform the design of AMS programmes to optimise AMU and curb risks of AMR [7-9].

9.2 Main thesis findings

This thesis used multiple methodological approaches to evaluate and explain AMU and AMR in the Fijian livestock production systems. The thesis presented five separate studies (Chapter 4, 5, 6, 7 and 8), and the main thesis findings are discussed here to correspond to the objectives of the PhD study. A snapshot of the findings is presented in Table 1.

Table 1 Key research findings

Objectives	**Findings**
Quantification of AMU and evaluation of AMU practice (Livestock farms: systems	A cross-sectional survey was conducted in the Central and Western divisions of the island of Viti Levu in Fiji. Socio-economic, demographic, livestock production and management, feed and feeding systems and AMU information from 210 livestock farmers and 26 managers representing 276 livestock enterprises (beef n = 72, dairy n = 74, broiler n = 57 and layer n = 73) were collected. Most

and enterprises) – **Objective 1,2 and 5.**	enterprises raised livestock in semi-commercial farming systems (n = 166, 60%) and were located in the Western division (n = 174, 63%). Farm AMU records were maintained by only 38 (16%) of the livestock farms (n = 236) surveyed. **Quantification of AMU (Chapter 4)** Antimicrobials were used by slightly more than half (56%) of the 276 participating livestock enterprises. Of these, 22% of the 276 enterprises used only antibiotics, 16% used only anthelmintics, and 18% used both antibiotics and anthelmintics. Annually, 44mg/PCU of antibiotics was used in all enterprises, lower than the global average of 118mg/PCU [10,11]. However, antibiotic use was higher than the national and global average in layer hens (146.4mg/PCU), substantially lower in the broiler chickens (12.4mg/PCU), dairy (8.3mg/PCU), and beef (0.7mg/PCU) enterprises. AMU was not affected by farming systems; however, there was a difference in AMU between different enterprises and systems. Anthelmintic use was higher in cattle enterprises compared to poultry enterprises (dairy > beef > layer > broiler). In comparison, the quarterly antibiotic use was highly associated with backyard farming systems. The antibiotic use was higher in broiler enterprises(mg/PCU) compared to layer and cattle enterprises (broiler > layer > dairy > beef). **Evaluation of AMU practice (Chapter 5)** A framework for categorising AMU practice in livestock farms was developed. Veterinary antimicrobials were used in 306 of 309(99%) incidents, and the remainder, 1% human antimicrobials, were used. Antimicrobials were used imprudently in 96% of incidents (298 of 309). Antibiotics were used imprudently in 94% (160 of 170) incidents compared to anthelmintics which were used imprudently in 99% (138 of 139) incidents. Antimicrobials were self-prescribed by

	farmers in 95% (294 of 309) incidents. All antibiotics used in commercial broiler enterprises were prescribed by a veterinarian. Antibiotics were used prophylactically in more than a fifth of the incidents (22%) and as growth promoters in 14%; however, antibiotics were used therapeutically in 65% of the incidents. Imprudent antibiotic use was more prevalent in the dairy, layer, and beef enterprises than in broiler enterprises. Antimicrobials were used more imprudently in semi-commercial and backyard systems than in commercial systems.
Explaining AMU and AMR (Farmers, veterinary services, livestock farms)- **Objective 2 and 3.**	**Livestock farmers (Chapter 6)** The attitude and knowledge of 19 livestock farmers' towards AMU and AMR were explored using semi-structured interviews. Four key themes were generated: 1) Uninformed use of antimicrobials and unaware of AMR, 2) Safeguarding livestock and generating income source as primary motivators for using antimicrobials 3) Medicine shortage results in hoarding and self-prescribing, and 4) Farm decisions on AMU and livestock management influenced by foreign farmers and veterinarians. Farmers were uninformed about antimicrobials and were unaware of AMR in livestock. The livestock farmers used medicines to protect their livestock, which was their primary source of income. Due to a lack of medicine, livestock farmers hoarded it and self-prescribed medicines, including antimicrobials. Foreign farmers and veterinarians were relied on by livestock farmers for information and guidance on livestock production, management, and medicine use. Livestock farmers had little faith in the local veterinarian's and para-veterinarian's knowledge and advice. **Veterinary services professionals (para-veterinarians and veterinarians) (Chapter 7)**

	The attitude, knowledge, and behaviour of ten veterinary professionals (eight para-veterinarians and two veterinarians) towards AMU and AMR were explored using semi-structured interviews. Three key themes were generated: 1) Antimicrobials prescribed based on availability rather than clinical need, 2) Para-veterinarians awareness and knowledge of AMR, and 3) Limited resources impede effective consultation and veterinary service delivery. AMU and AMR were not well understood by para-veterinarians. They prescribed and dispensed antimicrobials without being aware of the risks associated with inappropriate AMU. Para-veterinarians did not perform clinical examinations on the animals and made decisions about which antimicrobials to dispense from clinics based on farmers' perceived diagnoses. The general shortage of human resources, antimicrobials, and physical resources affected veterinary service delivery, where services to farmers' were delayed or not provided at all. **Cross-sectional survey** **Livestock farmers and farms (Chapter 8)** Socio-economic, demographic, livestock production and management information from 236 livestock farmers and managers with 276 livestock enterprises (beef n = 72, dairy n = 74, broiler n = 57 and layer n = 73) were evaluated. Farms that raised dairy cattle were more likely to use antibiotics and anthelmintics. Poultry enterprises were more likely to use antibiotics only. Farms that kept AMU records were more likely to use antibiotics. AMU in livestock farms was not influenced by the farmers' socio-economic and demographic characteristics but by livestock production and management factors such as enterprise type, farm management factors (records of AMU, use of medicated feed and feed supplements).

9.3 Contribution to knowledge

In developing countries, there is an increasing number of studies quantifying and exploring the drivers of AMU and AMR; however, very few studies have investigated AMU by different livestock production systems. Also, very few studies have explored the livestock farmers' and veterinary professionals' in-depth knowledge and understanding of AMU and AMR [12-20]. Recognising that data on drivers of AMU and AMR in developing countries context is limited [21,22]; therefore, this PhD thesis makes an important knowledge contributions on AMU and AMR in the Fijian livestock production systems context.

First record of AMU in Fijian cattle and poultry farm enterprises

The first contribution is the data on estimated quarterly and annual AMU in livestock farms by the enterprises and systems. Quantification of AMU requires a range of information, and the availability of useable and high-quality information in developing countries is challenging [23,24]. Notably, AMU records required for quantification is not maintained, especially in semi-commercial and backyard farming systems compared to commercial systems [25,26]. Therefore, using retrospective cross-sectional studies are less labour intensive and economical in collecting data for quantifying AMU [26-28].

Nonetheless, the outcomes from the cross-sectional survey (Chapter 4) demonstrated that AMU was considerably high in the backyard and semi-commercial systems and poultry enterprises. This may be due to a lack of access to veterinary services to obtain farm management advice and prescribing of antimicrobials by farmers themselves, as reported in chapters 5,6, 7 and 8. The findings in chapter 4 provide first time information on AMU in cattle herds and poultry flocks, respectively. Although data on AMU is becoming available in developed and developing countries [13,29], AMU quantification studies have not reported AMU in different farming systems, especially smallholder farms, which are predominant in developing countries such as Fiji [30-32]. Chapter 4 contributes to the existing literature on AMU by different enterprise types and systems. Considering the global intensification and commercialisation of livestock production [22,33,34], knowledge of AMU in different livestock production systems has become of greater importance.

Given that poultry and cattle production are becoming the major source of food of animal origins; therefore, information on AMU in poultry and cattle remains essential [35]. Although chapter 4 provides information on the AMU patterns in cattle and poultry sectors; however, comparison of AMU with other countries was not possible due to a lack of data. The backyard and semi-commercial farming systems are typical in developing countries; however, the AMU patterns in these transitional farms are limited [36-39]. Studies have been conducted in Asian and African developing countries [13,29]; however, there is limited focus on transitional farming systems (semi-commercial and backyard) where AMU is higher, as demonstrated by findings in chapter 4. Therefore, studies similar to the present study need to be prioritised in developing countries targeting semi-commercial and backyard systems. The findings of Chapter 4 have been published in a peer-reviewed journal that provides awareness on the patterns of AMU established using the AMU surveillance.

Innovative use of metrics to quantify AMU in livestock production systems

The second contribution is the innovative use of metrics to quantify AMU in Fijian livestock production systems (Chapter 4). Despite disparities in the different metrics, the globally used metric (mg/PCU) helped explain and compare the antibiotic use locally and globally [25,27,28,40]. Although there is no global golden standard metric fit for use globally, using a range of metrics allows better-evaluating patterns of use as different metrics provide insight using different parameters [25,27,28,40]. Therefore, using ESVAC and non-ESVAC or combining a range of metrics assists in establishing knowledge on AMU [25,27,28,40].

The AMU surveillance provides a snapshot of the current status of AMU and information is critically important for policymakers who can use the information to design programmes that may assist in targeting AMU reduction strategies [13,29]. Additionally, chapter 4 delivers a methodological framework that may be useful for quantifying AMU in resource-deprived developing countries like Fiji, where AMU status remains unquantified. Hence, chapter 4 addresses the knowledge gaps on AMU by providing data on AMU, which needs to be considered when developing AMS programmes in livestock production systems promoting prudent use of AMU.

First record of AMU practice in Fijian livestock production systems

The third main contribution is the comprehensive evaluation of the AMU practice in the Fijian livestock production systems (Chapter 5). AMU quantity provides insight into AMU patterns in different livestock production systems; however, it does not provide information on how these antimicrobials are used. Evaluation of AMU practice is critically important as it allows identification of more targeted areas of interventions that quantities may not portray [41,42]. Even though AMU under the supervision of veterinarians is advocated globally and self-prescribing is not recommended [46-48], such practices cannot be explained by patterns of AMU. Chapter 5 demonstrated a high prevalence of imprudent AMU practice in the backyard and semi-commercial farming systems and the dairy, layer, and beef enterprises compared to commercial broiler enterprises. Even though self-prescribing contributes to the growing risks to AMR in developing countries [20,43], veterinarians mainly prescribed antimicrobials in commercial broiler enterprises compared to para-veterinarians and self-prescribing by farmers in all other enterprises and systems.

The prophylactic use and use as growth promoters are prohibited [44,45]; however, chapter 5 demonstrated that antimicrobials were used prophylactically and for growth promotion. Hence, the novel finding of AMU practice demonstrated in Chapter 5 provides information that may assist in formulating a regulatory framework on the prohibition of AMU used prophylactically and used as growth promoters. Therefore, evaluating AMU practice in the local context is necessary to promote rational AMU in all livestock farms, including cattle and poultry.

Framework for categorisation of veterinary AMU in Fijian livestock farms

The fourth main contribution is the novel approach towards evaluating the AMU practice by categorising AMU into prudent and imprudent use using the framework developed. The information on the categorisation of AMU practices is limited in both developed and developing countries. Therefore, the framework developed using international standards and approaches similarly used in the human health sector allowed categorisation of AMU practice [45]. The results in Chapter 5 demonstrated the need for studies globally to understand AMU practices in livestock production systems. The findings in Chapter 5 make a stronger case for categorising AMU practice in resource-deprived countries like Fiji, where veterinarians' advice is limited to farmers [46-48], which was demonstrated by findings in chapter 6, 7 and 8. Chapter 5 further provides information on the prescribing patterns and clinical use of veterinary antimicrobials in Fijian livestock production systems using the framework developed.

The outcome of Chapter 5 provides policymakers and veterinarians with an indication of the areas that need intervention, which may improve rational prescribing and dispensing of antimicrobials for use in livestock production. The framework used in chapter 5 can also be replicated and used in other developing countries to evaluate AMU practice. The findings of Chapter 5 have been published in a peer-reviewed journal which provides the current status on the anthelmintic and antibiotic use practices in the Fijian livestock production system.

Knowledge and attitude of livestock farmers' and veterinary professionals' towards AMU and AMR

The fifth main contribution is, for the first time, an in-depth insight into the knowledge and attitude of Fijian livestock farmers' and veterinary professionals towards AMU and AMR was produced. The findings in chapter 6 demonstrated that farmers lacked knowledge and understanding of antimicrobials, use, and AMR associated with imprudent AMU. Additionally, the findings in Chapter 7 demonstrated that livestock officers who practised as para-veterinarians lacked knowledge and understanding of AMU and AMR. Farmers also hoarded and self—prescribed antimicrobials to protect their livestock from diseases and promote production, which provided an income source for their livelihoods. The veterinary service delivery was considered inadequate due to a lack of veterinary professionals and physical resources. Hence, the para-veterinarians prescribed and dispensed antimicrobials to farmers based on availability rather than clinical guidelines.

Based on unsatisfactory past experiences with veterinary services offered locally, farmers obtained farm management advice from social media, foreign farmers, veterinarians, and other farmers in social settings. For the first time, to our knowledge, first-hand information on the relationship between farmers and veterinary professionals in Fiji were explored, where knowledge and understanding of veterinary AMU and AMR in livestock production systems from farmers' and veterinary services professionals' perspectives were unknown. Both Chapter 6 and 7 provide much-needed information on the drivers of AMU and AMR; however, it further indicates that similar practices may be in other developing countries where lack of veterinarians [49,50] and farmers' lacking knowledge of AMU and AMR have been reported [43,51]. An increasing number of studies have focused on livestock farmers' attitudes and knowledge towards AMU and AMR [43,51]. Yet, very limited is known on the para-veterinarians knowledge and attitude towards AMU and AMR.

Additionally, in developed countries, veterinarians provide veterinary services to livestock farmers; however, in developing countries, para-veterinarians take the lead role in delivering veterinary services due to a lack of veterinarians [50]. Therefore, Chapter 7 provides essential information, particularly on the role of Fijian para-veterinarians' in veterinary services delivery and their knowledge and attitude towards AMU and AMR. The findings of Chapter 7 suggest the need for more studies exploring the attitude and knowledge of para-veterinarians towards AMU and AMR, especially in developing countries where para-veterinarians provide veterinary services.

Nonetheless, Chapter 6 and 7 make novel contributions on the drivers of AMU and AMR from farmers' and veterinary professionals' perspectives in the developing country context. Additionally, in my opinion, although Chapter 6 and 7 make important contributions on Fijian livestock farmers' and veterinary professionals' knowledge and attitude towards AMU and AMR, an understanding of drivers of AMU and AMR in all livestock farm enterprises apart from cattle and poultry should be considered an essential indicator as part of AMS programme. The findings of Chapter 6 have been published in a peer-reviewed academic journal and accepted for presentation at a conference to create awareness and provide insight into the current situation in Fiji. The findings of Chapter 7 have been submitted to a peer-reviewed academic journal.

Fijian livestock production and management

The sixth main contribution of this thesis to the literature is a description of Fijian livestock farms' socio-economic, demographic, livestock production, and management characteristics established using a hypothesised conceptual framework. The findings in Chapter 8 demonstrated that antibiotics and anthelmintics were more commonly used on dairy farms. Poultry farms were more likely to use only antibiotics, and antibiotics were more likely to be used on farms that kept AMU records. This was expected due to flock level administration being predominant in poultry enterprises and contracted farms' requirement to maintain AMU records [38].

AMU in livestock farms was not influenced by the farmer's socio-economic and demographic characteristics but by livestock production and management factors such as enterprise type and farm management factors (AMU records, medicated feed used and feed supplements). Although the study had fewer statistical findings due to lower statistical power, it provides valuable information on the livestock production systems. Chapter 8 also demonstrated that veterinarian and para-veterinarian farm visits were extremely low, which was expected as a lack of veterinarians had been reported earlier [52]. Therefore, Chapter 6, 7 and 8 provides information for policymakers to consider whilst designing policies that may ultimately enhance veterinary services to livestock farmers. It also provides information on self-prescribing practices, which may be presumably due to a lack of access to veterinarians. Chapter 8 adds knowledge on livestock production systems and shows the current livestock production and management practices used by Fijian livestock farmers and managers. The findings have been submitted to a peer-reviewed academic journal.

Using semi-structured interviews to generate in-depth knowledge on AMU and AMR

The seventh contribution is the method used to generate in-depth knowledge and understanding of AMU and AMR amongst the livestock farmers and veterinary professionals. Exploring and understanding drivers of AMU and AMR, particularly an in-depth understanding of the drivers from farmers' and veterinary services professionals' perspectives, is limited and also challenging [7]. Although many studies have used structured closed-ended scoring surveys to compare farmers' attitudes and knowledge on AMU and AMR; however, it does not provide flexibility in generating in-depth, rich accounts of lived experience, which helps to understand and explain the behaviour of farmers and veterinary professionals [8,9,53].

Additionally, knowledge and experience shared by the farmers and veterinary professionals do not provide the total reality of their AMU behaviour; therefore, in-depth exploration of attitude and knowledge is critically important to explain the drivers of the AMU and AMR approach [54-57]. Hence, more studies exploring the in-depth knowledge and understanding of livestock farmers and veterinary professionals are necessary to establish a broader understanding of the motivations of AMU in all contexts.

Use of theoretical and conceptual framework

The eighth contribution is the use of the theoretical and conceptual framework to collectively generate knowledge on AMU and drivers of AMU and AMR in Fijian livestock farms. The TPB as a theoretical framework has been used to explore and understand AMU behaviour in developed countries; however, minimal studies have used TPB in developing countries [53,58]. Although there are limitations in using TPB as a theoretical framework noting it does not account for the role of emotions and other actual behavioural controls such as environmental and socio-economic, and demographic factors [59-62], the use of TPB in chapter 6 and 7 provides in-depth knowledge on attitude and behaviour of livestock farmers and veterinary professionals respectively. The conceptual framework was developed and used to close the gaps in the TPB framework, which provides a better understanding of the characteristics of the Fijian livestock farms and farmers. Although AMR is a global issue, understanding the drivers from farmers, veterinary services, livestock production, and management is critically important as it aids in developing AMS programmes [1-3].

Additionally, limited studies, especially in developing country contexts, have used conceptual framework and TPB driven theoretical framework to quantify, evaluate and understand AMU and AMR. Therefore, on their own, conceptual, and theoretical frameworks are helpful but not comprehensive. However, together, they provide a comprehensive exploration of AMU and AMR.

9.4 Contribution to practice

The findings of this research programme may not represent the AMU behaviour and the knowledge and attitude towards the AMU and AMR at the whole country level. However, it provides AMU trends in cattle and poultry production systems. Also, it provides an in-depth insight into livestock farmers' and veterinary professionals' knowledge and attitude toward AMU and AMR. Therefore, it has notable implications for the country-level AMR and veterinary services policies.

The research programme demonstrated a general lack of knowledge on AMU and AMR amongst livestock farmers and para-veterinary professionals. The lack of access to veterinary services featured strongly in this programme of research; therefore, it is concluded that there were higher chances of imprudent AMU practices due to AMU without consulting the veterinary professionals. At the beginning of this research, several resources and policy gaps were identified [52]. This research programme demonstrated that transformation of and improvement of policies on AMU, AMR and veterinary services was necessary. Therefore, disseminating published articles to the policymakers resulted in the Fijian government recognising AMR in Fiji as an issue.

Additionally, the Fijian government recognised the gaps in veterinary services and legislation [63,64]. Therefore, the policies promoting improved veterinary services by increasing local capacity have been initiated by recruiting local veterinary graduates into the public sector to provide veterinary services to the farmers. Para-veterinarians' role in the Fijian livestock sector was unclear; however, the role of para-veterinarians in Fijian livestock has now been defined as a result of changes in the policies. Nevertheless, I recommend policymakers further engage with OIE to develop and adopt the competency guidelines for para-veterinarian professionals so that the remit of para-veterinary practices is clearly defined [50]. This programme of research has demonstrated that mixed method research assists in producing knowledge which can assist in improving veterinary clinical practice, ultimately contributing to mitigating the AMR at the country level. Nevertheless, more work is required to extend the AMR research at the country level with the engagement of other key stakeholders, detailed in the next section.

9.5 Recommendations

The following recommendations, divided into short, medium to long term, are suggested for implementation to improve the estimation of AMU, promote prudent use of antimicrobials, and curb the imprudent use in different enterprises and systems in Fiji and in other developing countries.

9.5.1 Short term

Training and awareness

Farm level

- Authorities could implement national awareness programmes on AMU and AMR in Fijian livestock production systems. Additionally, targeted training and awareness programmes should include farmers, veterinarians, para-veterinarians, pharmacists, and other stakeholders in the agri-food value chain to increase awareness of the antimicrobials, the prudent AMU, and associated risks with imprudent AMU. The programme of research demonstrates the higher AMU in semi-commercial and backyard livestock farmers (chapter 4) and higher imprudent AMU practice (chapter 5). Lack of knowledge and understanding of AMU and AMR (chapters 6 and 7) and AMU being more likely in dairy farms and antibiotic use in poultry farms was also demonstrated. Therefore, these national awareness programmes could target smallholder farmers and create awareness of prudent AMU practices in these smallholder cattle and poultry farms.

Additionally, general awareness of AMU and AMR in livestock production and its impact on human health could be the theme for country-level awareness; however, more specific sectoral level awareness tailor-made to the cattle and poultry sector could be implemented since livestock production and management of cattle and poultry differ. Therefore, I recommend adopting awareness programmes on AMU and AMR in the cattle and poultry sector and intertwining awareness of on-farm biosecurity practices so that livestock farmers are more aware of how and when to use different medicines, including antimicrobials, when managing their livestock.

- Authorities could target awareness programmes and improve by increasing the farm veterinarian and para-veterinarian farm visits to the backyard and semi-commercial farming systems where AMU is currently high and imprudently used. Moreover, system-based programmes could improve awareness of the prudent use of antimicrobials and associated risks. This could further enhance the farmers' confidence in the local veterinary service and enable farm practices in compliance with local policies.

  Developing and improving farmer and veterinarian relationships is paramount since veterinarians serve as knowledge hubs for livestock farmers. The government could allocate more funds to accommodate physical and human resources to improve farm visits. Farm visits may help develop the interrelationship and bonds, ultimately developing trust between farmers and veterinary professionals. Chapters 6 and 7 demonstrated a lack of confidence and trust, while chapters 5 and 8 demonstrated a lack of veterinary services. Therefore, improving farm veterinary extension services by increasing farm visits and sharing knowledge on livestock production and management could create awareness and a better understanding of the correct farm biosecurity risk management practices.

The veterinary extension services could focus on specific areas during farm visits where AMU and AMR information could be provided to farmers. Veterinary extension services could be educational as they could share information on new policies and farm practices, aligning and creating more consistent livestock management practices. Farm extension visits may also help veterinary professionals understand and report at the ministerial level on livestock farmers' challenges. Hence such information is critical and assists in developing new policies and assistance programmes at the country level. Additionally, these frequent acquaintances and communications could improve the working relationship between farmers and veterinary professionals in the agri-food value chain.

National level

- Authorities could consider establishing enterprise and sectoral level farmer associations similar to RUMA [65] so that farmer training and programmes could be efficiently implemented and followed up. Fiji has a national AMR working group focusing on country-level programmes at the country level. However, specific programmes targeting the livestock sector in general and more enterprise-level programmes are necessary due to vast differences in livestock production and management practices. These tailor-made enterprise-level programmes need to focus on specific topics such as training livestock farmers on AMU in livestock production, farm biosecurity risk management strategies which involve the use of medicines, feed, antiseptics, and other complementary medicines including antimicrobials, livestock health management, roles of local para-veterinarian and veterinarians in livestock production, farm record keeping, and prudent AMU practices. These trainings are critical and can be staged in phases all year round. Further, a follow-up programme could be implemented to allow refresher sessions for all livestock farmers. These programmes could be adopted as part of the national programme and conducted at the national level so that livestock farmers and other aspiring farmers, including the consumers and other stakeholders, are also targeted.

As part of this national AMS programme, pamphlets on these key areas in all local languages could be disseminated[66]. Additionally, a national campaign using local newspapers and television networks could be used to create impetus locally[66]. These programmes could also use social media platforms to actively target and engage the broader population so that essential information topics as part of the AMS programme could be disseminated in a timely manner as implemented in other developing countries[67]. Nevertheless, the national AMR working group should also consider incorporating awareness programmes in schools and universities similarly implemented in other countries to create awareness of AMR at all levels from earlier stages[68].

Additionally, the national awareness programmes could emphasise the need to prohibit antimicrobials used prophylactically and used as growth promoters. Subsequently, the authorities could consider implementing a national policy banning AMU for prophylactic use and growth promotion in the Fijian livestock sector, similarly implemented in other countries [69].

Organisational level

At the ministerial level, national training programme frameworks could be developed using the FAO and OIE farmer training and awareness guidelines. However, similarly to RUMA, the enterprise-level programmes could be tailor-made and implemented by the provincial livestock and production office farm extension services team. Farmers' associations could be one of the platforms used for conducting these training programmes. Programmes led by veterinary professionals at the provincial and district level would be appropriate so that correct, technically informed pieces of training are implemented in line with national policies. This provincial-level training is critically important as the association creates a platform for farmers to discuss their livestock production and management with veterinary professionals. An essential first step is to establish

provincial-level enterprise associations; however, where possible, the established provincial-level platforms could be used to target a wider audience.
The provincial level association established for training programmes for livestock farmers could be used for all additional pieces of training when needed. The livestock extension officers and veterinary professionals are based in all provinces. Therefore, they could actively participate in disseminating the training programmes so that the Ministry is not additionally burdened.

- Authorities could initiate training needs analysis as part of training and monitoring programmes so that training programmes could be improved as they are implemented. Training and awareness programmes on special topics such as managing farm biosecurity risks, the use of antimicrobials, vaccines, feed supplements, nutritional supplements, and other antimicrobial agents require a more collaborative approach with the local university where farm school programmes could be implemented so that the medicinal and non-medicinal products are used correctly. Awareness should be raised that the use of human medicines in animals is prohibited. Authorities should target improving awareness of the importance of maintaining farm records, AMU records, and managing farm biosecurity risks in these farm school programmes.

Establishment of Fijian national AMU and AMR surveillance programme

- There is no AMU surveillance framework in Fiji at the moment, and the framework used in this PhD chapter 4 was economical, simple, and robust. Therefore, I recommend policymakers consider adopting the quantification framework used in chapter 4 as the national AMU surveillance framework for quantifying AMU in farm enterprises. Additionally, I recommend that policymakers extend the surveillance by including other food and companion animals. The AMU survey could consider a random sampling method and expand the whole survey countrywide, including other islands apart from Viti Levu. Moreover, the national survey could include AMU sales data to compare local use with global reference, aligning with the OIE and ESVAC guidelines [10,28,70].

- The national survey could also consider incorporating all-year-round animal disease surveillance; so that animal disease patterns data could be accessible and available to understand the AMU practices.

- The authorities should further expand the national survey on establishing the national antimicrobial residue levels in food from animal origins and establish microbial resistance assay surveillance programmes to develop the antimicrobials resistance levels in livestock production systems and the agri-food value chain at large [71].

9.5.2 Medium to long term

Enhancement of current policies

- The transformation and modernisation of veterinary, medicinal products and food standards legal framework could be conducted to comply with the international standards advocated by the OIE, WHO, and FAO so that the legal classification of antimicrobials are clearly defined and categorised, the prescribing and dispensing of the antimicrobials are clearly outlined and aligned with international standards [46,72]. It is also essential to clearly outline the scope of practice of para-veterinarians, veterinarians, pharmacists, and other suitably qualified personnel in the legal framework.

- The national procurement and supply chain of antimicrobials could be reviewed, and a more sustainable supply chain of antimicrobials should be adopted to curb the antimicrobial hoarding by farmers and curd the self-prescribing of antimicrobials by farmers. Additionally, the authorities could consider subsidising the cost of antimicrobials. The cost barrier is addressed, and fair and easier access to antimicrobial is locally but only on the prescription of an authorised prescriber.

Veterinary services enhancements

Veterinary services at the national level

- A national veterinary medicines directorate similar to VMD[71] and EMA[28] could be established to oversee the conduct of AMU and AMR surveillance programmes and collect livestock parameters to develop the national defined daily doses and course doses by different enterprises.

Additionally, the veterinary medicines directorate should consider publishing and updating the livestock sector on the veterinary market authorisation and subsequently articulate policies on prescribing, dispensing, and using antimicrobials in food animals. The access and dispensing of antibiotics should be only on veterinarians' prescription, and non-veterinarians should not be permitted to prescribe antibiotics. Furthermore, the directorate should consider establishing enterprise-specific guidelines on using antimicrobials in target species, cascade use of antibiotics, AMU record-keeping and enterprise-specific awareness of prudent use of antimicrobials in the agri-food value chain. Additionally, the national veterinary medicines directorate could establish an audit process so that all organisational, systems and policy changes implemented could be audited to track the progress. Also, lessons learnt from the audit process could be used to improve and mitigate gaps in the implemented policies.

- National and sectoral level policies should promote the training of local veterinarians and para-veterinarians aligned to critical competencies stipulated in the OIE framework so that the veterinary professionals are up to date with the current knowledge and international practices. Additionally, OIE provides technical assistance to improve the performance of veterinary services. Hence, the Fijian government could seek technical assistance from the OIE on improving veterinary frameworks and aligning to international standards. The veterinary governing authority needs to develop legislation on the code of conduct of para-veterinarians so that continuous training and development programmes are in place for the para-veterinarians to upskill themselves as part of continuing professional development. Professionalising the para-veterinarian role improves the overall para-veterinarian practice; hence, helping mitigate risks of incorrect diagnosis and imprudent prescribing and using of antimicrobials in fields.

Local veterinary capacity

- Authorities could allocate more resources and funding to recruit more veterinarians and improve veterinary services infrastructure so that all livestock farmers have access to veterinarians and antibiotics are only prescribed by veterinarians. Additionally, authorities should establish a national training framework for para-veterinarians so that they acquire the necessary skills to deliver informed veterinary extension advice to farmers and assist the veterinarians in addressing the current void due to the lack of veterinarians. I recommend that the terms of reference for veterinary and para-veterinary practice be developed. Additionally, livestock farmers and veterinary professionals need to be informed on the scope of practice so that veterinary professionals can provide services without fear and intimidation and only practice and make farm decisions which are technically and scientifically informed.

Veterinary resources

- Authorities could allocate larger budgets so that necessary veterinary consumables and resources required for executing veterinary services are available to veterinary professionals. Chapter 7 demonstrates the use of antimicrobials, although when antimicrobials and other treatment options are appropriate, equipping the veterinary professionals with medicines, physical resources and appropriate training needs to be prioritised so that medicines, including antimicrobials, are used prudently.
- Lastly, the authorities could establish and adopt one health framework so that expertise from the animal and human health sector could collaborate to efficiently deliver AMS programmes and provide the expertise that may be scarce, especially in resource scare developing countries like Fiji. Chapter 7 demonstrated the unsustainable supply of veterinary medicines in veterinary clinics; therefore, pharmacists' expertise could be better utilised by involving pharmacists in the medicine supply chain management, forecasting and procurement so that risks of imprudent AMU could be mitigated by improving the medicine supply chain. This would ultimately improve access to antimicrobials and promote prudent AMU practices in livestock farms by farmers and veterinary professionals.

9.6 Methodological rigour

Mixed methods research includes data collection, analysis, and interpretation of the quantitative and qualitative studies within a study [55,73]. This PhD thesis used a mixed-methods approach using a cross-sectional survey (quantitative) and semi-structured interviews (qualitative). The quantitative studies (Chapter 4,5 and 8) were conceptually driven, whilst the qualitative studies (Chapter 6 and 7) were theoretically driven. In the context of this PhD thesis, quantification of antimicrobials in beef, dairy, broiler, and layer provides the pattern of AMU. However, the quantities of antimicrobials do not provide information on the motivation for AMU. Therefore, incorporating qualitative methods provides insight into the drivers of AMU and allows an understanding of the reasons behind the patterns of AMU.

This PhD thesis used methodological triangulation [55,73,74], where quantitative methods were used to measure (Chapter 4) and evaluate (Chapter 5) whilst the qualitative methods were used to explain (Chapter 6, 7 and 8) the psychological and contextual drivers of AMU and AMR in Fijian livestock production systems. Either method has limitations; however, combining methods allows the establishment of evidence that enables a better understanding of a phenomenon compared to standalone approaches [55,73,75]. Data from both strands were separately analysed and reported as chapters/papers; however, the summary of findings was presented addressing the research questions in this current discussion chapter.

Both quantitative and qualitative studies provided findings that helped evaluate and explain AMU; hence, both quantitative and qualitative approaches were given equal priority [55,73]. The criteria for rigour in quantitative research include validity, reliability, replicability, and generalizability [79,82,83]; however, in qualitative research, assessing rigour includes credibility, transferability, dependability, and confirmability, which are often considered the 'gold standard' [55,76,77]. Additionally, reflexivity was also included because it was used as a key part of the thematic analysis [78,79]. There is a difference in the criteria for establishing rigour in both approaches and limited literature outlining the criteria for rigour in mixed methods research. Most mixed-methods studies have used criteria applicable to the quantitative and qualitative methods separately, and in this thesis, this precedent was followed [77].

Quantitative

The research team met and appraised the methodology to ensure the researcher followed methods rigorously from start to completion. Due to the limitations (summarised below section 9.6), random sampling was not possible; therefore, data transformation (logarithmic) was done to obtain normally distributed data for analyses to be performed for statistical significance and for generalisation in local context. The survey was piloted with participants; however, due to the nature of the survey that is being designed based on the hypothesised conceptual framework, the validity and reliability of the survey could not be established. Yet, the empirical survey assisted in collecting the required data to answer the research questions. The purposive and snowball sampling methods were used to recruit a representative sample geographically distributed across Viti Levu, Fiji.

The findings may not be generalisable due to many factors which affect the quantification of AMU; however, it provides the pattern of use where intervention could be made. The methodology for quantitative studies (Chapter 4, 5 and 8) was presented in each chapter, which could be easily replicated in other settings; however, the results could not be generalised and applicable to all settings due to livestock production and management factors significantly differ in different jurisdictions.

Qualitative

The credibility criteria used in qualitative research help researchers demonstrate confidence in the results where research findings are accurate, believable, and obtained from the transcripts in which participants' experience and insights were accounted. In this PhD thesis, the farmers were interviewed to explore their knowledge and understanding of AMU and AMR; however, the para-veterinarians and veterinarians were also interviewed to establish credibility in either study's findings. The quotes were included in Chapter 6 and 7 to establish credibility. The methodology of Chapter 6 and 7, which was based on TPB as a theoretical framework, informed the design of the study, including the development of interview guides, sampling methods, recruitment criteria, data management and analysis method, except for coding example and all key research tools essential in assisting research findings applicable and transferable to other settings were reported in Chapter 6 and 7 and in appendices. The research team continuously discussed the coding and themes to maintain dependability and conformability. Since the subject area was animal-related but cross-cutting interdisciplinary, the entire analyses and drafting process was iterative to ensure clarity and consistency.

Both inductive (reflexive thematic analysis) and theoretical coding (TPB framework) were used to compare the findings using both approaches. Reflexive thematic analysis provides more flexibility whilst the deductive approach is more constrained; however, both approaches assisted in establishing similar themes. The reflexivity criteria account for the researchers' experience in the areas of research that are subjective [78,79]. In this PhD thesis, I acknowledged my professional knowledge and expertise in pharmacy, agrosecurity, food security, and one health, which assisted in constructing and interpreting the participants' experience.

9.7 Summary of thesis limitations

The PhD journey is a learning process with many constraints (time, finances, and covid-19 pandemic), leading to data limitations. Therefore, the results of this thesis should be carefully interpreted, considering the limitations. The major limitation identified at the conception of the studies was the availability of information on livestock performance data, animal census data and information required to develop the study protocols, including random sampling methods. The other major limitation was the unequal representation by farming systems and livestock enterprises. Limited broiler and commercial enterprises could be identified and contacted to participate in the survey.

Additionally, the semi-commercial farmers' operations are transitional in nature, where they raise livestock for sale and domestic use. Moreover, some farmers classified themselves as semi-commercial; however, they were transitional; therefore, future studies should include specific inclusion criteria to classify farming systems appropriately. The other major limitation was access to farm records and AMU records. The records were accessed where available; however, in instances where farmers had no records, the farmers provided verbal recollections of events in the past three months. Therefore, there is a likelihood of farmers incorrectly estimating the AMU. Therefore, care must be taken when interpreting the results.

Another major limitation was that farmers provided the indications they had used antimicrobials for; however, the actual illness/disease being treated was unknown. The interpretation was based on the research teams' understanding and evaluation of the purpose of use. The practicality of categorisation and use of the decision-making framework for categorising antimicrobials into prudent and imprudent use may have limitations noting the AMU practise is different between the developed and developing countries; therefore, the use of the framework and its applicability may not be appropriate but, establishing knowledge and building a foundation provides guidance where methods could be improved based on the findings of this PhD thesis. Reflexive thematic analysis has its own bias because the researcher is the instrument where the experiences and knowledge of the researcher can influence the interpretation and construction of themes from the transcripts of the semi-structured interviews.

The use of purposive and snowball sampling may lead to some biases. However, to address bias and independence, the interview transcripts were analysed and reported separately for livestock farmers and veterinary service professionals. Additionally, the approach gave equal priority to livestock farmers' and veterinary professionals' so that in-depth accounts of lived experiences of farmers and veterinary professionals towards AMU and AMR could be explored. Also, in each study, theoretically driven (TPB) deductive analysis and inductive reflexive thematic analysis was used to allow flexibility in unpacking rich information, which helped formulate the studies' findings. Additionally, using both (inductive and deductive) allowed us to explore further any key findings that may be left out using either approach on its own. Due to time constraints, the interviews were conducted and analysed later; however, future studies should consider analysing transcripts as interviews progress.

In chapter 8, the major limitation was the sample size which compromised the power of the study and statistical analysis. Therefore, future quantitative studies need to consider probability-based sampling and equal representation for more robust analysis across all enterprises and systems. Lastly, the researcher is not a veterinarian by profession, so interpretation specific veterinary technical constructs were discussed amongst the research team, which included pharmacists, animal scientists, and veterinarians. All studies were scrutinised by all members of the research team.

Additionally, the gender-based analysis was not conducted because most participants were heads of households who presumably make decisions at the household level despite the actual farm management involving other family members[80,81]. Therefore, future studies should consider recruiting participants who are directly involved in the management of the farm.

In summary, the key lesson learnt from the current PhD thesis was that attention should be given to time, and narrower scoped studies should be conceived so that necessary data to address the study objectives can be collected, analysed, and disseminated to the audience in the local context.

9.8 Future research perspectives

This PhD thesis provides invaluable information and conceptual and theoretical frameworks that could be used for future studies. Future studies can consider evaluating and explaining AMU focusing on:

- *How do experience and inherited cultural knowledge influence the AMU behaviour and adaptation of AMS programmes by livestock farmers?* Cultural knowledge acquired and experience is believed to influence attitude and knowledge [82,83]; however, there is very limited information on how culturally acquired knowledge influences AMU behaviour and also adapting the AMS programmes. Therefore, exploring the cultural knowledge would provide information that may be very useful to understand and measure the success of the AMS programmes as current programmes do not consider cultural constructs. In-depth ethnographic research with livestock farmers from diverse cultural backgrounds would provide valuable information.

- *What are the roles of pharmacists and other public and private sector key stakeholders in the agri-food value chain towards AMU and AMR?* International organisations promote adopting a one health approach towards addressing the growing risks of AMR. Pharmacists are perceived as experts in medicine use and safety [84]; however, their role in the veterinary AMU and AMR in the agri-food value chain is unknown. Little work has been done in this area; therefore, future research needs to understand their attitude and knowledge. Similarly, the other stakeholders in agri-food value chains such as feed suppliers, veterinary medicine suppliers, farm gate agents, abattoir and other stakeholders within the food value chain need to be included, and their knowledge and attitude need to be explored to understand how risks of AMR can be mitigated along the food chain. For instance, establishing antimicrobial residue levels may be a national priority; however, a lack of insight into the stakeholders' knowledge on AMU and AMR may have an impact on the residue level policy implementation. Therefore, future research needs to consider all stakeholders to understand the situation better so that AMS programmes can be successfully implemented to promote prudent AMU practices.

- *How much antimicrobials are used yearly in different livestock production systems?* Longitudinal AMU surveys could capture the AMU across all weather seasons and other burdens of diseases over the year to quantify AMU in various livestock enterprises and systems, including enterprises that were not in the scope of this PhD thesis [26,85-88]. The findings presented in this PhD thesis were from a cross-sectional survey over three months; however, the yearlong survey will provide a better estimation of AMU across livestock production systems. The ESVAC guidelines suggested random sampling to improve the power of the study [70,89]; therefore, probability-based sampling should be considered in future longitudinal studies. However, a cross-sectional survey is also suggested in enterprises where antimicrobials remain unquantified, while the longitudinal survey would be conducted in enterprises that were investigated in this PhD thesis. Additionally, the surveys need to consider incorporating the quantification parameters such as population at risk, which should consider incorporating traded animal population, live weight of animals at breeding stages for better estimation of the population at risk and consider all animals at different breeding stages. Differences between systems and enterprises could be compared with mg/PCU metrics, including other metrics where feasible.

- *Is there a relationship between farm outputs in enterprises that use antimicrobials prophylactically and for growth promotion compared to enterprises that used no antimicrobials?* A randomly sampled study exploring the relationship would provide an insight into the effects on the outputs in farms with different administration purposes. Previous studies have highlighted the use of antimicrobials for growth promotion and prophylactic use; however, there is a current knowledge gap on the effects of use on growth promotion, especially when most countries, excluding the EU and UK [44,45];, have still not banned the use of antimicrobials for growth promotion [13,90]. The findings may help raise impetus on international organisations advocating for a global ban on the use of antimicrobials for growth promotion. The study could further investigate the residue levels in animal products from farms that use antimicrobials prophylactically and for growth promotion compared to farms that use therapeutically or do not use antimicrobials.

- Lastly, expanding the study in Chapter 8, enterprise modelling could include a randomly sampled study that investigates the farmers' socio-economic, demographic, and enterprise production and management affects AMU and misuse in livestock production systems. Further investigation would be greatly beneficial as it will provide information that will streamline the targeted areas on intervention. The framework of study in Chapter 8 provides an empirical, conceptual framework that may help evaluate and understand AMU drivers in a bigger sample of farmers than semi-structured interviews with limitations of their own. Development and incorporation of the biosecurity framework into the study used in other studies may also help understand and narrow down areas for intervention.

9.9 Conclusions

This PhD thesis shows AMU is high in smallholder farms, i.e., backyard and semi-commercial dairy, beef, and layer enterprises in Fiji. The farmers and para-veterinarians lacked knowledge and awareness of AMU and AMR, which may have contributed to the inappropriate AMU. Therefore, evaluating AMU and explaining AMU and AMR in different enterprises and systems in the agri-food value chain is critically important, noting AMR's global risks to humans and livestock. Exploring and understanding psychological and contextual drivers of AMU apart from patterns of AMU helped identify targeted intervention areas to promote prudent use of antimicrobials. AMS programmes promoting one health approach towards AMU surveillance and training and awareness on AMU and AMR targeted at a local enterprise and systems-level is recommended. Improved veterinary infrastructure and veterinary legislative framework are required to strengthen veterinary service advisory and AMS programmes to reduce the AMU and promote prudent use of antimicrobial locally.

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Appendices

Appendix A

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PARTICIPANT INFORMATION SHEET

Study Title: Qualitative and Quantitative Survey of Antimicrobial Usage in Livestock Sectors of Fiji

Please read the information below before you decide

You are being invited to take part in a research study. I will provide you with the following information to help you understand why the research is being carried out and what it involves. Please take time to read the following information carefully before making your decision. Ask for any clarifications or for more information.

What is the purpose of the study?

This is a PhD study registered at University of Reading, School of Agriculture, and Policy & Development. The aim of this study is to quantify and understand the antimicrobial usage in the livestock sector of Fiji.

Livestock sector contributes significantly to agricultural sector, and it is important to note the direct relation it has with the livelihoods of Fijians. Livestock production has been part of our life and we continue to face all visible global threats but there are other invisible threats which are becoming a major problem globally. A small tropical country like Fiji is equally vulnerable to the growing threats which is faced by other developed nations. Antimicrobials (also known as antibiotics) have been used in both the livestock sector and the human health sector. There is evidence suggesting the use has increased significantly in the past decade and this has caused a problem called ‘resistance’. This means that the bacteria that cause infection do not respond anymore to antibiotics.

Antibiotic resistance is a big problem for people and livestock across the whole world because without effective antibiotics, we cannot treat either livestock or people when they become sick. Fijis is a developing South Pacific tropical country with a thriving agricultural sector thus safeguarding this sector is vital for social and economic security and prosperity. To safeguard our food source and livelihood we need to understand the risks of antibiotic resistance to Fijians and the livestock sector of Fiji as we are not aware of the extent to which antibiotics are used in Fiji in the livestock sector. Hence the purpose of the study is to quantify, explore and understand the antimicrobial usage in the livestock sector of Fiji.

Why have I been chosen?

You are chosen because you keep livestock (cattle or poultry), which was the main selection criterion for this study.

If you wish to participate in this study, please contact Xavier Khan, PhD Researcher via email x.r.s.khan@pgr.reading.ac.uk or contact on mobile number +679 9233677 or +679 7233677

Do I have to take part?

No. it is up to you to decide whether to take part. Participation is entirely voluntary, and you are free to withdraw from the survey at any time you feel uncomfortable or unwilling to participate, and you do not have to specify a reason. If you wish to withdraw, please contact Xavier Khan (details above).

What do I have to do if I take part?

Participant information sheet v5 20/05/2019

This study includes an interview. For this interview, I will visit your farm or residence and will ask questions for no more than 30 min. The interview will be discontinued as soon as you express your unwillingness to continue. With your consent, the interview will be recorded and transcribed.

What are any possible disadvantages and risks of taking part?
This study is designed with minimal potential risks to all participants. The PhD researcher will avoid asking any sensitive questions. You have the right not to answer every question. Please be advised that the researcher will maintain the confidentiality of the data. It will take time out of your day, but every effort will be made to minimise any inconvenience and to ensure your comfort in the interview process.
Many people value the opportunity to talk about their experience and provide valuable information which may be helpful to everyone. It will be possible to take a break or stop at any point during the interview. If at the end of the interview it has brought to attention your willingness to participate further in qualitative study, with your consent it will be further discussed.

What are the possible benefits of taking part?
Although this research may seem to not directly benefit you, it does affect every Fijian indirectly. Your invaluable experience and expertise in this area enables you to take this opportunity to talk about your experience and express opinions on a variety of subjects to an interested, non-judgemental listener (the researcher).

What will happen if I do not want to carry on with the study?
If you agree to be interviewed, you can withdraw at any time during or after the interview. However, we would ask to be able to use all data collected up to the point of your withdrawal which would be kept subject to confidentiality procedures.

Complaints
We do not anticipate any problems arising during this study. If you do have a concern, however about any aspect of this study or the conduct of the researcher, please feel free to contact my research supervisor. (See contact details above)

Will my taking part in this study be kept confidential?
All information which is collected from the study will be kept strictly confidential. Every step will be also taken to assure your anonymity. However, in reporting the data we would like permission to refer to your age and gender which will be used for statistical analysis.
The data will be anonymized by using codes and any quotes used in the research (such as in the PhD thesis, publications, presentations at conferences or seminars) will use non-identifiable codes rather than the participant's details.

What will happen to the data?
The data recorded from the interview will be analysed and used in a thesis to be submitted by the PhD researcher. The results will be used in publications, presentations at conferences or seminars. All data I collect will be stored securely electronically on a password-protected computer or in hard copy version in a locked cupboard. Data collected will be managed and maintained in accordance with guidelines of Data Protection Policy of the University of Reading and the General Data Protection Regulation (GDPR) of the UK. The data will be destroyed upon fulfilment of all requirements of completion of the PhD Studies.

What will happen to the results of the research study?
The results of the research study will be written up and form the basis of my PhD thesis. Part of the study may also be submitted for publication. An additional short report of the research findings will be provided for distribution to the participants and Fijian Government.

Who is organizing and funding the research?
The research is a PhD project registered with University of Reading.

Participant information sheet v5 20/05/2019

Who has reviewed the study?
The research was reviewed by the University of Reading School of Agriculture Policy and Development Ethics Committee and ethical clearance was granted with reference number 00772P.

Consent Statement
By participating in this interview, you are acknowledging that you understand the terms and conditions of participation in this study and that you consent to these terms.

Where can I get more information?
If you would like to take part in the study or if you have any questions, please do contact using contact details as above.

Thank you for your time to read this information sheet and participate in this survey.

Participant information sheet v5 20/05/2019

Appendix B

Survey questionnaire V11 26/06/2019

Survey Questionnaire for Data Collection on Antimicrobial Use in Farms Questionnaire No. _______ Date of Survey: __/__/____ Version *11 _260619*

Section 1: General Information about the Farm, Farmer, and Farm Manager (Circle or fill in blanks where appropriate)

1.1 **District**: ________________________ 1.2 **Division**: ________________________ 1.3 **Province**________________________________

1.4 **Age Group of Farmer** (*where applicable*): 10-19yrs 20-39yrs 40-59yrs over 60yrs Prefer not to comment

1.5 **Gender**: Male Female Prefer not to comment

1.6 **Level of Education** (*where applicable*): Primary Secondary Tertiary Agricultural College Never attended Prefer not to comment

1.7 **Ethnicity**: Itaukei Indo-Fijian Rotuman Chinese Others Prefer not to comment

1.8 **Household income from farming**: <=25% 25-50% 51-75% v >=76% Prefer not to comment

1.9 **Household income greater than USD$8820(FJD$18,768.96 GDP per capita)**: Yes, No Not sure Prefer not to comment

1.10 **Animals raised:** Beef Dairy Mixed (Dairy & Beef) Poultry (Layer Birds) Poultry Meat Birds (Mixed (Layer & Meat)

1.11 **Size of Farm**: <1ha 1-3ha 3-5ha 5-10ha 10-20ha 20-50ha 50-100ha >100ha (*NB: 1 ha= 2.471acres) or* _______ acres

1.12 **Farm Tenure**: Freehold Crown Lease Agricultural Leased TLTB lease Mataqali Squatter Commercial Lease Prefer not to comment

1.13 **Farm Type**: Backyard Semi Commercial Commercial Not sure Prefer not to comment

1.14 **Type of Production:** Organic Conventional Not sure Prefer not to comment

1.15 **Farm Ownership**: Individual Household Company Cooperative Contract Farming Prefer not to comment

1.16 **Number of years Farm in operations**: ______ years Prefer not to comment

1.17 **Number of farm workers employed**: _____ employees Prefer not to comment

1.18 **Type of Farming**: Livestock Mixed (crop & livestock) Prefer not to comment

1.19 **Farm Association Memberships**: Yes, No Prefer not to comment , List : ____

1.20 **Veterinarian/ Para-veterinarian farm visits per year**: _________ Not sure Prefer not to comment

1.21 **Farm Fencing**: Yes, No Prefer not to comment

1.22 **Animal Housing**: Yes No Prefer not to comment Not applicable, List: ____________________________________

1.23 **Grazing method used:** Open grazing Rotational Grazing Not sure Prefer not to comment Not applicable

1.24 **Birds raised:** Cages (layers) Sheds (broiler) Free Range Not sure Prefer not to comment Not applicable

1.25 **Feed milling facility**: Yes No Prefer not to comment Not applicable

1.26 Does your farm keep a record of all the animals you farm? Yes, No Prefer not to comment

1.27 Does your farm keep antimicrobial use records? Yes No Prefer not to comment (***Refer appendix 1 to record information***)

(NB: if you select YES, list all antimicrobials used in the last three calendar months and if you select NO, list all antimicrobials used in last three calendar months that you can recall)

Section 2: Information about Farm Population and Production (Information Source: Farm Records Verbal Recall Records for last 3 calendar months)

2.1 Cattle Farm: Beef

Population (no.)			Average Weight (kg)			Total Beef Production (kg)		Slaughtering				Breed / No. or %	No. Animals dead		
								No. on Farm slaughter		No. sold for slaughtering					
Fattening Cattle	Breeding Cattle	Calves	Fattening Cattle	Breeding Cattle	Calves	Monthly (kg)	Yearly (kg)	Fattening Cattle	Breeding Cattle	Fattening Cattle	Breeding Cattle	1………………………/…………… 2………………………/…………… 3………………………/…………… 4………………………/……………	Fattening cattle	Breeding cattle	Calves

2.2 Cattle Farm: Dairy

Population (no.)				Average Weight (kg)				Total Milk Production (Litres)		Slaughtering						Breed/No. or %	No Animals dead			
										No. on farm slaughter			No. sold for slaughtering							
Lactating Cow	Dry Cow	Heifers	Calves	Lactating Cow	Dry Cow	Heifers	Calves	Monthly (Litres)	Yearly (Litres)	Lactating Cow	Dry Cow	Heifers	Lactating Cow	Dry Cow	Heifers	1………………………/………… 2………………………/………… 3………………………/………… 4………………………/…………	Lactating Cow	Dry Cow	Heifers	Calves

2.3 Poultry Farm – Laying Birds

Population (no.)		Average Weight (kg)		Total Egg Production		Average No. Laying Cycle (weeks)	Average No. birds per laying cycle	Slaughtering				Breed/ No. or %	No. Birds dead	
								No. on farm slaughter		No. sold for slaughtering				
Breeding Birds	Layer Birds	Breeding Birds	Layer Birds	Production Monthly(no.)	Production Yearly(no)	Layer Birds		Breeding Birds	Layer Birds	Breeding Birds	Layer Birds	1…………………/………….. 2…………………/………… 3…………………/………… 4…………………/…………	Breeding birds	Layers birds

2.4 Poultry Farm – Broiler (Meat)

Population (no.)		Average Weight (kg)		Meat Production		No. of Production cycles	Production cycle (weeks)	Average no. birds per production cycle	Slaughtering				Breed / No. or %	No. Birds dead	
Breeding Birds	Meat Birds	Breeding Birds	Meat Birds	Monthly (kg)	Yearly (kg)	Meat Birds	Meat Birds		No. on farm slaughter		No. sold for slaughtering		1…………………/………….. 2…………………/………… 3…………………/………… 4…………………/…………	Breeding birds	Meat Birds
									Breeding Birds	Meat Birds	Breeding Birds	Meat Birds			

Section 3 – Information on Other Medicines Usage and Feed Information

3.1. List all other medicines or supplements administered at the farms. Indicate the purpose if possible *(NB Use extra sheets to where possible)*

Name of medicine/ supplements	Animals Medicine / supplements Administered	Purpose

3.2 Does your farm use medicated feed? Yes No Not sure Prefer not to Comment (list below)

Name of Feed	Packsize (kg)	Species Used	Number of animals fed daily	Average amount administered daily (weight in kg)	Source

Survey questionnaire V11 26/06/2019

Appendix 1 – Information on Antimicrobial Use *(NB: Use additional sheets to record data when needed)* **Source: Farm Records Verbal Recall Records for last 3 calendar months**

Guide for completing table
Type of animals: *(Calves < 12 months, Cattle > 12 months), Calves, Breeding Cattle, Fattening Cattle, Lactating Cows, Dry Cows, Heifers, Breeding Birds, Laying Birds, Meat Birds*
Dosage form: *Bolus (BOLUS), T- Topical, ORAL SOLU-Oral Solution, INJ- Injection, INTRAMAM- Intramammary, INTRAMAM-DC- Intramammary Dry Cow, INTRAUT- Intrauterine , ORAL PWD- Powder in feed, PREMIX-premix(medicated feed), TABL- Capsules or Tablets-, others*
Volume/Amount: *ML or Litre for liquid preparations/ Amount – number of tablets or capsules, mg, or grams for powdered preparation*
Prescriber *–Veterinarian, Para veterinarians, Self-prescribed, Pharmacist, Other farmers*
Source *– P- prescription, OTC- over the counter, Veterinarian supplied, Para veterinarian supplied, Other farmers, Farm cabinet, Online pharmacy*, Other sources
Pack size and Strength *– whichever is available*

Date	Name of Antimicrobial	Type of Animal	Dosage form	Strength	Packsize	Volume /Amount	Duration	Purpose	Number of animals administered	Prescriber	Source

(NB. Extra Sheets to be included where necessary and sheets can be used to record other information or observations as necessary)

----------End of Survey-------
