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POTENTIAL TRANSMISSION OF ZOONOSES BETWEEN THE HUMAN-DOMESTIC-WILDLIFE INTERFACE AND ITS IMPLICATION FOR SUSTAINABLE HEALTH

BY

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DECLARATION

I, Linda Ama Owusuaa Amoah, declare that except for references to other works which have been duly acknowledged, this work was carried out by me under the supervision of Prof. Langbong Bimi, Dr Benjamin Ofori-Yeboah and Prof. Eric Sampane-Donkor. I further declare that, as far as I am aware, this work has not been presented in part or in full anywhere for a degree or certificate.

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ABSTRACT

Zoonoses have been of great public health concern and a global phenomenon that continues to challenge both veterinary and human health systems. The risk of zoonoses is predicted to be higher in domestic settings where animals are constantly in close contact with humans and exposure to zoonotic pathogens is very high. In Ghana, some studies to identify zoonotic diseases transmitted by domestic animals or animals in the wild usually consider either the human-domestic interface or human-wildlife interface. Considering that in recent times diseases continue to emerge from unexpected reservoir hosts and through novel pathways, this study investigated zoonotic diseases that are potentially transmissible by domestic and wild animals to humans across the human-domestic-wildlife interface. It also assessed the awareness and knowledge of owners of companion animals on zoonoses in two human-dominated landscapes. The cross-sectional study involved fieldwork and laboratory processing of biological samples from dogs, cats, and rodents using molecular techniques. Specifically, Polymerase Chain Reaction (PCR) and gel electrophoresis were used to investigate the presence or absence of zoonotic pathogens in biological samples. In addition, questionnaires were administered to owners of companion animals in households and veterinary institutions in designated study areas. Secondary data on zoonotic diseases presented at selected health facilities were also accessed and evaluated to complement the field data. Overall, 404 animals comprising 185(45.8%) dogs, 15(3.7%) cats and 204 (50.5%) rodents were sampled from households, veterinary institutions and selected study sites. In all, seven (7) species of rodents were trapped with *Arvicanthis niloticus* and *Praomys tullbergi* identified as the dominant species in the urban and peri-urban areas, respectively. The prevalence of *Babesia* spp. was the highest (80.7%), followed by *Staphylococcus* spp. (72.5%) and the least was *Ancylostoma* spp. (18.1%). For zoonotic helminths (*Toxocara canis*, *Strongyloides stercoralis* and *Ancylostoma* spp.), a prevalence of 30.12% was recorded. The study found significant differences in the prevalence of *T.*

canis ($p<0.001$), *S. stercoralis* ($p=0.033$), and *Salmonella* spp. ($p<0.001$), *Staphylococcus* spp. ($p=0.017$) and *Babesia* spp. ($p=0.029$) between the two human-dominated landscapes. Similarly, there were significant differences in the prevalence of *T. canis* ($p=0.034$), *S. stercoralis* ($p<0.001$) and *Babesia* spp. ($p<0.001$) between the households and veterinary institutions as well as among sampled animals ($p<0.05$). On the whole, 13.9% of sampled animals had a single or mono-zoonotic infection, while 80.9% were co-infected with multiple zoonotic pathogens. Additionally, medical records from Shai-Osudoku and Pentecost Hospitals revealed that helminth infections were the commonest zoonoses presented by clients, particularly those under 18 years old. Conversely, staphylococcal infections were the highest zoonotic infections reported by clients of the University of Ghana Hospital. Again, 33.8% of 230 respondents who participated in the survey owned companion animals for companionship or as part of the family. Remarkably, 38.9% of the respondents had never dewormed their companion animals. While 62% of respondents had vaccinated their animals, 10.1% did it over a year ago, implying that about 48.1% of these animals were at risk of infectious diseases and could transmit the same to their owners. Furthermore, significant positive associations were found between the educational level of respondents and the frequency of vaccinating pets ($r_s=0.254$, $p<0.001$) as well as respondents' knowledge of causes or sources of zoonoses ($r_s=0.141$, $p=0.049$). On the contrary, there was a significant negative association between the frequency of deworming pets and the main reason for keeping such animals ($r_s=-0.203$, $p=0.011$) besides the prevention of zoonoses ($r_s=-0.260$, $p=0.001$). Findings from this study indicate companion animals and rodents are reservoir hosts to zoonotic pathogens of public health importance that can potentially be transmissible to their owners and the community. Also, because these animals are co-infected with multiple zoonotic pathogens, it suggests there could be serious implications for sustainable health, which SDG 3 seeks to achieve. Data from the animal interface and the medical records from the human interface indicate the potential transmission of zoonoses, especially helminthiasis, in the studied communities. In addition, the urban areas were identified to best support the potential transmission of zoonoses contrary to the peri-urban areas. Thus, active surveillance of zoonoses in animals in close contact with humans in our urban and peri-urban communities is urgently required. Again, respondents had some knowledge of zoonotic diseases from companion animals, although most were ignorant of zoonoses from rodents. Findings from the survey indicate that a high proportion of owners of companion animals in the study areas were engaged in activities that predispose them to zoonotic diseases. It is recommended that public education campaigns and awareness creation programmes using a one-health approach should be started in earnest to ensure the effective prevention and control of zoonotic diseases.

DEDICATION

This thesis is dedicated to the '**Faithful God**'. To Him be all the praise.

To my husband and my family, you are the best.

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LIST OF ABBREVIATIONS

CALLISTO	Companion Animals multisectoraL interprofessionaL and Interdisciplinary Strategic Think tank On zoonoses
CDC	Centres for Disease Control and Prevention
DALYs	Disability Adjusted Life Years
DNA	Deoxyribonucleic acid
EIDs	Emerging Infectious Diseases
EZD	Emerging Zoonotic Diseases
GAMA	Greater Accra Metropolitan Assembly
MRSA	Methicillin Resistant *Staphylococcus aureus*
NZDs	Neglected Zoonotic Diseases
PCR	Polymerase Chain Reaction
WHO	World Health Organisation

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Infectious diseases continue to impact health systems and the global economy heavily. In recent times, the world has become more susceptible to threats of infectious diseases as a result of globalisation (ease of international trade and travel), urbanisation and other vital determinants (Cascio, Bosilkovski, Rodriguez-Morales, & Pappas, 2011; Wu, Perrings & Kinzig, 2016; Angulo, Cassell, Tappero, & Bunnell, 2017; Kapata et al., 2020). Infectious diseases spread rapidly, and in some cases, outbreaks at local levels lead to pandemics when not appropriately managed, as has been witnessed in contemporary times (Morse et al., 2012; Fitzmaurice et al., 2017).

Humans and animals have suffered considerably from the consequences or impact of infectious diseases. Such diseases continue to be a leading cause of high morbidity and mortality globally. For instance, a report by the World Health Organization assessed that 17.3 million (33%) out of the 52.2 million universal deaths recorded in 1996 were due to infectious diseases (Murray & Lopez, 1996). Furthermore, a reasonably recent report also showed that infectious diseases accounted for 15.8% of all mortalities worldwide (Wang et al., 2016). In developing or low-income countries, infectious diseases represent about 43% of mortalities (Murray & Lopez, 1996). The impact of infectious disease pandemics experienced in the last decade has been deleterious (Morse et al., 2012; Pike, Bogich, Elwood, Finnoff, & Daszak, 2014; Cleaveland et al., 2017; Kapata et al., 2020).

Many ravaging infectious diseases have been identified to be zoonotic in origin. Reports show that an estimated 61% of infectious diseases that affect humans and 75% of emerging infections are zoonotic (Mackenstedt, Jenkins, & Romig, 2015; Salyer, Silver, Simone, & Behravesh, 2017; Cunningham, Daszak, & Wood, 2017). Zoonotic diseases or Zoonoses are infectious diseases transmitted from vertebrate animals to man under natural conditions (Perkins, Cattadori, & Hudson, 2005; Ajat, 2016; Odeniran & Ademola, 2016). These diseases cause significant morbidity and mortality, especially in developing countries, in addition to the economic losses and negative impact on travel and commerce (Burroughs, Knobler, & Lederberg, 2002, Jones et al., 2008; Gebreyes et al., 2014). Annually, zoonotic diseases claim the lives of 2.7 million persons signifying a critical threat to health security (Gebreyes et al., 2014; Salyer et al., 2017). Nearly all the pandemics that occurred over the last decade originated from animals or were zoonotic (Slingenbergh, Gilbert, Balogh de, & Wint, 2004). For that reason, any pandemic to occur in the future is likely to have its origin in an animal. Consequently, Bardosh et al.(2017) think that zoonoses will continue to incite a great degree of public policy attention in the years ahead.

In Africa, the actual burden of zoonoses is lacking because most zoonotic diseases do not show specific clinical presentations causing under-diagnosis or under-reporting. Most of the presentations of zoonotic infections overlap with other febrile non-zoonotic illnesses, thus leading to misattribution in places where the awareness of different pathogens that present similar symptoms are higher (Halliday et al., 2015). Again, some zoonotic infections could go undetected partly due to unawareness of primary healthcare givers about such diseases, lack of appropriate diagnostic tools and the gap in communication between medical and veterinary doctors (Damborg et al., 2016).

Zoonotic diseases are usually classified based on their route of transmission (vector-borne, foodborne), pathogen type (bacteria, protozoa, helminths, among others) or level of person-to-person transmissibility (Karesh et al., 2012). The transmission of zoonotic pathogens can occur through any of the following routes: direct contact; oral; the environment; aerosols, and vectors (Kumar, Damodar, Ravikanth, & Vijayakumar, 2012; Ajat, 2016).

Zoonotic infections can spread within human populations once introduced or be spilt over from animal reservoirs (Cleaveland et al., 2017). According to Perkins et al.(2005), most zoonotic reservoirs are primarily mammals compared to other animal species. Several studies have corroborated that many emerging or re-emerging zoonotic infections are from mammalian reservoir hosts (Jones et al., 2008; Han, Yang, & Park, 2016). Regarding directly transmitted pathogens, contact is an indispensable condition for pathogen spillover (Alexander & McNutt, 2010). Therefore, people are regularly exposed to such zoonotic diseases while performing their domestic and occupational activities (Dzingirai et al., 2017).

Several animals act as agents of zoonotic disease transmission by serving as different types of hosts and maintaining infections in nature (Jones et al., 2013; Plourde et al., 2017). Animals in the wild (rodents) and domestic animals (referring to cats and dogs) are known to be competent reservoirs of many zoonotic diseases significant to human health and are responsible for the transmission of several bacteria, viral, protozoan and helminthic infections (Gerhold & Jessup, 2013; Whiley, McLean, & Ross, 2016; Kostopoulou et al., 2017). Both domestic and wild animals are also involved in the emergence of zoonotic diseases (Cleaveland, Laurenson, & Taylor, 2001).

Several zoonotic infections have emanated from wildlife (Woolhouse, 2002; Kruse, Kirkemo, & Handeland, 2004; Jones et al., 2013; Cuervo-Soto, López-Pazos, & Batista-García, 2018). Rodents, for instance, play critical roles in sustaining pathogen transmission cycles, whether urban or rural (Meerburg, Singleton, & Kijlstra, 2009). Transmission of zoonotic infections from rodents to humans is either by direct exposure to their urine, saliva and blood or indirectly through contaminated surfaces/foodstuffs, the environment and ectoparasites they harbour (Meerburg et al., 2009; Bonwitt et al., 2017). Furthermore, rodents found close to human settlements create the prospects for cross-species transmission of pathogens (Mills & Childs, 1998; Meerburg et al., 2009; Mgode et al., 2014). In addition to the infections they transmit to humans, rodents are also important pests known to cause severe damage to food in storage, agricultural farms, and physical damage (Meerburg, 2006). Several reports have pointed to the extensive economic losses caused by these animals in pre-harvest and post-harvest (Meerburg et al., 2009; Bonwitt et al., 2017).

Domestic animals, such as pets/companion animals, have been implicated in transmitting several zoonotic pathogens. Keeping animals as companion animals has existed for centuries, and according to Islam and Towell (2013), this has become a cultural phenomenon worldwide. Companion animals play a diversity of roles in our societies today. One cannot lose sight of the fact that these animals provide an essential source of social and psychological support to their owners (Chomel, 2014; Prokop & Tunnicliffe, 2010). Presently, a variety of animal species are kept as companion animals. These include dogs, cats, rabbits, birds, and other reptiles or amphibians. Nonetheless, dogs and cats remain preferred by most owners (Goni et al., 2018).

It is common knowledge that dogs and cats have shared the environment of humans for several decades. Over the years, their population in households have steadily increased in both developed and developing countries (Esch & Petersen, 2013; Chomel, 2014). However, their population has reached record-high levels in developed countries (Day, 2011). In addition to being companions, dogs, for instance, serve as guards, law enforcers, hunters or scavengers and delicacies (food) for man in some parts of the world (Macpherson, 2005; Elieza, 2016). On the other hand, cats control rodent populations in human settlements and farm settings in many low-income countries (Woodcock, Addo-Yobo, Taggart, Craven, & Custovic, 2001; Bukar-Kolo, Igbokwe, & Egwu, 2018).

Human's intimate relationship with companion animals, their presence on every continent, and their various roles have caused companion animals such as dogs and cats to share more than 60 parasite species with humans (Macpherson, 2005). For this reason, dogs and cats have been recognised to play vital roles in many zoonotic disease transmissions; they act as definitive, intermediate or reservoir hosts. Both animals are sources of important bacterial, viral, parasitic and protozoan diseases. There are also reports of emerging multidrug-resistant zoonotic bacterial infections in dogs and cats, which is also of significant public health concern (Damborg et al., 2016).

Many factors have been identified to impact the transmission of zoonoses globally and locally. For instance, behaviour and cultural practices impact human activities and how they interrelate with the environment (Alexander & McNutt, 2010). It is recognised that human behaviour (including human/anthropogenic activities) such as land use and change of natural habitats into production landscapes have further increased the proliferation of zoonotic diseases globally (Macpherson, 2005; Salyer et al., 2017).

Modification in human-induced landscapes is also a key factor identified to play a vital role in the transmission of zoonotic pathogens, which sometimes lead to outbreaks (Patz et al., 2004; Mackenstedt et al., 2015). Therefore, human-dominated landscapes, which include urban and peri-urban areas, facilitate infectious disease transmissions. Urbanisation has led to the transformation of many natural landscapes into habitations dominated mainly by artificial structures (Moule, Michelangeli, Thompson, & Chapple, 2016). For instance, the fast rate of urbanisation has increased the emergence of peri-urban communities or zones at the fringes of many cities due to population spillover. Peri-urban zones or areas are temporary belts sandwiched between cities and rural areas with both urban and rural characteristics existing simultaneously (Budiyantini & Pratiwi, 2016). Many people now live in the outskirts of urban areas where rented accommodation and building houses, among others, are relatively cheaper.

Consequently, due to population spillover, humans continue to encroach on habitats of wild animals. Over the years, many wildlife populations have become established in and around human settlements. The frequency of contact between humans and wildlife populations in the urban and peri-urban areas varies from sporadic to regular encounters, subsequently increasing the probability of pathogen transmission between them (Mackenstedt et al., 2015).

Everyone is at risk of contracting zoonotic diseases. However, children, the aged, pregnant women and immunodeficient or immunocompromised persons are at a higher risk (Burroughs et al., 2002; Ghasemzadeh & Namazi, 2015; Ebani, 2017). Certain occupations and domestic activities likewise put some people at a higher risk of exposure to zoonotic infections. Veterinarians, livestock keepers, abattoir workers and laboratory scientists, to mention a few, are highly exposed to zoonotic pathogens during their work. Domestic activities like hunting, farming near wildlife habitats and handling or consuming game predispose humans to zoonotic diseases.

As a result of increasing zoonotic events over the past two decades, strategies for the prevention and control of zoonoses cannot be overemphasized. To effectively tackle zoonotic diseases, much attention has been directed towards transmission control, prevention and reducing disease burden in humans and animals. As such, many countries continue to develop fundamental capacities and strategies to handle the threats of zoonoses, although most often, these strategies are reactive rather than proactive. Rapidly identifying, responding to, and controlling public health crises such as epidemics of zoonoses at their source is crucial to attaining global health security (Pike et al., 2014; Cleaveland et al., 2017; Salyer et al., 2017).

It is not a hidden truth that most sub-Saharan African countries do not have national surveillance strategies to monitor the burden of zoonotic diseases and implement the appropriate control measures. Thus, a better understanding of the transmission cycles of zoonotic pathogens would go a long way to aid in designing effective control strategies (Odeniran & Ademola, 2016).

1.2 Justification

In most domestic settings in Ghana, domestic and wild animals play various essential roles in the epidemiology of zoonotic infections. Direct contacts like petting or physical injuries and indirect contacts create favourable conditions for disease transmission (Damborg et al., 2016). Cleaveland et al.(2001) argue that the risk of zoonoses will be highest in domestic settings where mammals (dogs, cats and rodents) are always in close contact with humans and exposure to disease pathogens are very high.

In many homes, a close relationship between humans and their companion animals continues to exist, however, at a risk. Keeping dogs and cats has recently been seen as a social status symbol in Ghana, mainly among the well-to-do luminaries and sometimes ordinary citizens. On some occasions, people are seen with their companion animals in luxurious cars, and now and again, their pictures flaunt the various social media. Currently, in Ghana, there is the German shepherd dog club made up of persons who seek to gain the knowledge needed to train and keep these breeds of dogs according to acceptable standards. Although the above trend appears to be increasing, it is not entirely the case in most households that own companion animals. Nevertheless, in most homes, these animals are loved and catered for in whatever best way the owners can afford.

Rodents, carriers of focal zoonotic pathogens from the wild, often visit human settlements. These animals cause various forms of destruction; thus, people acquire cats most often to reduce their population and the damages caused by them. Apart from being a nuisance, rodents serve as food for some cats and dogs in those human settlements. Consequently, companion animals may become infected with diseases borne by the rodents as they feed on them and amplify the probability of zoonotic disease transmission to humans.

In the urban and peri-urban areas, Kardjadj and Ben-Mahdi (2019) suggest that humans and animals, time and again, suffer from similar pathogens probably because they share similar environments, increasing the probability of pathogen transmission through disease spillovers and spillbacks. Those continuous interactions appear inevitable, especially when companion animals are made to look for food and are not adequately housed. Other factors like unsanitary conditions, congestion, and lack of personal hygiene aggravate zoonotic disease transmission. Therefore, the presence of these animals in our communities suggests the possibility of serious disease transmission with grave implications for Sustainable Development Goal (SDG) 3. Given the increasing number of companion animals in households and the bond between the owners, knowledge of the potential zoonotic diseases transmitted from these companion animals is of prime importance.

In recent times, new diseases continue to emerge from unexpected reservoir hosts and through novel pathways (Cunningham et al., 2017). Interestingly, Carvalho-Pereira et al.

(2018) found *Toxocara* sp. and *Ascaris* sp. in the faecal samples of rats, although they suggest rodents are not known as natural reservoirs of these parasites. Could this be a case of a new transmission route for the parasite or just a mere coincidence? Thus, due to the complexity of interactions found among humans, companion animals and rodents, it is essential to investigate the zoonotic diseases that these selected animals potentially transmit in our human-dominated landscapes (urban and peri-urban spaces).

Enhanced and effective surveillance, efficient reporting of diseases, rapid detection of disease outbreaks, and advanced research geared towards identifying risk factors are vital strategies to control infectious diseases. The study sought to measure the awareness, knowledge and risk factors of zoonoses among selected communities. Such information will aid in formulating the right policies and educational programmes by the appropriate stakeholders to educate the citizenry on zoonoses and their prevention.

The extant literature reveals that a significant number of studies carried out in Ghana to identify zoonotic diseases transmitted by domestic animals or animals in the wild usually consider either the human-domestic interface or human-wildlife interface (Johnson, Gakuya, Mbuthia, Mande, and Maingi 2015; Owusu, 2015; Amissah-Reynolds et al., 2016; Johnson et al., 2016; Lopes et al., 2018; Baah, 2019; Aboagye et al., 2019; Boyko et al., 2020). Currently, there is not much data on zoonotic infections circulating among companion animals and animals in the wild that are pathogenic to humans in Ghana. Thus, the present study will contribute to knowledge in that regard, considering the role of the environment in zoonotic disease transmission based on the one health approach.

1.3 Aims and Objectives of the Study

1.3.1 Study Aim

The study aimed to investigate zoonotic diseases that selected domestic and wild animals can potentially transmit to humans in two human-dominated landscapes. Again, it sought to gather relevant information on the human-domestic-wildlife interactions and how households create favourable conditions that facilitate these interactions. The study also considered how these interactions could form transmission pathways for zoonotic infections.

1.3.2 Specific Objectives of the Study

The study set out to address specific objectives as follows:

1. Investigate the prevalence of zoonotic infections (bacterial, protozoa, and helminthic) in selected animal species.
2. Explore which human-dominated landscape best support potential zoonotic disease transmission.
3. Evaluate the awareness and knowledge of inhabitants of the study communities regarding zoonotic diseases and associated risks and risk factors.
4. Determine relationships between associated risk factors of zoonoses and their impact on sustainable health in the two human-dominated landscapes.

1.3.3 Research Questions

This study was guided by these research questions:

1. What zoonotic pathogens are shared among the selected animal species?
2. Of the zoonotic pathogens identified, are the prevalences an imminent threat to human health?

3. Which human-dominated landscape (urban or peri-urban) records the highest zoonotic infection prevalence, and is there a link between potential zoonoses transmission and human-dominated landscapes?
4. Are people in study areas aware of zoonoses, the associated or risk factors and their impact on sustainable human health?
5. Are there relationships between the associated or risk factors of zoonoses?

1.4 Organisation of the Thesis

The entire thesis is structured into six chapters. The first chapter introduces zoonotic diseases and the role of domestic and wild animals in the transmission of zoonoses. The chapter also provides justification for the research and states the aim and objectives of the study. Chapter two is on the review of pertinent literature on infectious and zoonotic diseases. It focuses on the emergence and re-emergence of zoonotic diseases, wildlife, and domestic animals as sources of zoonotic diseases. This chapter further examines the extant literature on some selected zoonotic diseases of interest, drivers of zoonotic infections, and the general level of knowledge and awareness of the disease.

The third chapter gives the various techniques or procedures employed in collecting and processing data and information on the different ethical considerations. Chapter four, which is in two sections, presents results on the prevalence of zoonotic diseases across the two human-dominated landscapes and findings from the survey, including respondents' awareness and knowledge of zoonotic diseases. The fifth chapter discusses the results, while the last chapter (Chapter 6) gives the conclusions derived from the findings and discussions with some recommendations.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter reviews pertinent literature generally on infectious and zoonotic diseases with emphasis on the roles of domestic and wild animals in the transmission cycles of some specific zoonotic diseases. Particular reference is made to the public health significance of companion animals (dogs and cats) and rodents in transmitting specific zoonotic diseases. The chapter also details a few zoonoses drivers, awareness and level of knowledge about the disease and some associated risk factors. It then ends with a brief background on One-health and its relevance in the control of zoonotic diseases.

2.2 Infectious Diseases

Infectious diseases are a significant burden to both humans and animals with a profound and deleterious impact that threatens many nations across the globe (Morse et al., 2012; Cunningham et al., 2017; Kelly et al., 2017; Kapata et al., 2020). They have been accountable for the highest global burden of mortality and morbidity for several decades(Snyder & Ravi, 2018). These diseases remain a prime cause of fatality in humans (Gebreyes et al., 2014), and they are responsible for the decline in populations of animals throughout the world (Wiethoelter, Beltrán-Alcrudo, Kock, & Mor, 2015)

Undoubtedly, infectious diseases are tough to manage, tend to spread rapidly (highly contagious) and may take quite some time or even years for some drugs and vaccines to be developed (Cunningham et al., 2017; Schwarz et al., 2017). To further aggravate the issue, many of these drugs or vaccines are very costly. Hence, several resources are needed in fighting infectious diseases locally and globally. However, in several instances, resources become depleted along the way, making it difficult to win this never-ending war between humans and infectious diseases (Jones et al., 2008).

At the animal interface, infectious diseases have contributed to considerable economic losses and threatened the health security of humans due to disease spillover, an identified precursor to disease emergence in humans (Wiethoelter et al., 2015). In the livestock sector, for example, infectious diseases are responsible for significant economic losses because of decreased productivity and market values, high mortality rates, loss of trade and food insecurity (Jones et al., 2008; Morse et al., 2012; Wiethoelter et al., 2015).

Different pathogens cause many infectious diseases and include bacteria, protozoa, parasites, fungi, viruses and prions with various means of transmission. A total of 1,415 infectious pathogens that affect humans were identified by Taylor, Latham, and Woolhouse (2001). Of this number, about 217 were viruses and prions, 538 were bacteria and rickettsia, fungi were 307, 66 were protozoans, and 287 were helminths. These infectious pathogens are transmitted directly or indirectly via vectors and are responsible for diseases that can be less severe or fatal in other cases. They also found that 357 species out of 1415 species of infectious pathogens were transmitted by more than a single route. Again, they identified that 43% of these infectious pathogens were transmitted via direct contact, whereas 52% were through indirect contact.

Today, globalisation, the increasing volume of human travel and trade worldwide, and other determinants have aggravated the spread of infectious pathogens from one country to another within the shortest time (Zyga & Zografakis-Sfakianakis, 2011; Snyder & Ravi, 2018). In the view of Snyder and Ravi (2018), globalisation was the all-encompassing driver behind the influenza and cholera (both infectious diseases) pandemics that claimed the lives of millions of people centuries ago. Several persons and countries are exposed to exotic and life-threatening infectious diseases. In some instances, pathogens are transported undetected (Messenger, Barnes, & Gray, 2014) and introduced to naïve populations with various implications (Jones et al., 2013).

In the past two decades, global infectious disease outbreaks have threatened many nations' health security. These, among others, have revealed how insufficiently prepared the world is for some changing disease dynamics (Kelly et al., 2017) and underscores the need for effective disease surveillance. Over the decades, it has also been recognized that any infectious disease outbreak could lead to a pandemic with serious repercussions (Fitzmaurice et al., 2017; Kapata et al., 2020). Pandemics constantly threaten global health security since they cause severe mortalities and economic losses (Angulo et al., 2017).

These pandemics have also highlighted the ease at which some infectious diseases are transmitted within the shortest time (Cascio et al., 2011; Wu et al., 2016). Hence, several alarm bells continue to sound about the need to strengthen local and global health systems as the probability of future pandemics is undoubtedly high. And so, effective surveillance and diagnosis, critical in effectively detecting and controlling infectious diseases, are being targeted by relevant stakeholders to go a long way to lessen the severe impact of disease outbreaks on countries worldwide.

2.2.1 Emerging and Re-Emerging Infectious Diseases

Increasingly, several infectious diseases are being discovered in newer regions away from areas that were conventionally "hyper-endemic" to certain diseases (Dzingirai et al., 2017). Such diseases, termed emerging infectious diseases, are critical health issues with a significant impact on global health, economy and security (Jones et al., 2008; Allen et al., 2017). According to reports, existing infectious diseases continue to re-emerge across various geographical regions and populations with alterations in their epidemiology now and then (Cantas & Suer, 2014; Bloom, Black, & Rappuoli, 2017). Almost half of the infectious diseases identified recently can be categorised as emerging, according to Hallaj (2010).

In the last two decades, many infectious diseases have emerged or re-emerged, a situation that has attracted much global attention. Over the past decade, reports of novel infectious disease emergence like Severe Acute Respiratory Syndrome (SARS), Middle Eastern Respiratory Syndrome (MERS), Zika virus, Ebola and SARS-CoV-2 and re-emergence of some infectious diseases were documented all over the globe (Kelly et al., 2017; Bardosh et al., 2017; Cleaveland et al., 2017; Goni et al., 2018; Kapata et al., 2020). In the past 60 years, data shows that more than 300 distinct emerging disease episodes have been reported (Jones et al., 2008).

Several studies have identified factors that drive disease emergence or re-emergence (Cleaveland et al., 2001; Engering, Hogerwerf, & Slingenbergh, 2013; Lindahl & Grace, 2015). These factors could be ecological, environmental or biological. Several studies have recognised that climatic conditions, urbanisation and changes in land use, agriculture intensification, human behaviour, international travel and trade, and pathogen characteristics support the emergence and re-emergence of infectious diseases (Cleaveland et al., 2001; Bengis et al., 2004; Kruse et al., 2004; Slingenbergh et al., 2004; Macpherson, 2005; Jones et al., 2008; Neiderud, 2015; Allen et al., 2017).

Infectious pathogens that continue to live in the environment, for example, are believed to have a greater discriminatory affinity and are prone to infecting a higher number of hosts and taxonomic orders, making them very prone to emergence than pathogens that have restricted host (Cleaveland et al., 2001).

The emergence of infectious disease events was classified by Engering et al. (2013, p.2) into three groupings: (i) pathogens appearing in a novel host, and this could be from spillover to total species jumps; (ii) mutant pathogens exhibiting new traits in the same host as well as a surge in virulence, antimicrobial resistance and host immune evasion; and (iii) disease complexes developing in a different geographical area, via range expansion/long-distance jumps. They suggested that each event is distinguished by a set of drivers of emergence, corresponding pathogen characteristic profiles, disease ecology, and transmission dynamics.

Although infectious diseases continue to emerge, the resources needed to fight their emergence are scantily allotted (Jones et al., 2008). Unfortunately, many efforts aimed at reducing the impact of EIDs, in the view of Pike et al. (2014), have mostly been post-emergence outbreak control, isolating the infected and drug and vaccine development. Delays in rapid response to novel emerged pathogens, globalisation, and weak health systems, among other factors, have resulted in far-reaching mortalities and economic impact across the globe, as was witnessed in the Ebola pandemic of West Africa and SARS-CoV-2 (Pike et al., 2014; Bengis et al., 2004; Kapata et al., 2020).

Trend analyses of EIDs indicate that their incidence and economic impact continue to increase (Jones et al., 2008; Pike et al., 2014). A comprehensive review of literature by Taylor et al. (2001) revealed that 175 species of infectious agents were linked to emerging diseases. They again established that 44% of emerging infectious agents are viruses or prions, 30% are bacteria or rickettsia, 11% are protozoa, and 6% are helminths. Their review further revealed that 53% of emerging infections could be spread by direct contact and 47% by indirect contact. A parallel study by Jones et al. (2008) identified that about three hundred and thirty-five (335) infectious diseases emerged between 1940 and 2000. From 1996-2009, an estimated 53% of EID outbreaks were recorded in Africa (Chan et al., 2010). Morse et al. (2012), backtracing to the first occurrence of EID in human populations, also pointed to an increase in emerging new pathogens. With the current trends, Woolhouse (2008) suggests that more emerging infectious diseases seem imminent.

The upsurge in emerging and re-emerging infectious diseases is attributed to determinants like urbanisation, climate change, international travels and trade, intensification of agriculture, and ecological factors (Cleaveland et al., 2001; Bengis et al., 2004; Kruse et al., 2004; Jones et al., 2008; Jones et al., 2013; Slingenbergh et al., 2004; Neiderud, 2015; Allen et al., 2017; Goni et al., 2018). For instance, Morse et al. (2012) found a strong connection between the emergence of critical categories of EIDs and human population density, confirming the hypothesis that disease emergence is propelled mainly by human activities or anthropogenic changes. These findings were supported in a review by Gebreyes et al. (2014), who further grouped these determinants into genetic, biological, environmental, socio-economic and political factors. Results from Jones et al. (2008) in their analyses of a database of EIDs events also corroborated that sources of EIDs are significantly linked to socio-economic, environmental and ecological factors.

There is a growing awareness of the significant threats of emerging infectious diseases (EIDs) from animals. Out of the 1415 infectious pathogens identified by Cleaveland et al. (2001), 868 were categorized as zoonotic, and 175 were placed under emerging pathogens. A more significant number of EIDs documented are from non-humans, and their emergence mainly entails interactions among the human-domestic-wildlife interface in fast-changing environments (Karesh et al., 2012; Jones et al., 2013). About three-fourths of human infectious diseases and a high number of EIDs events in humans have been identified as from animals (zoonotic in origin). A significant number of these diseases are from wildlife compared to domestic animals (Jones et al., 2008; Gebreyes et al., 2014; Klous, Huss, Heederik, & Coutinho, 2016; Miller et al., 2017; Allen et al., 2017). In this regard, the study by Jones et al. (2008) revealed that about 52.0% of EID events between 1990–2000 originated from pathogens in the wild, and this proportion, they suggested, has surged over time. In the study by Morse et al. (2012), they found a strong association between the emergence of zoonoses of wildlife origin and both human density and the universal spread of wildlife biodiversity.

2.3 Zoonotic Diseases

Zoonoses have been of great concern to humankind ever since the domestication of animals began about ten centuries ago (Gebreyes et al., 2014). It is a global phenomenon in developed and developing countries. An increase in zoonoses was observed when people started to live in groups and came into close contact with vertebrates as a result of agriculture and the domestication of animals (Pearce-Duvet, 2006). To date, it is a significant public health problem that challenges veterinary and health systems universally (Miller et al., 2017). It is generally agreed upon that zoonosis signifies a critical threat to health security worldwide (Salyer et al., 2017). Nearly 50% of 1000 (thousand) identified species of pathogens observed in companion animals and livestock were zoonotic in origin (Cleaveland et al., 2001). It suggests that various pathogens consistently break through barriers between animals and humans, including parasites, viruses, bacteria, rickettsia, fungi and prions (Morse et al., 2012; Ajat, 2016; Fèvre et al., 2017).

Zoonoses refer to infectious diseases transmitted from vertebrate animals to humans under natural conditions (Slingenbergh et al., 2004; Meerburg, 2006; Ajat, 2016). Transmission could be by direct contact with urine, blood and saliva and indirectly through oral routes, fomites, aerosols or vectors (Center for Food Security & Public Health, 2014; Centers for Disease Control, 2017). Direct contact involves the pathogen being inside an infected animal or in the environment where humans get exposed via open wounds, mucous membranes or injured skin. In contrast, the oral route involves ingesting pathogen-contaminated food or water. Transmission via aerosols also occurs when droplets of an infected animal are passed via the air to humans or humans get exposed to soil contaminated with faeces, urine or bacteria (Center for Food Security & Public Health, 2014). Quantitative analysis on zoonotic disease transmission by Taylor et al. (2001) revealed that 35% and 61% of zoonotic infections could be transmitted via direct and indirect contacts, respectively, while 22% were via vectors.

In the view of Slingenbergh et al. (2004), the term zoonosis fits an extensive range of epidemiological conditions. According to them, specific pathogens are mainly restricted to animal reservoirs, and human cases are either sporadic or signify dead-end infections as in anthrax diseases. In contrast, some pathogens like salmonellosis are established in humans and animals. In other cases, animals act as primary hosts, with sporadic epidemics observed in humans and transmission resulting in subsequent death as in Ebola viruses. Some pathogens, they also described, have progressively adjusted to human-human transmission and are easily transmitted between humans. In contrast, others are suddenly seen in human populations, although of animal origin.

According to Cuervo-Soto et al. (2018), several important pathogens that infect humans are either zoonotic or started as zoonosis before adapting to humans. In the view of Perkins et al. (2005), zoonotic diseases will continually be caused by spillover infections because these diseases always re-invade human populations from animal reservoir hosts. They believe, however, that when an infection is established, and human-to-human transmissions are reported consistently, then that infection loses the zoonotic ‘label’.

Regarding their epidemiological features and consequences, Zoonotic diseases are grouped into endemic zoonoses and the less regular epidemic and emerging zoonoses (Kemunto et al., 2018). According to Karesh et al. (2012), the differences between endemic and emerging zoonoses could be considered geographical or temporal. Endemic zoonoses are very common, while epidemic and emerging zoonoses are recorded sporadically in outbreaks in neglected populaces or are novel and re-appear with increased incidence or in geographical range (Grace, Gilbert, Randolph, & Kang’ethe, 2012). Reports show that emerging zoonoses alone were responsible for most of the key and ravaging epidemics recorded within the last two decades (Slingenbergh et al., 2004; Jones et al., 2008; Gebreyes et al., 2014).

Most zoonotic diseases with epidemic and pandemic potentials that present universal economic and health challenges are researched on a large scale and funded expansively for effective control (Grace et al., 2012; Leach et al., 2017). Conversely, endemic zoonotic diseases do not receive much focus and the needed funds for control and are therefore termed Neglected Zoonotic Diseases (NZDs) (World Health Organization [WHO], 2009; Fèvre et al., 2017). Biological and epidemiological data on disease prevalence of NZDs, burden and risks in humans and animals are mostly lacking because such diseases are comparatively underfunded and under-researched at many levels, especially in developing countries. Thus they are likely to be poorly comprehended and controlled (Fèvre et al., 2017).

2.3.1 Emerging and Re-Emerging Zoonotic Diseases

Zoonotic diseases continue to emerge or re-emerge such that in the past decade, the incidence of emerging and re-emerging zoonoses has been reported to increase (Macpherson, 2005; Perkins et al., 2005). For instance, most of the frequently recorded emerging and re-emerging diseases in sub-Saharan Africa are zoonotic (Mangesho et al., 2017). This rise in incidence rates, others believe, could be due to redirected focus on such diseases in contemporary times (Morse et al., 2012; Angulo et al., 2017). Some also believe the surge in disease occurrence could be caused by a synergy of prevailing factors like human interactions with animals, population increase, urbanisation, climate change, global travel and trade, among others (Taylor et al., 2001; Cleaveland et al., 2001; Patz et al., 2014; Bengis et al., 2004; Woolhouse & Gowtage-Sequeria, 2005; Jones et al., 2008; Morse et al., 2012).

Emerging zoonoses are increasingly becoming severe public health and social-economic threats universally. They are reported to have caused damages over hundreds of billions of United States dollars over the last two decades (Jones et al., 2008; Karesh et al., 2012). By definition, emerging zoonotic diseases are zoonoses freshly identified or newly evolved or illnesses that occurred before but are increasing in incidence in a geographical, host or vector range (Slingenbergh et al., 2004). Simply, it is an existing zoonotic disease that shows up again or invades new areas or regions. Approximately 400 emerging infectious diseases that are zoonotic have been identified since 1940 (Jones et al., 2008).

Perkins et al. (2005) enumerated five steps toward the emergence of zoonotic diseases as follows: a. the first step, which is interspecific exposure, occurs when humans get exposed to infectious pathogens with the level of risk determined by the level of ‘propagule pressure’ which may be affected by anthropogenic and environmental factors; b. the second step involves the pathogen overcoming the host's defence mechanism which includes the mucus membrane and other secretions; c. the third step involves the pathogen establishing within the host either in a cell or tissue suitable for its development; d. this stage involves the pathogen producing infective stages, which is very critical for the pathogen; e. lastly, the pathogen being able to persist by using the human-to-human transmission route without which the infection caused by the pathogen disappears.

Many efforts in the past were made to control some zoonotic diseases' prevalence. Unfortunately, several of these diseases, which hitherto had been controlled in several regions and parts of the world, are beginning to re-appear: such diseases are termed re-emerging zoonotic diseases (Slingenbergh et al., 2004; Bengis et al., 2004; Jones et al., 2008; Allen et al., 2017). Both emerging and re-emerging zoonotic diseases are reported regularly in Sub-Saharan Africa (Mangesho et al., 2017). The increase in the incidence of emerging and re-emerging zoonotic diseases in Sub-Saharan Africa and the world at large could be due to the renewed interest in studying these diseases in recent times. For example, attention to Emerging zoonotic diseases (EZD) is believed to have gained much momentum after deadly zoonotic disease outbreaks in the past decades led to the loss of several lives and a significant decline in economic growth (Morse et al., 2012; Angulo et al., 2017). This notwithstanding, trend analyses of EZD by Pike et al. (2014) corroborated the assertion that there was a substantial rise in emerging zoonotic diseases.

The emergence of zoonotic infections is associated with many determinants or factors which, according to Burroughs et al. (2002), hardly ever act alone. Some determinants include alterations in human behaviour, human interactions with wildlife or domestic animals which interact with wildlife, socio-economic, geographical regions and ecological and environmental factors (Taylor et al., 2001; Patz et al., 2004; Woolhouse & Gowtage-

Sequeria, 2005; Cunningham et al., 2017). Similarly, zoonotic disease re-emergence is driven by similar factors listed above. Also, habitat and population densities that impact host numbers, pathogens or vectors account for the natural rise or decline of disease activity in various geographical areas and over different periods (Bengis et al., 2004).

2.3.2 Hotspots of Zoonotic Infections

Some regions have been tagged to be hotspots of zoonotic disease emergence. Morse et al. (2012) describe hotspots as regions with anthropogenic activities taking place alongside high wildlife biodiversity and associated microbial biodiversity. Areas in the lower latitudes have been identified to be hotspots for emerging wildlife and vector-borne zoonotic diseases (Jones et al., 2008).

South-East Asia has recorded several epidemics of zoonoses such as the Highly Pathogenic Avian Influenza (H5N1), pandemic influenza A (H1N1), and Severe Acute Respiratory Syndrome (SARS), including the novel Coronavirus (SARS-CoV 2) (Morse et al., 2012; Morand et al., 2019). Thus, it has been a hotspot for EIDs and emerging zoonotic diseases. In addition, the sub-Sahara African region has been identified as a hotspot for EIDs, specifically emerging zoonotic diseases. Africa, for the past decade, has not been left out of the brunt of epidemics and pandemics. A recent zoonotic disease pandemic in West Africa that claimed several thousands of lives was the Ebola haemorrhagic fever virus (Medley et al., 2020). These two regions have a high prevalence of endemic zoonoses (Grace et al., 2012).

According to Hundal, Sodhi, Gupta, Singh, and Chahal (2016), the Indian subcontinent is also known as one of the global hotspots at high risk for the emergence of novel infectious diseases.

2.3.3 Global Burden of Zoonoses

Zoonoses account for 2.5 billion cases of ailment in humans globally, with millions of death recorded yearly (Gebreyes et al., 2014; Osbjer et al., 2015). In low–income countries, zoonoses are responsible for about 43.7% of deaths (Wang et al., 2016). Again, zoonoses and emerging zoonotic diseases account for more than 25% of the disability-adjusted life years (DALYs) lost to infectious diseases in low-income countries and less than 1% in advanced countries (Grace et al., 2012). Over 2.2 million human mortalities and 2.4 billion cases each year are attributed to endemic zoonoses alone (Grace et al., 2012). With this staggering estimate, Grace et al. (2012) believe the actual public health and economic impact of zoonoses are underestimated primarily due to the under-reporting of disease events. This could probably explain why endemic zoonoses are still somewhat neglected, as noted by Cunningham et al. (2017).

The economic burden attributable to zoonoses universally is known to be very high (Gebreyes et al., 2014). Zoonotic diseases are not only significant causes of morbidity and mortality in humans but also considerably impact their well-being as these diseases affect livestock production and food security (Christou, 2011; Molyneux et al., 2011). Zoonoses are envisaged to cause substantial economic losses in the agriculture sector (Klous et al., 2016). A World Bank report estimated the financial loss associated with six zoonotic diseases in specific countries between 1997 and 2009 to be US$80,000,000,000 (The World Bank, 2012; Gebreyes et al., 2014). Similarly, a current communication from the International Livestock Research Institute emphasises that zoonotic diseases pose a significant challenge to alleviating poverty, which SDG goal 1 seeks to address as zoonoses considerably impact 1,000,000,000 livestock keepers (Grace et al., 2012).

Year after year, there are reports of disease outbreaks locally, and many of these causative pathogens have the possibility of escalating to infect people globally (Angulo et al., 2017). Zoonotic disease outbreaks occur by supposedly new agents or identified microorganisms that surface in areas or species in which the disease was undetermined beforehand (Burroughs et al., 2002). Whenever zoonotic diseases become pandemic, they impact society negatively. Their effects can be overwhelmingly grievous, as evidenced in the Ebola virus pandemic in Africa a couple of years ago and the SARS-CoV-2 pandemic (Bengis et al., 2014; Pike et al., 2014; Gondwe, 2020).

2.3.4 Burden of Zoonoses in Africa

Endemic, emerging, and re-emerging zoonotic diseases pose a great challenge to public health, although they disproportionately affect communities in low-income countries. The human burden and impact in such countries far outweigh those recorded in developed countries (Gebreyes et al., 2014; Osbjer et al., 2015). Nevertheless, there are no known regional estimates of endemic, emerging and re-emerging zoonoses burden in low-income countries, particularly in Africa. All these three epidemiological forms of zoonotic diseases exact a significant impact on human populations. Considering current trends, Salyer et al. (2017) believe that endemic zoonoses might present a more challenging and enduring threat to human and animal health than emerging and re-emerging zoonoses.

Endemic zoonoses are very common in Africa, mainly Sub-Sahara Africa (WHO, 2009), yet their aetiologies of several human diseases are under-reported (Zhang et al., 2016). This category of diseases is hardly recognised and poorly understood (Halliday et al., 2015). Although they are not given much attention on the international health platform, they have a considerable effect on the health and economies of countries (Zhang et al., 2016). Notably, endemic zoonoses directly impact human health and well-being and indirectly affect the livelihoods and food security of persons in tropical regions (Halliday et al., 2015).

The true burden of zoonoses in Africa is lacking since many zoonoses do not have specific clinical presentations. Hence, some zoonotic diseases are underdiagnosed or underreported because most presentations overlap with other febrile illnesses that are non-zoonotic. This occurrence often interferes with their clinical recognition, resulting in misattribution in areas with greater awareness of other pathogens presenting similar symptoms (Halliday et al., 2015; Zhang et al., 2016). Therefore, the burden of endemic zoonoses is mainly deficient, a situation that has negatively influenced the awareness and appreciation of the disease among policymakers and clinicians (Halliday et al., 2015).

2.4 Hosts of Zoonotic Diseases

Many animal species are known to host an array of zoonotic pathogens. These animals act as agents of zoonotic diseases by serving as different types of hosts; intermediate, reservoir and accidental hosts, among others (Jones et al., 2013; Plourde et al., 2017). Several groups of animals (companion animals, other domestic and animals in the wild) act as reservoirs of zoonotic diseases by maintaining infections in nature and playing various significant roles in their transmission in both human and animal populations (Bengis et al., 2004; Gebreyes et al., 2014; Han et al., 2016; Panti-May, 2016).

Wild and domestic animals are highly potential sources of infections; pathogens do thrive, grow and replicate in such animals. The recent Ebola virus epidemic that occurred in some West African countries and the 2009 Influenza A (H1N1) pandemic point to the crucial role animals play in the emergence of pathogen strains and the erratic nature of pathogens (Gebreyes et al., 2014). With the progress of time, several human infections are of animal origin. Besides, wild and domestic animals carry ectoparasites such as ticks, fleas, and mites responsible for transmitting important vector-borne diseases to humans (Ficová et al., 2011). Many tick species, for example, are vectors of several zoonotic infections, and they transmit a wide range of pathogens (De La Fuente, Estrada-Pena, Venzal, Kocan, & Sonenshine, 2008).

Many zoonotic reservoirs have been identified as mammals (Morse et al., 2012). Although mammals are a minor fraction of identified animal species, they present the most significant risk to humans with regard to zoonotic diseases (Cleaveland et al., 2001). Several research works have revealed that infectious diseases can jump the species barrier linking humans and non-human mammals (Perkins et al., 2005; Morse et al., 2012; Engering et al., 2013). Many novel pathogens or parasites documented for the past decade emerged from mammalian reservoir hosts. Cleaveland et al. (2001) also observed that most zoonotic pathogens had rodent (22.5%), carnivore (43.0%) or ungulate (39.3%) hosts, and only a few were recognised to have primate hosts (12.9%).

2.4.1 Wildlife as Sources of Zoonoses

The impact of wildlife on the epidemiology of infectious diseases and zoonoses, to be specific, can never be underestimated. Wildlife is increasingly being recognised as the source of several emerging pathogens with high-impact threats to global health, economic growth and security (Kruse et al., 2004; Jones et al., 2013; Kamins et al., 2015; Klous et al., 2016; Cunningham et al., 2017; Cuervo-Soto et al., 2018). For example, several neglected tropical diseases are said to have their origins in animals in the wild who act as disease reservoirs (Odeniran & Ademola, 2016; Whiley et al., 2016). Jones et al. (2008) found over 70% of zoonotic EIDs to be caused by pathogens from wildlife.

Wild animals act as critical agents for zoonoses transmission. Nearly 75% of zoonotic diseases that emerged during the past 20 years had a wildlife source (Woolhouse, 2002). This explains why zoonotic diseases having wildlife reservoirs are a significant public health problem worldwide (Kruse et al., 2004). It is estimated that not less than 79% of reported domestic animal diseases in North America alone have a recognised wildlife element linked to either the transmission or maintenance of the pathogen or its lifecycle (Miller et al., 2013). Of this percentage, 40% are diseases transmitted between humans and animals. Consequently, persistent public health attention is directed at identifying reservoirs of zoonotic pathogens in wildlife species (Karesh et al., 2012).

Many research works have acknowledged threats posed by pathogens from wildlife (Gebreyes et al., 2004; Bengis et al., 2004; Jones et al., 2013; Odeniran & Ademola, 2016; Cunningham et al., 2017). These pathogens negatively impact human health, agriculture, conservation, and wildlife-based economies (Bengis et al., 2004). Pathogens from wildlife that incited intense public health concern include Ebola, Nipah, West Nile, Avian influenza, HIV-1 and HIV-2 (Cunningham et al., 2017).

2.4.1.2 Rodents as Agents of Zoonotic Infections

The order *Rodentia* has been documented to be the single largest, diversified and speciose of all mammals, making up 40% of this group (Huchon et al., 2002; Han et al., 2016). In all, there are more than 2000 species of rodents with about 30 families (Esfandiari et al., 2017). Members of this order are usually characterised by a lone pair of incessantly growing incisors found in each of the jaws. Their incisors are used for excavating burrows, gnawing food and defending themselves.

Rodents usually have a mixed diet, although some are identified to eat mainly seeds or green vegetation (Phan et al., 2011). In terms of body size, they are relatively small yet strong. Some species are arboreal; others dwell on the surface of the ground, while some are aquatic or underground dwellers. About ca 2200 existing rodent species, comprising rats, mice, voles, squirrels and guinea pigs, are known (Phan et al., 2011). There are differences in the biology and ecology of members of this group. According to Kay and Hoekstra (2008), the differences are observed in their size, shape and weight.

Rodents perform significant ecological roles such as being part of the food web, aerating the soil and increasing water absorption due to the burrowing activities of some species. They also serve as biological indicators of contamination in wetlands and terrestrials (U.S EPA, 2003). In addition, rodents are used as companion animals for research and sometimes serve as food in some parts of the world and many others.

Rodents are frequently found around human settlements. Their increased interactions with humans are attributed to persons building homes in/near wildlife habitats and engaging in hunting or farming activities. These species are attracted to houses, kitchens, and food stores mostly built with mud and wattle (Bonwitt et al., 2017). Mostly, rodents are nocturnal animals, so their activities are highest at night, moving very close to humans, possibly because of the dark conditions that characterize indoors of people's homes. For some rodents like rats and mice, their activities in peoples' homes are revealed by continual sounds of soft-footed movement and signs of nocturnal activities coupled with the presence of faeces and husks around dishes and grain stores (Bonwitt et al., 2017).

Rats are typically small to medium-sized rodents with long tails (Paul et al., 2016; Bonwitt et al., 2017). True rats, *Rattus rattus*, have been recognised as one of the dominant rodents in and around human settlements or homesteads (Mahlaba, Monadjem, McCleery, & Belmain, 2017). They are generally black and brown in colour. According to Paul et al. (2016), this species is of utmost significance to man as they are prevalent. Likewise, the Norway rat, *Rattus norvegicus,* is documented to be the most effective invasive mammalian species. It is known to acclimatise well in both rural and urban environments, tolerate a vast array of temperatures and show high reproductive rates (Panti-May et al., 2016; Carvalho-Pereira et al., 2018). *Rattus norvegicus* is known to be responsible for causing significant economic losses due to its varied diet, contamination of food in storage with faeces and urine, and causing infrastructure damage due to their burrowing and gnawing activities (Singleton, 2003; Carvalho-Pereira et al., 2017). The Norway rat exhibit peri-domestic habits, which leads to regular human-rodent contacts in high human population densities (Carvalho-Pereira et al., 2018). They contaminate the environment with their excreted faeces which contain the infectious stages of parasites they harbour.

Multimammate rats of the genus *Mastomys* are very prevalent in sub-Saharan Africa. Species of rodents that form this group, commonly referred to as Murids, are morphologically hard to differentiate (Leirs, Verhagen, & Verheyen, 1990). They are of significant importance to food security as they cause widespread damage to agricultural products and are also critical in public health as they are carriers of fatal pathogens, which are causes of diseases like plague and Lassa fever. Population outbreak of these species has been linked to the aftermath of heavy rains (Leirs et al., 1990). Several studies have been conducted in different geographical regions to show the relationship between rainfall and the reproduction of *Mastomys* (Fiedler, 1988b as cited in Leirs et al., 1990). The outcome of these studies appeared to support this assertion, although the applicability of findings varied per the geographical areas.

Another rat for consideration is the *Arvicanthis* spp. These species are known agricultural pets and hosts of important infectious diseases. It has an extensive distribution across sub-Saharan Africa (Fagir & El-Rayah, 2009; Sadlova et al., 2020). According to Sadlova et al.(2020), dense populations of *Arvicanthis* spp. are found near human settlements in sub-Saharan Africa. In some parts of Accra, this rodent is locally referred to as 'beela' or 'beera'.

2.4.1.3 Economic and Health impact of Rodents

Generally, animals that belong to the order Rodentia pose significant threats to food security, especially in developing countries. For instance, rodents are recognised as pests and, because of their gnawing habit, are responsible for enormous economic losses, food spoilage and structural damages (Meerburg, 2006; Bonwitt et al., 2017). Several reports have recounted the extensive damages caused by these animals on agricultural farms, destroying several acres and hectares of farm produce and grains in storage (Han et al., 2016; Bonwitt et al., 2017). All across Asia, rodents cause extensive pre-harvest losses of cereals enough to feed about 220 million persons (Meerburg et al., 2009). In homes, they contaminate foods that are not appropriately stored and damage shoes, bags, and money notes. Their activities are lengthened by the perpetually dark setting formed indoors, creating more prospects for environmental contamination and disease spreading (McCormick, 1987; Bonwitt et al., 2017).

Furthermore, rodents have long been identified to contribute significantly to the enzootic cycles of bacterial, viral and protozoan zoonoses (Ficová et al., 2011). Of 2,277 existing rodent species, 217 are reservoir hosts harbouring 66 zoonotic diseases (Han, Schmidt, Bowden, & Drake, 2015). In addition, they act as amplifying hosts of some pathogens (Meerburg et al., 2009). According to Meerburg et al. (2009), there has been an upsurge in human diseases caused by small-mammal reservoirs in the last decade, and rodents have been implicated in many of these zoonotic diseases. Rodents who live near humans offer opportunities for cross-species transmission of pathogens they harbour (Mills & Childs, 1998; Meerburg et al., 2009; Mgode et al., 2014). For example, peri-urban rodents, as suggested by Meerburg et al. (2009), provide a link between wildlife and humans, causing the exposure of humans to zoonotic pathogens in the natural ecosystem.

Rodents can maintain pathogen transmission cycles in various environments, whether in urban or rural areas (Meerburg et al., 2009). Transmission of zoonotic pathogens from rodents to humans is either by direct exposure to fluids like their urine, saliva, and blood or indirectly through surfaces, foodstuffs or surface water polluted by these fluids (Mills & Childs, 1998; Meerburg et al., 2009; Bonwitt et al., 2017; Young et al., 2018). Their constant interactions with humans make them a frequent source of zoonotic infections (Parmenter et al., 1998; Phan et al., 2011).

Many rodent species are essential reservoirs of diseases (Han et al., 2015). For instance, *R. norvegicus* are hosts to bacterial and protozoa pathogens such as *Leptospira*, *Salmonella* and *Toxoplasma gondii* (Costa et al., 2015; Walker et al., 2017; Carvalho-Pereira et al., 2018). *Arvicanthis* spp. are also hosts of protozoal and bacterial infections like leishmaniasis and plague (Sadlova et al., 2020). The Multimammate mouse, *Mastomys natalensis*, is the focal reservoir for Lassa virus (LASV). However, other *Mastomys* spp. have lately been identified as reservoirs with their role in human diseases yet unknown (Olayemi et al., 2016). Rodents are also hosts of several zoonotic helminths. The Norway rats, for example, are hosts to *Strongyloides* spp., *Hymenolepis nana* and *Trichinella spiralis* (Meerburg, 2006). Carvalho-Pereira et al. (2018) identified eleven (11) species of helminths, which comprised five species known to cause human diseases, in the faeces of 299 *Rattus* *norvegicus*. A similar study by Ogunniyi, Balogun, and Shasanya (2014) in Nigeria revealed a prevalence of 58% helminthic infection in domestic rats found in Ibadan.

2.4.1.4 Distribution and Ecology of Rodents

Rodents are widespread: they are found on every continent but not in Antarctica (Meerburg et al., 2009). It is reported that humans played diverse roles in their spread to several areas and are well-known to be adaptable to nearly every terrestrial habitat. The rodents *Mus musculus, Rattus rattus* and *Rattus norvegicus* are described as the most invasive of all mammals (Puckett et al., 2016). These species are found in almost every place inhabited by humans. In a study by Borchert, Mach, and Linder (2007), *Rattus rattus* (88.9%) followed by *Arvicanthis* sp. (8.9%) were the prevalent rodent species trapped in villages in Uganda. *Arvicanthis* sp. was the commonest, typical of this rodent as it is known to be a peri-domestic animal.

The multimammate rat, *Mastomys natalensis,* is also very common in Sub-Sahara Africa (Leirs, Verhagen, Verheyen, Mwanjabe, & Mbise, 1996). However, other studies seem to suggest that these species are dominant all over the continent (Massawe et al., 2011). The Norway rat, *Rattus norvegicus,* native to China and Mongolia, is reported to have a global distribution (Puckett et al., 2016).

Rodents tend to have restricted movement in their life span, so they are usually observed to foster strong interactions with specific habitats (Timbuka & Kabigumila, 2006). In Upper Guinea, *M. natalensis* forms between 95% and 98% of rodents found in houses (Bonwitt et al., 2017). According to Fichet-Calvet et al. (2007), the average trapping success of *M. natalensis* has always been higher inside houses. This is of concern as *M. natalensis* is a competent reservoir of important zoonotic infections such as LASV (Lecompte et al., 2006;

Kronmann et al., 2013). *Rattus norvegicus* is also known to live close to humans (Panti-May et al., 2016). In most urban areas, high populations of *Rattus norvegicus* are supported by poor sanitary conditions (uncollected garbage), open sewers or drains and poor housing constructions which favour burrowing activities (Costa et al., 2014; Panti-May et al., 2016).

Generally, rodents are described to exhibit spatial and temporal fluctuations in population figures (Massawe et al., 2011). Ecological studies indicate that abundance of rodent species, especially in houses, spikes during the dry season. Their numbers are twice as many in houses compared to the rainy/wet season, perhaps due to the abundance of food supply indoors, which may be limited in the wild or outdoor (Fichet-Calvet et al., 2007). On the contrary, Massawe et al. (2011) recorded high populations of *Mastomys natalensis* both during and after the rains. For Norway rats (*Rattus norvegicus*), the study by Panti-May et al. (2016) in Brazil revealed that their population abundance was independent of the season because high numbers were recorded regardless of the season.

2.4.2 Domestic Animals as Sources of Zoonoses

Domestic animals have lived along with humans for several centuries and have contributed in no small way to their well-being. Yet these animals, which include livestock and pets or companion animals, are essential sources of zoonotic infections. For this study, only companion animals are discussed.

2.4.2.1 Companion Animals

Keeping animals as pets or companion animals has been an old-age practice. Since the middle of the 20th century, pets or companion animals have often been considered family members within households and sometimes are substitutes for children (Beck & Meyers, 1996; Chomel, 2014). Keeping companion animals has become integral to most cultures in different societies (Beck & Meyers, 1996; Islam & Towell, 2013).

People keep companion animals for various reasons and benefits. Several studies have enumerated the benefits of owning these animals (Wright, Jung, Holman, Marano, & Mcquiston, 2008; Esch & Petersen, 2013, Chomel, 2014), although other studies gave contradictory outcomes (Islam & Towell, 2013). Companion animals are of significant value to children and older adults, especially the aged and infirmed. Children who live in homes where companion animals are kept are identified to have some social, educational and health benefits (Prokop & Tunnicliffe, 2010). Keeping companion animals is known to promote social, healthy and educational merits in children (Prokop & Tunnicliffe, 2010). Interactions with companion animals are said to positively impact physiological functions like blood pressure as well as the psychological well-being of the owner (Beck & Meyers, 1996; Chomel, 2014). Again, keeping companion animals is well acknowledged to curb loneliness, as is evident in many situations. The aged/elderly are also provided with meaningful regular activities when they care for their companion animals. This practice is said to keep them active. Furthermore, some companion animals have also been used for Animal Facilitated Therapy (AFT) (Beck & Meyers, 1996) and other alternative forms of treatment until this very day.

Companion animals, as defined by the CALLISTO (Companion Animals multisectoraL interprofessionaL and Interdisciplinary Strategic Think tank On zoonoses) project, encompass domesticated animals or house-bred or wild-caught animals permanently held captive by people for companionship, pleasure, work or psychological support (Rijks, Cito, Cunningham, Rantsios, & Giovannini, 2016). These animals usually spend most of their lives within the domestic setting in a close physical relationship with their owners (Day, 2011).

Animals that are kept as pets or for companionship include but are not limited to dogs, cats, rabbits, ornamental fish, birds and some reptiles (Damborg et al., 2016; Rijks et al., 2016). Similar to the advanced countries, dogs and cats are the commonest and most preferred of animals kept as companion animals in sub-Saharan Africa, including Ghana (Islam & Towell, 2013; Amissah-Reynolds et al., 2016; Goni et al., 2018; Issah, Ansah, & Alagma, 2020).

For centuries, dogs and cats have shared the environment with man (Chomel, 2014). Reports show that companion animal populations (dogs and cats) have increased significantly in developed and developing countries (Chomel, 2014; Damborg et al., 2016; Mekibib & Sheferaw, 2018). As of 1994, about 56% of households in the United States had companion animals, with more than half of these households owning more than one companion animal (Beck & Meyers, 1996). A more recent estimate showed that more than 77 million dogs and 93 million cats are found in households in the United States (Esch & Petersen, 2013). Similar trends have been observed in Australia, Europe, Japan and China (Islam & Towell, 2013).

In 1992, a survey conducted in South Africa revealed that over 3.9 million dogs and nearly 1 million cats were found in households (Odendaal, 1994). Unfortunately, there are no estimates of pet/companion animal ownership in Ghana yet. In a study by Woodcock et al. (2001), pet ownership in Ghana was relatively high, although disproportionately low compared to the Western countries.

In recent times, the bond between man and companion animals (especially dogs and cats) has become so strong that they may be found to share the same bed or meal plates with their owners in some regions of the world. Besides, some dogs and cats are provided with an excellent standard of healthcare, although others do not enjoy such benefits since their owners may not be able to afford such luxury. It is worth noting that about $ 103.6 billion were spent by owners of companion animals or pets in the United States of America (U.S.A) alone (American Pet Products Association [APPA], 2021). This is far from the situation witnessed in Africa, where some companion animals get limited care due to poverty (Amissah-Reynolds et al., 2016; Chidumayo, 2018). In all, attitudes toward companion animals are influenced by social interest, culture, occupation and religion, among other factors (Macpherson, 2005).

2.4.2.2 Dog: Man's Best Friend

For several decades, dogs (*Canis familaris*) have been great companions of man to the extent that they are referred to as 'man's best friend'. They are thought to have been domesticated before cats and were initially drawn to hunter-gatherer societies (Mahlaba et al., 2017). Human-dog interactions have had significant implications on humans' social, economic and health costs over the years (Kardjadj & Ben-Mahdi, 2019). Dogs have been associated with human activities such as hunting, herding and protection, commonly observed in developing countries, although they are mostly kept as companions in developed nations. In the western world, dogs are owned for various reasons; psychological, health-wise or simply for companionship where they are given the best of care. These dogs are taken out for walks almost every morning, well-groomed and given excellent veterinary care.

On the contrary, in developing countries like Ghana, dogs are mostly kept to protect their owners against intruders, that is, for security reasons (Woodcock et al., 2001). Findings from research by Amissah-Reynolds et al. (2016) in Mampong in the Ashanti region of Ghana showed that most (70%) dogs owned were for security purposes only. It is obvious that dogs in such parts of the world are infrequently vaccinated or dewormed against infections and lack proper health attention even when ill. Forty-six per cent (46%) of participants in the study by Amissah-Reynolds et al. (2016) had never dewormed their dogs, yet the majority (73%) of them fed their dogs straight off the ground.

Dogs in this part of the world do not get the best care. Improper housing for these dogs or the lack of it produces the best environment for their health status to be compromised. Again, because of the lack of policies on pet ownership or reinforcement, these animals are not given the best veterinary care. As such, dogs who may be infected with zoonotic pathogens in such communities will act as potential agents of zoonoses because they directly defecate pathogen-infested faeces into the environment where humans constantly live (Amissah-Reynolds et al., 2016; Mulugeta et al., 2019).

In recent times, this trend appears to be changing in some urban areas where the affluent reside. These 'modern dog owners' are much more bonded to their dogs than was traditionally the case. Presently, more exotic species of dogs in various sizes are being kept as companion animals in households where they are treated especially like family members. These dogs are given very interesting names such as Mr Spike, Rooney, Champion, and well-meaning traditional names, which are usually influenced by many factors. The breeds of dogs found in Ghana include Alsatians, the German shepherd, Boerboels, Rotweiller and Labradors. Quite recently, the keeping of exotic breeds of dogs has taken a different turn altogether. The affluent and famous are commonly sighted with exotic species of dogs on social media platforms. Such exotic species may seem to be kept as status symbols by their owners to improve their social standing in society. In the capital of Ghana, it is relatively a common sight to find these dogs in luxurious cars with their owners. All these notwithstanding, most Ghanaians have yet to fully grasp the habit or attitude of keeping their companion animals comfortable and healthy.

2.4.2.3 The Domestic Cat

Cats, scientifically referred to as *Felis catus*, have been connected to the human population for several decades. It is said that wild cats, some time past, were attracted and drawn to human settlements for predatory activities of feeding on rodent pests that wreaked havoc on farms and destroyed many grains in storage (Serpell, 2013; Mahlaba et al. 2017). To date, cats are still used to control the populations of rodents in human settlements and agricultural settings (Woodcock et al., 2001; Serpell, 2013; Bukar-Kolo et al., 2018), a popular reason for keeping these animals in low-income countries as compared to the advanced countries where they serve primarily as companions. In some developed countries, they are considered family members and treated as such (Passantino & Masucci, 2016).

Regrettably, in the sub-Saharan region, there is unsatisfactory veterinary care for these companion animals and inadequate regulations and education for their owners. Furthermore, in Africa, several myths and superstitions have been linked to the domestic cat (Bukar-Kolo et al., 2018). In the middle ages, cats were associated with witchcraft and demonic activities (Turner & Bateson, 2000; Bukar-Kolo et al., 2018). Until now, some believe witches do turn into cats, among other beliefs. Because of these beliefs, the domestic cat has been harshly victimised for several decades (Serpell, 2013; Bukar-Kolo et al., 2018).

Cats are usually solitary animals and feed on many small vertebrates by ambushing their prey. Mammals are the most common prey of domestic cats, next to birds, reptiles, amphibians and invertebrates (Loyd, Hernandez, Carroll, Abernathy, & Marshall, 2013). Rodents form an essential diet of cats, especially feral cats; however, a video monitoring of free-roaming cats in the South Eastern United States revealed that 33% of prey retrieved from outdoor cats were reptiles (Loyd et al., 2013).

The population of cats worldwide is unknown since, according to Carvelli, Iacoponi, & Scaramozzino (2016), cat census has not yet been identified as a critical asset to public health. The population of cats kept as companion animals in Ghana is also lacking. Bukar-Kolo et al. (2018) conducted a survey to determine the human-cat relationship, myths or superstition, and their effect on cat ownership revealed that 168 households owned a cat in Maiduguri, North-eastern Nigeria. Out of this number, about 55.5% of the cats were kept by older women. Similar to the situation in Ghana, Bukar-Kolo et al. (2018) also observed that cats were not given appropriate feed, medications and shelter.

2.4.2.4 Companion Animals as Sources of Zoonotic Infections

Companion animals are potential sources of emerging and re-emerging infectious diseases of humans that are of significant public health concern (Rijks et al., 2016). They are recognised to be vital in transmitting various zoonotic diseases (Goni et al., 2018). Close contact with companion animals creates optimal conditions or opportunities for transmitting zoonotic pathogens. The movement of humans and their domestic animals, for instance, has been identified as the conduit for the transmission of zoonoses since antiquity (Macpherson, 2005). The CALLISTO project, for example, played a critical role in raising risk awareness in healthy human-animal relationships. It aimed at giving an overview of the role of companion animals as sources of infectious diseases for man and food animals, discovering knowledge and technology gaps for very relevant zoonotic diseases and recommending directed actions to cut down risks of zoonoses from companion animals (Rijks et al., 2016).

Dogs have been implicated in several infectious disease transmission to humans due to the close interactions between them. They are hosts of many zoonotic infections, which are of considerable health importance to man worldwide. As such, dogs are said to be sentinels for human diseases (Salb et al., 2008). A cross-sectional study by Ortega-Pacheco et al. (2015) alluded to the fact that there existed a common source of zoonotic diseases between dogs and humans. According to Jones et al. (2008), dogs act as intermediaries for over sixty zoonotic infections transmitted to humans. For instance, dogs share similar pathogens like *Toxoplasma*, *Cryptosporidium*, *Giardia*, *Ancylostoma* and *Toxocara* with humans (Macpherson, 2005; Gerhold & Jessup, 2013; Ortega-Pacheco et al., 2015; Ebani, 2017; Mekibib & Sheferaw, 2018; Boyko et al., 2020). Dogs are also a probable source of methicillin-resistant *Staphylococcus aureus* and probably cause the zoonotic spread of genetic elements responsible for anti-microbial drug resistance(Cutler, Fooks, & Van Der Poel, 2010).

The potential zoonotic risk presented by dogs is highly affected by the natural cycle of the particular pathogen with which the dog is infected. To this, Kardjadj and Ben-Mahdi (2019) believe that a comprehension of the demographic features of the population of dogs could significantly impact the transmission and maintenance of pathogenic agents.

Cats are also a potential source and reservoir of key parasitic, viral, bacterial, and fungal zoonotic organisms (Gerhold & Jessup, 2013; Taetzsch, Bertke, & Gruszynski, 2018). For instance, cats are associated with zoonotic diseases like toxoplasmosis, toxocariasis and bartonellosis (Gerhold & Jessup, 2013). They are the only definitive host and only source of *T. gondii* oocysts in the environment (Taetzsch et al., 2018). Zoonotic infections from cats are transmitted to humans either directly (such as inoculation into a scratch wound or bite) or indirectly, for instance, by ingesting the pathogen that has been shed into the environment through the faeces (Taetzsch et al., 2018). Cats are known to prefer sandy substrates where they defecate and so such environments have potentially high parasite load. Investigations of soil samples in the United States, Japan and the UK revealed that 30% of playground soil and 75% sandbox soil tested were positive for the eggs of *Toxocara* sp. (Rabinowitz & Conti, 2010).

2.5. Agents of Zoonotic Diseases

Pathogens that can infect two or more species and persevere in other species with a greater host population are accountable for nearly all the recent outbreaks of diseases (Daszak, Cunningham, & Hyatt, 2000; Cleaveland et al., 2001). Several pathogens of public health, agricultural or economic relevance are transmitted by domestic animals (including companion animals) and animals from the wild. Approximately 50% of bacteria, 70% of protozoa, 95% of helminths and 80% of viruses infective to humans and animals are transmitted by these two groups (Taylor et al., 2001).

2.5.1 Bacterial Zoonoses

Bacterial agents cause most zoonotic diseases compared to other pathogens (Han et al., 2016; Ebani, 2017). A greater part of emerging infectious disease pathogens was identified by Jones et al. (2008) to be either bacterial or rickettsial in origin. In addition, Perkins et al. (2005) believe that bacteria zoonoses and fungi are thrice more likely to lead to emerging diseases than non-zoonotic bacteria and fungi. Quantitative analysis by Taylor et al. (2001) discovered that out of 1,415 infectious pathogens studied, bacteria or rickettsia made up 31% of zoonoses (emerging and non-emerging). In a study by Zhang et al. (2016), about 870 prospective inpatient cohorts from 2007-2008 in the Kilimanjaro region of Tanzania had more than 25% of febrile hospital admissions attributed to bacterial zoonoses.

Undoubtedly, foodborne bacterial zoonoses attracted much attention in time past as compared to companion animal-related bacterial zoonoses (Damborg et al., 2016). However, this trend appears to be changing since bacterial zoonoses caused by infected animals are recognised to pose serious challenges to the health of the human population (Chomel, 2014; Ebani, 2017). For example, companion animals are reported to be infected with a wide array of bacteria that could be pathogenic to humans and other animals (Damborg et al., 2016). They provide a conduit for spreading zoonotic bacterial infections (Goni et al., 2018).

Bacterial infections from companion animals are usually transmitted through bites, scratches, petting or licking. People typically get infected due to their age or immune status and closeness with the animal (Meerburg et al., 2009; Chomel, 2014; Damborg et al., 2016). Children are more likely to suffer from zoonotic bacterial infections as they tend to have more direct contact with companion animals and become exposed to bacteria from the animal and contaminated household environment (Damborg et al., 2016).

On the other hand, rodent-borne zoonotic bacteria are transmitted to humans directly through bites or scratches and indirectly through contamination of the environment. Rodents habitually visit sites (sewers & garbage disposals) where bacteria flourish and are good reservoir hosts of several bacterial pathogens. Infected rodents can transmit *Salmonella*, *Leptospira* and Campylobacter to humans through their droppings (Meerburg, 2006; Mgode et al., 2014; Costa et al., 2015).

2.5.1.1 *Staphylococcus*: Aetiology, Transmission and Impact on Human health

Staphylococcus is a gram-positive bacterium in the order Bacillales (Family: Micrococcaceae) which usually appear spherical or cocci in shape and form clusters like a bunch of grapes under the microscope (Foster, 1996). *Staphylococci* are facultative anaerobic bacteria, non-motile and unable to generate spores. They are commensals that can colonize the skin, sebaceous glands and the mucosa of humans and animals (Vincze, 2014).

The genus *Staphylococcus* comprises about 72 species and sub-species, including *Staphylococcus aureus*, *S. epidermidis* and *S. pseudointermedius* (Foster, 1996; Vincze, 2014). The taxonomy of *Staphylococcus* is based on the 16S rRNA (Ghebremedhin, Layer, König, & König, 2008). The *Staphylococcus* bacteriae can colonize an extensive range of species: birds, reptiles and mammals (humans, domestic and wild), and transmissions are either through aerosols or by directly coming into contact with infected animals, persons or fomites.

About 30% of humans are colonised with *Staphylococcus aureus*, a very important bacterium (Mrochen et al., 2018) that causes a wide range of infections in humans and animals (Vincze, 2014). *S. aureus* is a common human commensal pathogen responsible for superficial skin infections like boils, keratitis, and impetigo, and severe and deep-rooted infections like osteomyelitis, pneumonia, sepsis and furunculosis in humans (Foster, 1996; Mrochen et al., 2018). This opportunistic bacterium is also responsible for most of the nosocomial infections of surgical wounds reported worldwide (Mrochen et al., 2018). The spread of methicillin-resistant *S. aureus* (MRSA) raises health concerns and global security because of the limited treatment options for this bacteria (Vincze, 2014).

Companion animals like dogs and cats are mostly colonised with *Staphylococcus pseudointermedius* (Chomel, 2014). However, many cases in time past pointed to the existence of *Staphylococcus aureus*, which later became a growing concern in veterinary medicine (Vincze, 2014). Reports show that both species, *S. aureus* and *S.*

pseudointermedius are found on the skin or mucous of companion animals. Hence, close contact between companion animals and humans could support conditions for zoonotic transmission of *S. aureus* (Gómez-Sanz, Torres, Benito, Lozano, & Zarazaga, 2013).

Staphylococcus aureus appears to be commonly linked to wound infections in dogs and cats. Some case reports have also revealed the zoonotic potential of MRSA between owners within a household and companion animals (Vincze, 2014). Weese et al. (2006) isolated MRSA from five (5) dogs and three (3) cats who exhibited clinical infections, a cat that had been in contact with two (2) infected cats and 16% of household contacts or veterinarians. Their study further suggested that MRSA could be transmitted between humans and animals several times within a household or veterinary clinic. Ge et al. (2019) likewise isolated eleven (11) MRSA from urban rodents and a single MRSA isolate from a house shrew in Guangzhou, China. They observed that the isolates from the rodents had comparable antimicrobial resistance and molecular features to those found in humans.

2.5.1.2 *Salmonella:* Aetiology, Transmission and Impact on Human Health

Salmonellae are gram-negative bacilli that belong to the family *Enterobacteriaceae* (Pan American Health Organization, 2001; World Health Organization [WHO], 2018). This bacterium is a facultative anaerobe that appears rod-shaped. The genus *Salmonella* is classified into two species by the World Health Organisation (WHO), namely *Salmonella enterica* (type species) and *Salmonella bongori* based on variation in their 16S rRNA sequence (Eng et al., 2015). Classification by serotype based on three key antigenic determinants, somatic (O), capsular (K) and flagellar (H), was also developed by Kauffman and White (Eng et al., 2015). In all, more than 2,500 serotypes of *Salmonella* have been identified (Eng et al., 2015; CDC, 2019).

Salmonella typhi and *S. paratyphi* are referred to as typhoidal *Salmonella* strains, while *Salmonella* strains, apart from *S. typhi* and *S. paratyphi*, are termed as non-typhoidal strains (Eng et al., 2015; Johnson et al., 2018). About 93.8 million nontyphoidal *Salmonella* infections are recorded yearly worldwide, with over 150 000 deaths (Majowicz et al., 2010). Out of this estimate, over 80 million of the cases are foodborne. Children (infants and young children) are very vulnerable to this infection; hence disease incidence is highest in this risk group (Majowicz et al., 2010). All serotypes can trigger diseases in humans, but others (Typhi, Sendai, and Paratyphi) tend to be host-specific (Gal-Mor et al., 2014; WHO, 2018). *Salmonella Typhi* causes typhoid fever, whereas *Salmonella* Paratyphi A, B, and C are responsible for paratyphoid fever. Only humans are the reservoir of these two typhoidal *Salmonella* species (Johnson et al., 2018).

Salmonella is transmitted either directly or indirectly via the faecal-oral route (Damborg et al., 2016) or consumption of contaminated food of animal origin (Public Health and Primary Health Care Division, 2011). Humans get infected when they do not practice good hygiene or incidentally ingest contaminated water or food (Eng et al., 2015; WHO, 2018). Primarily, humans are asymptomatic, although some may develop symptoms within 6-72 hours post-infection (WHO, 2018).

Clinical symptoms of *Salmonella* include fever, abdominal cramps and diarrhoea with blood (sometimes without blood for non-typhoidal strains). Gastroenteritis is the frequent symptom of non-typhoidal *Salmonella* infection recorded universally (Majowicz et al., 2010). Vulnerable groups like the elderly, children under five(5), pregnant women, and immuno-compromised individuals are more susceptible to this infection (Trevejo, Barr, & Robinson, 2005). Non-typhoidal *Salmonella* (NTS) strains are mainly found in animal reservoirs (Eng et al., 2015). Two key *Salmonella* species, *Salmonella* enterica serotype

Enteritidis and *Salmonella* enterica serotype Typhimurium, are transferred from animals to humans (WHO, 2018). *Salmonella typhimurium* is associated with acute and renowned pathologies (Ebani, 2017).

All *Salmonellae* are zoonotic except for *S. Typhi* and the paratyphoid serotypes (Pan American Health Organization(PAHO), 2001). Animals serve as reservoir hosts of zoonotic *Salmonellae*. *Salmonella* colonises a wide range of animal hosts, but they are commonly distributed in domestic and wild animals. Animal reservoirs maintain the animal-to-animal cycle through their excreta or infected eggs of fowls; hence they play a significant role in the epidemiology of *Salmonella* (PAHO, 2001). Companion animals are usually subclinical, yet infections could progress from mild to fatal conditions of gastroenteritis and septicaemia (Marks, Rankin, Byrne, & Weese, 2011).

Many serotypes of *Salmonella* have been detected in dogs and cats who may be asymptomatic or symptomatic (PAHO, 2001; Sanchez, Hofacre, Lee, Maurer, & Doyle, 2002). Reports indicate that dogs get infected when they ingest the faeces of other domestic or peridomestic animals or even humans (PAHO, 2001). A higher prevalence of salmonellosis could be found in stray dogs and cats who feed on raw foods (Marks et al., 2011). It is estimated that between 1 and 36% and 1 and 18% of *Salmonella* spp. are isolated from healthy dogs and cats, respectively(Sanchez et al., 2002). Elsewhere, cat exposure has been documented to be a risk factor for juvenile salmonellosis (Younus et al., 2010). In the case of rodents, they are usually infected with *Salmonella* serotypes most common in their environment (PAHO, 2001).

An increasing number of studies have revealed that reptiles are usually infected by diverse *Salmonella* spp. serotypes (Pedersen, Nordentoft, & Hammer, 2009, Ebani, 2017). For example, *Salmonella enterica* subspecies *enterica* has reportedly been isolated from cold-blooded animals like reptiles (Ebani, 2017). This serotype is the commonest of *Salmonella* species isolated from individuals suffering from Salmonellosis. Reptiles, according to Ebani (2017), most often do not develop the *Salmonellae* disease when infected, but their faeces are a well-known cause of human infections. *Salmonella* is transmitted to dogs and cats from lizards when they feed on the lizards. The bacteria pathogen picked from the lizard could make the dog or cat ill and exhibit symptoms like bloody diarrhoea, vomiting or lethargy.

2.5.1.3 Query Fever/Q Fever: Aetiology, Transmission and Impact on Human Health

Query or Q fever is a ubiquitous zoonotic bacterial disease with an extensive distribution worldwide (Kato et al., 1998; Kargar et al., 2015; Berggren, 2017), although it is not recorded in New Zealand (Ministry of Health New Zealand, 2021). This highly infectious disease is caused by an intracellular, obligate gram-negative bacteria, *Coxiella burnetii*, which is highly sustainable (Weber & Rutala, 2001; Kargar et al., 2015; Berggren, 2017). This zoonotic bacterium was first described in 1937 in Australia (Eldin et al., 2017).

Coxiella. burnetii is considered possible biological warfare (bioterrorism) due to its high infectiousness or virulence (Fenollar et al., 2004; Honarmand, 2012; CDC, 2019). It is also reported to be a common cause of fever in intertropical areas (Eldin et al., 2017). A major outbreak in the Netherlands indicated that the disease could become a critical public health concern (Delsing, Kullberg, & Bleeker-Rovers, 2010). The prevalence of Q fever varies from country to country due to epidemiological differences and whether the disease is reported or not (Eldin et al., 2017). For instance, Q fever was not reported in the United States until 1999, and because of better recognition of disease cases, there was a rise in the number of human cases from 2000 to 2004 (McQuiston & Childs, 2002).

Coxiella burnetii has a wide range of hosts: mammals (big and small) and non-mammals such as fish, amphibians, reptiles and birds. Reservoir hosts comprise domestic animals (cattle, sheep, dogs, cats and goats) and invertebrates (ticks), even though small wild rodents appear to be vital reservoir hosts (Honarmand, 2012; Kargar et al., 2015). This bacteria is usually shed in faeces, urine, milk, vaginal mucus, and semen, as well as birth products of mammals (Kargar et al., 2015). Humans are commonly susceptible to this bacterial infection, and a few are just what is needed to cause an infection (Berggren, 2017). According to Kersh et al. (2010) and Honarmand (2012), because this pathogen is highly infectious, one to ten organisms can cause Q fever in humans. The main source of human infection is farm animals (Fenollar et al., 2004) and domestic cats and dogs (Shaw, Day, Birtles, & Breitschwerdt, 2001). Clinically healthy cattle are known to be the primary source of *C. burnetii* infections in Iran (Rahimi, Doosti, Ameri, Kabiri, & Sharifian, 2010).

Humans acquire this infection through inhalation of infected fomites from domestic animals, usually after contact with parturient animals and their birth products, wool and via the consumption of contaminated food like milk (Weber & Rutala, 2001; Kargar et al., 2015). Though some researchers believe milk is a route of disease transmission, Vicari et al. (2013) believe otherwise. They suggest that this route is not an efficient one. In a study by Kargar et al. (2015), they detected the presence of *C. burnetii* in 70 bovine milk samples by PCR targeting three different genes. Prevalence of 17.14%, 10% and 10% were recorded using Trans-PCR, OMP-PCR and Coc-PCR, respectively. Human infections have been reported from intradermal injections, transfusion of blood, transplacental transmission and autopsies (Weber & Rutala, 2001). Tick bites are also transmission routes of Q fever (Berggren, 2017).

An important feature of this bacterium is its ability to survive for long periods in various environments since it is desiccation-resistant. According to Weber and Rutala (2001), even winds can spread this pathogen for long distances facilitating its easy transmission. Thus one can get infected without close contact with animals. Contaminated clothes have also been identified as a source of infection in humans (Weber & Rutala, 2001).

Coxiella burnetii can cause chronic and acute infections in humans (Kato et al., 1998; Raoult et al., 2000; Fenollar et al., 2004). Acute Q fever is typically benign, with about 60% of infected patients known to be asymptomatic, while for symptomatic persons, clinical presentations are broad and polymorphic (Fenollar et al., 2004). The main forms of acute Q fever that have been defined are mostly febrile sicknesses, jaundice, muscle pains and shortness of breath (Fenollar et al., 2004; Honarmand et al., 2012). *C. burnetii* can survive for protracted periods in the host leading to chronic infections (Berggren, 2017). Chronic Q fever is predictably fatal and persons suffering from it usually suffer from endocarditis (Fenollar et al., 2004; Eldin et al., 2017).

Kato et al. (1998) found 33% of the patients to be positive in using PCR to detect *C. burnetii* in blood samples from 52 patients with chronic nonspecific symptoms. These patients had been sick with headaches, lethargy, and muscle and joint aches for over a decade and had no diagnostic or treatment history of Q fever. They also found 9.6% of 52 healthy samples positive for *C. burnetii*. Their findings indicated a high proportion of infection among adult patients with lifelong, general complaints who lived closely with animals.

2.5.1.4 Antimicrobial/Antibiotic Resistance

Antimicrobial resistance, a topmost priority issue in contemporary times, has been acknowledged as an emerging public health concern worldwide (Mrochen et al., 2018). The purpose of antimicrobials is to provide great selective pressure on susceptible bacterial population(s), which means that non-susceptible forms can escape this pressure (Wassenaar & Silley, 2008). Antimicrobials are medicines that avert the growth of or destroy microorganisms (World Health Organization, 2017).

Bacterial resistance to antimicrobials is predicted to lead to challenges in selecting therapeutic agents to treat bacterial infections (Lloyd, 2007). Many antimicrobials are used daily, and there is evidence of growing use in the agricultural, veterinary and health sectors. Farm animals, companion animals and humans are regularly treated with these antimicrobials. Some of the substances used in human medicine, according to Lloyd (2007), are also found in antimicrobials regularly used for animals. Indiscriminate use of important antimicrobials in animals leads to modifications in the flora of the colon, creating an ideal environment for replicating resistant bacteria (PAHO, 2001). Eventually, this creates the avenue for the emergence of antimicrobial-resistant pathogens since several pathogens are shared between humans and animals.

Reviews by Bywater (2004) and Bywater et al. (2004) revealed that less than 4% of resistance in antimicrobials observed in humans could be linked to zoonotic organisms, a trend that appears to be changing.

The resistance of bacterial pathogens to some antimicrobials continues to rise globally, which has been revealed by several works on several pathogens (Musser, 1996; Lloyd, 2007; Wassenaar & Silley, 2008; Wright et al., 2008). The threat to global health security is acquiring infections with multidrug-resistant bacteria (Huijben et al., 2013), particularly those with zoonotic potential and pose a tremendous public health challenge for human health and veterinary medicine.

It is worth noting that most bacterial zoonoses are directly associated with the occurrence of drug-resistant bacterial strains (Gebreyes et al., 2014). Therefore, antimicrobial resistance has been identified as an additional risk of bacteria zoonoses worldwide (Gebreyes et al., 2014). Additionally, it is predicted that antibiotic-resistance genes found in some bacteria could probably act as a source of antibiotic resistance that can be transferred to others (Ebani, 2017). For instance, the probable transmission of antimicrobial resistance from enteric zoonotic bacteria in food animals to humans is currently a concern (Bywater et al., 2004).

Multiple antibiotic resistance is commonly reported for *Staphylococcus aureus* (Foster, 1996). This bacterium is identified to have the ability to swiftly develop resistance to several antibiotics used clinically (Pantosti et al., 2007; Ge et al., 2019). Presently, Methicilin-Resistant *Staphylococcus aureus* (MRSA) is of utmost public health importance, causing numerous health issues (Musser, 1996; Baptiste et al., 2005; Lloyd, 2007). Strains of *S. aureus*-resistant methicillin were documented in the United Kingdom shortly after clinical use, and later on, hospital outbreaks were reported in Europe (Musser, 1996).

There is a rise in livestock-associated methicillin-resistant *S. aureus strains* like ST398 and multidrug-resistant (MDR) methicillin-resistant *S. pseudintermedius* (MRSP) in dogs in Europe and North America (Perreten et al., 2010; Gómez-Sanz et al., 2013). Companion animals are said to be the origin of infection of multidrug-resistant bacteria of zoonotic potential (Damborg et al., 2016). Several studies have reported MRSA in companion animals (Van Duijkeren et al., 2004; Baptiste et al., 2005; Llyod, 2007, Chomel, 2014), which is undoubtedly an emerging health issue globally. In the United States of America, for example, MRSA is considered an emerged pathogen of importance among companion animals and horses in the field of veterinary medicine (Wright et al., 2008; Espinosa-Gongora et al., 2012). Increasing reports suggest that these animals (for instance, dogs and cats) play vital roles in household MRSA transmission (Baptise et al., 2005; Llyod, 2007; Weese et al., 2006). In cases of dog-to-human transmission of MRSA, dogs act as reservoir hosts (van Duijkeren et al., 2004).

For animals in the wild, a study by Ge et al. (2019) to characterise *S. aureus* and MRSA in urban rodents in china recorded the prevalence rate of *S. aureus* to be 25.4%. In addition, they observed that urban rodents carried various MRSA strains, including strains discovered in humans and domestic animals.

Salmonella resistance profiles correlate strongly to particular serovars (Wassenaar & Silley, 2008). An estimated 60%-80% of *Salmonella typhimurium* clinical isolates found in Kenya have been identified as multi-drug resistant (Gebreyes et al., 2014). A worrying trend observed by contemporary studies points to a multidrug-resistant haplotype (H58) that is spreading across Africa from Southeast Asia, where it is quickly escalating (Kariuki et al., 2010). Currently, there are urgent calls for best practices and the prudent use of antimicrobials in healthcare delivery, veterinary services and the agriculture sector for the prevention and control of antimicrobial resistance (Bywater et al., 2004; Lloyd, 2007; Damborg et al., 2016; World Health Organization, 2017). Prudent use of antimicrobials will also help prevent the occurrences or spread of resistant phenotypes (Gebreyes et al., 2014; WHO, 2017).

2.5.2 Parasitic Zoonoses: Helminthiasis

Intestinal helminth infections are common infections with significant health concerns worldwide. Higher prevalence rates are reported in countries/communities with poor sanitary conditions, low socioeconomic status, and inadequate supply of social amenities. Helminths are responsible for several diseases that cause many morbidities in humans, especially children, the elderly and pregnant women. Almost all helminths (95%) pathogenic to humans are said to be zoonotic and are transmitted by direct or indirect contact with the infective stages (Taylor et al., 2001; Ayinmode, Obebe, & Olayemi, 2016). Most helminth infections are Soil-transmitted helminths (STHs). STH are helminths that have part of their developmental stages taking place in the soil. Nearly two billion persons are infected with STH globally.

Companion animals and rodents play vital roles in transmitting important zoonotic helminth infections. Thus, keeping companion animals is a major risk factor in contracting zoonoses. Ekong, Juryit, Dika, Nguku, & Musenero (2012) suggested a direct link between the occurrence of zoonotic helminth infections in humans in any area/locality and the occurrence of diseases in animals found in that same area. This was confirmed by Mulugeta et al. (2019), who documented an overall prevalence of 71.6 % of helminth infection in dogs in Hossana, Ethiopia. Furthermore, a prevalence rate of 17.62% was recorded in their owners. A more recent study by Boyko et al. (2020) also reported that individual dog ownership was a major predictor of hookworm infection in Kintampo North, Ghana, affirming the view of Ekong et al. (2012). Often, companion animals excrete eggs and cysts of important helminth species into the human environment predisposing their owners and anyone else who lives in such an environment to zoonotic infections.

Different prevalence of zoonotic helminth infections at various geographical locations have been reported in companion animals. For instance, the mean prevalence of 18.1% was documented by Ekong et al. (2012) in Jos, Nigeria. A similar study by Amissah-Reynolds et al. (2016) established that about 53% of dogs sampled in Mampong in the Ashanti region had helminths infections. They further observed that dogs kept for companionship recorded a higher prevalence (69.2%) of zoonotic helminths than dogs that were used for hunting (66.7%) and security (44.0%) purposes, even though statistically, the differences were not significant.

Several zoonotic helminth infections are of public health concern, but only hookworm (*Ancylostoma* spp.), *Toxocara* sp. and *Strongyloides stercoralis* were considered in this present study. All three species are key zoonotic helminths distributed worldwide (Taetzsch et al., 2018), yet they are regarded as either Neglected Tropical Diseases or Neglected Zoonotic Diseases (Hotez et al., 2016; Varatharajalu & Rao, 2016; World Health Organization [WHO], 2021). According to Chidumayo (2018), *Ancylostoma* and *Toxocara* are the most frequently documented helminths in sub-Saharan Africa.

2.5.2.1 Hookworm: Aetiology, Transmission and Impact on Human Health

Hookworms are haematophagous intestinal nematodes that infect humans, companion animals (dogs and cats), and other mammals (Liu et al., 2013; Hu et al., 2015). These nematodes belong to the superfamily Ancylostomatidea. Over half a billion persons are affected by hookworm infections worldwide (Centers for Disease Control and Prevention[CDC], 2020). Hookworm infection causes significant morbidity in resource-limited countries, especially. Disability Adjusted Life Years (DALYs) associated with hookworm are estimated to be 3.23 million (Pisarski, 2019).

Ancylostoma is a blood-feeding parasite that infects companion animals and other mammals, with species prevalence suggested to be linked to geographical distribution (Liu et al., 2013). Several hookworm species can produce patent infections in specific hosts, and many of these parasitic nematodes are zoonotic (Spickler, 2013). *Ancylostoma duodenale*, *Necator americanus* and *Ancylostoma ceylanicum* are hookworms maintained in humans and are responsible for patent infections, though other rare intestinal infections caused by other hookworm species are reported elsewhere (Spickler, 2013). Until recently, *Ancylostoma duodenale* and *Necator americanus* were the classical intestinal hookworms known to be pathogenic to humans before some studies pointed to *A. ceylanicum* as an emerging intestinal nematode of public health concern (Centers for Disease Control and Prevention[CDC], 2019). This notwithstanding, *Ancylostoma duodenale* and *Necator americanus* which are found in warm and tropical regions of the world are the two commonest hookworms accountable for most human infections (Gamar, Musa, Altayb, Mohamed, & Abakar, 2018). All three species are reported to share similar life cycles but differ in their pathogenicity and host specificity (Hii et al., 2018).

Ancylostoma ceylanicum, which is well-known as the second most prevalent hookworm species in the Asia Pacific region, is also zoonotic in nature (Hii et al., 2018). It is reported in some parts of Asia, Africa, Australia, and the Middle East. Research indicates that the adult worm can reach maturity and patent intestinal infections in humans only for a short time (Torgerson & Macpherson, 2011). Nevertheless, it continues to gain recognition as an intestinal parasite of humans (CDC, 2019). Reports show that *A. ceylanicum* has been observed in 6-23% of patent infections in humans in certain parts of Asia (Spickler, 2013). Cats and dogs are recognised to be the primary reservoirs of *A. ceylanicum* for human diseases in households or communities (Inpankaew et al., 2014).

Ancylostoma ceylanicum, in addition to *Ancylostoma caninum and A. braziliense*, are identified aetiological agents of canine hookworm infections (Torgerson & Macpherson, 2011). Ortega-Pacheco et al. (2015) recorded a relatively high prevalence rate (70.8%) of *Ancylostoma caninum* from dogs in a rural community of Yucatan, Mexico. *Ancylostoma caninum* was also recognised as the predominant helminth (91.8%) found in Yarrabah dogs in Australia (Smout, Skerratt, Johnson, Butler, & Congdon, 2018). However, in their research, Smout et al. (2018) did not record *A. ceylanicum* infection in the sampled domestic dogs.

In felids(cats), *A. ceylanicum*, *A. tubaeforme* and *A. braziliense* are frequently detected (Torgerson & Macpherson, 2011; Spickler, 2013). Even though *A. caninum* infections are mostly reported in dogs, findings from a study by Liu et al. (2013) revealed otherwise. In their work, the prevalence of *A. caninum* recorded in cats using a molecular technique and microscopy were 95.1% and 83.3%, respectively. The prevalence of *A. caninum* infection was 54.9%, and mixed infections with both *A. caninum* and *A. ceylanicum* were 40.2%. Their results suggested that cats may be the definitive host of *A. caninum* in China. Furthermore, they pointed out the possibility of cross-infection between dogs and cats in that region.

Ancylostoma caninum and *A. braziliense* are recognised zoonotic hookworms connected to human diseases. Infections with *A. caninum* are documented to cause eosinophilic enteritis, while *A. braziliense* is known for causing cutaneous larval migrans (Torgerson & Macpherson, 2011; CDC, 2019). Sometimes, *A. caninum* ends up in the intestines of humans. Both species are distributed in tropical and sub-tropical regions of the world, even though *A. caninum* has been described as the most widespread hookworm (Torgerson & Macpherson, 2011; Spickler, 2013; Gamar et al., 2018).

Humans become diseased with hookworms (both zoonotic and non-zoonotic) via ingestion or skin penetration culminating in various clinical presentations (Torgerson & Macpherson, 2011; Spickler, 2013). Most zoonotic hookworms remain in the epidermis, where they migrate briefly before dying. They are responsible for iron deficiency anaemia, retardation of intellectual growth and physical development in children (World Health Organization [WHO], 2020). In pregnant women, infections may cause severe complications, low birth weight and increased infant mortality (Hotez & Whitham, 2014; Hii et al., 2018). These worms also cause abdominal pain and diarrhoea when found in the intestines, respiratory conditions, and other symptoms during larvae migration through the host body (Spickler, 2013).

The eggs of species of hookworms are excreted in the faeces of an infected animal or person. When these get deposited onto the field or soil or bushes, they mature and hatch into infective larvae that can penetrate the skin or be ingested, leading to diseases. These eggs can survive for several months to years in the environment (Pisarski, 2019). Diagnosis of hookworm infections is by the detection of eggs in the stool of an infected individual either through microscopy or molecular techniques, with the latter being more effective and accurate than the former because of the morphological similarity of the eggs of the various *Ancylostoma* spp. Diagnosis of zoonotic hookworms is even more challenging, and this is usually done using clinical indications, positive serology and implicitly through a patient's speedy recovery after treatment with mebendazole (Torgerson & Macpherson, 2011).

A prevalence rate of about 29% of hookworm infection in humans has been recorded in sub-Saharan Africa (Hotez & Kamath, 2009). In the research by Fèvre et al. (2017) to study human and animal infectious diseases in Lake Victoria, Kenya, they recorded a high prevalence of humans (36.3%) infected with hookworm (*Ancylostoma duodenale*/*Necator* *americanus*). They, however, observed that exposure to other zoonotic infections was comparatively fewer.

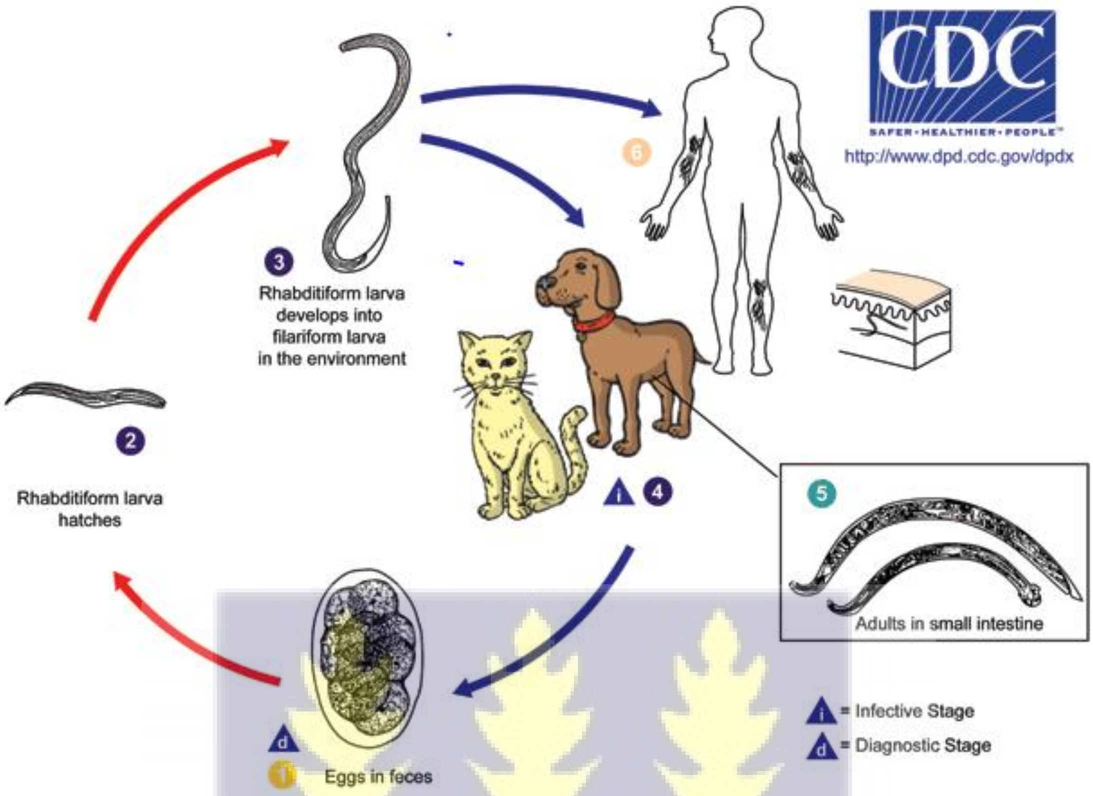

Figure 1: The life cycle of the hookworm

In Ghana, various studies have reported different prevalence of hookworm infections in humans and companion animals. In North-eastern Ghana, a high prevalence rate of 50% was documented by Yelifari et al. (2005). At Kintampo North, Humphries et al. (2011) recorded an overall prevalence of 45% in humans. A prospective study by Boyko et al. (2020) in the same area also found hookworm eggs in 43% of dog faecal samples collected using microscopy. However, after using PCR, a prevalence rate of 47% was observed, and the hookworm was identified as *Necator americanus*.

In Southern Ghana, prevalence reported in companion animals are not too far from prevalence documented in Northern Ghana. In the Greater Accra Region, Johnson et al.

(2015) found Ancylostoma eggs in 46.8% of dogs that were sampled in their study. Interestingly, these dogs were owned and not stray calling into question the care these companion animals receive from their owners. A relatively lower prevalence of 16.9% of *Ancylostoma* spp was reported in dogs in Mampong, Ashanti Region (Amissah-Reynolds et al., 2016).

2.5.2.2 Toxocariasis: Aetiology, Transmission and Impact on Human Health

Toxocariasis is a prevalent zoonotic infection of global health importance. This disease causes considerable socio-economic impact, especially on poor communities and it is estimated to affect millions of children who are found in these communities (Torgerson & Macpherson, 2011; Chen et al., 2018). Toxocariasis is reported in several countries although the majority of cases are found in the U.S.A, Austria, France, Japan, Korea, Brazil and China (Chen et al., 2018). The past few years saw Toxocariasis gaining much attention due to increased cases and eventually, it was put on the list of the five most neglected parasitic infections by the United States Centre for Disease Control (Chen et al., 2018). An estimated 14% of people in the United States of America are reported to be infected with *Toxocara* spp. (Woodhall, Eberhard, & Parise, 2014).

Toxocariasis is caused by the pathogen *Toxocara*, a nematode of the family Toxocaridae. Members of the genus *Toxocara* comprise four valid species: *Toxocara canis*, *T. cati*, *T. vitulorum* and *T. malaysiensis* (definitive hosts are domestic animals) (Spickler, 2016; Chen et al., 2018). There are other genus species like *T. tanuki*, *T. apodemi* and *T. paradoxura* which have wild animals as their definitive hosts (Spickler, 2016). *Toxocara canis*, *T. cati* and *T. vitulorum* are recorded globally but *T. malaysiensis* has only been documented in Malaysia, China and Vietnam (Chen et al., 2018).

Wild and domesticated animals as well as birds (for instance quails and ducks) and some invertebrates act as paratenic hosts of this parasite. Domestic animals like dogs and cats play very critical roles in the direct transmission of *Toxocara* by acting as natural hosts who contaminate the environment through which humans get infected (Spickler, 2016; Holland, 2015; Chidumayo, 2018). In dogs, *Toxocara canis* is the *main Toxocara* species whereas felids or cats are the definitive hosts for *T. cati* (Lee, Schantz, Kazacos, Montgomery, & Bowman, 2010). Interestingly, some reports elsewhere have found *T. canis* in the faeces of cats and *T. cati* in canine faeces (Spickler, 2016). *T. malaysiensis* has also been identified in cats (Spickler, 2016).

Alternative to the direct transmission of *Toxocara* spp., this parasite can be transmitted indirectly through an intermediate host, which according to Shakespeare (2009), are mostly small rodents. In this case, the rodents ingest the ova, which later hatches in their small intestine, develops into L2 and then moves into the muscle tissue (Shakespeare, 2009). The encysted larvae are then transmitted to any dog or cat that feeds on the infected rodent. Infected animals may shed several quantities of unembryonated eggs via their faeces. The eggs are not immediately infectious at this stage until they develop into the infective stage (third stage larvae) in the environment (Spickler, 2016).

Mature *Toxocara* worms are responsible for intestinal illnesses in definitive hosts, and the larvae are responsible for organ damage when migrating through the tissues of their definitive and paratenic hosts (Shakespeare, 2009; Spickler, 2016).

Animals develop infections after ingesting embryonated eggs from the contaminated environment or larvae in tissues of paratenic hosts. In adult dogs and puppies, for instance, a number of the larvae may not be able to penetrate the intestinal wall, perhaps due to immunity. Others may penetrate but will not be able to complete the migration from the lungs to the intestines but instead travel to other organs such as the liver, kidneys, muscles and viscera and become dormant hypobiotic larvae (Spickler, 2016). It has also been suggested that *Toxocara canis* may be transmitted *in utero,* unlike *T. cati* (Spickler, 2016).

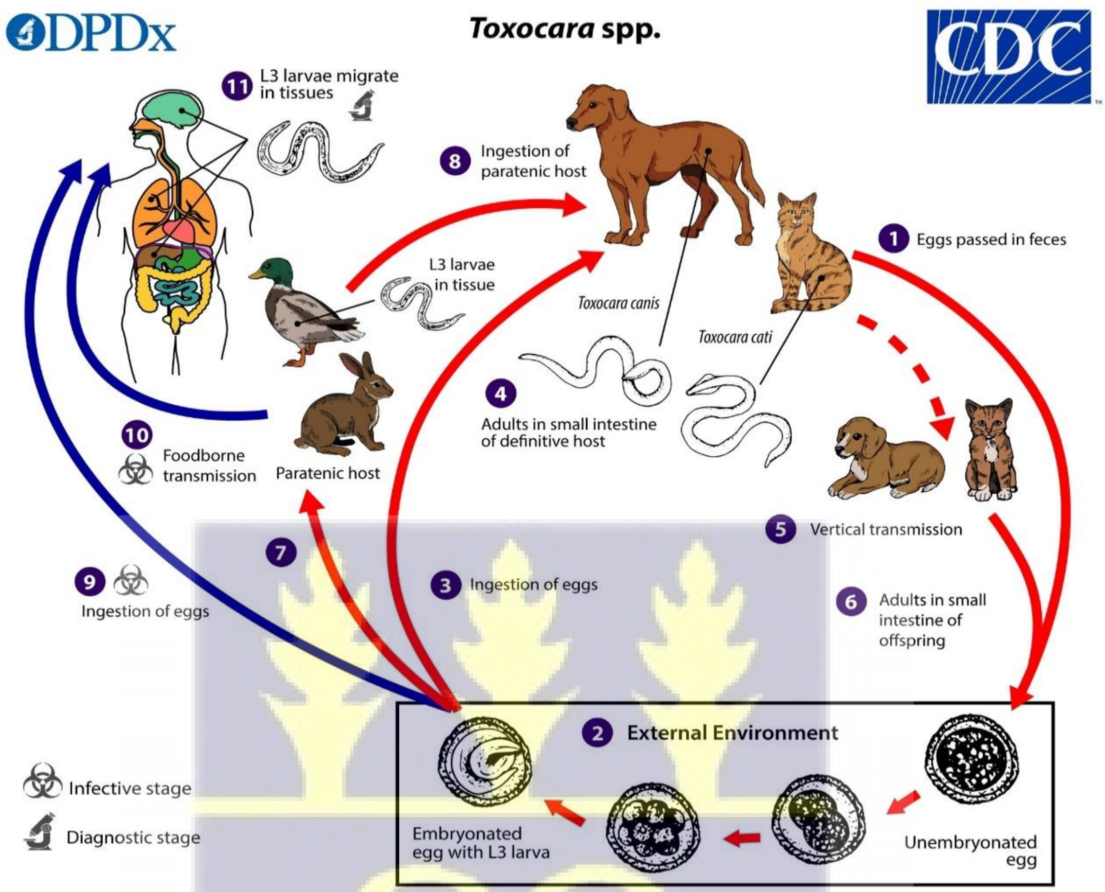

Figure 2: The life cycle of *Toxocara* sp.

Human toxocariasis, a known common helminth infection, is mostly caused by *Toxocara canis* and *T. cati* (Lee et al., 2010; Spickler, 2016). Human infections have been recorded in almost 100 countries since the first human case was reported (Fan, Liao, & Cheng, 2013). Children, in particular, get infected with *Toxocara* when they ingest either the parasite ova or oocysts that are excreted into the environment by dogs or cats through contact with soil or through ingested contaminated products or undercooked meat which contains the cyst (Lee et al., 2010; Taetzsch et al., 2018; Chen et al., 2018). It is reported that many countries, especially their urban public spaces, have environments contaminated with high numbers of

Toxocara eggs (Holland, 2015). Of late, another mode of transmission that has been suggested is contact with embryonated *Toxocara* eggs on the hair coat of dogs (Aydenizöz-Özkayhan, Yağci, & Erat, 2008).

The *Toxocara* parasite can produce extra-intestinal pathologies in infected humans even though infections are mainly asymptomatic (Fan et al., 2013). This parasite does not complete its maturation in humans. Yet, the larva can migrate through the body of humans for a while, causing symptoms that span from mild, inexplicit discomfort, visual disorders, blindness and other neurological syndromes (Spickler, 2016; Chen et al., 2018). Upon ingesting the infective stage, the larvae move through the visceral organs, ocular tissue, heart, and central nervous system. In the process, organs could be damaged, causing severe morbidity (Lee et al., 2010; Taetzsch et al., 2018). *Toxocara canis* also causes diarrhoea, impairs growth and leads to mortality when recorded in high numbers in puppies (Overgaauw & van Knapen, 2013). Some infected dogs are described to excrete eggs more often than others (Nijsse, Mughini-Gras, Wagenaar, & Ploeger, 2016)). These frequent shedders are recognised to pose a great challenge in communities where they live with their owners.

Varying prevalence of *Toxocara* infections have been recorded across the globe. In the Netherlands, Nijsse et al. (2016) reported a prevalence of 4.5 % of dogs infected with *Toxocara*. A relatively higher prevalence of 29.4% was documented in dogs in Australia (Smout et al., 2018). In sub-Saharan Africa, the prevalence rate of 9.8 % of *T. canis* was recorded by Ayinmode et al. (2016) in Ibadan, Nigeria. In Hossana, Ethiopia, Mulugeta et al. (2019) reported a much higher prevalence of 34% *T. canis* infection in dogs.

Some studies in Ghana have also documented different prevalence rates. A study by Johnson et al. (2015) in the Greater Accra region of Ghana reported a prevalence of 5.8%. Similar work by Amissah-Reynolds et al. (2016) in Mampong, Ashanti Region, recorded a comparatively higher prevalence rate of more than 18%. Boyko et al. (2020) also found anti-*Toxocara* antibodies in 62% of dogs recruited for their study in Kintampo. They observed that reactivity was connected to dog ownership.

2.5.2.3 Strongyloidiasis: Aetiology, Transmission and Impact on Human Health

Strongyloidiasis is a soil-transmitted helminth infection widely distributed yet neglected (Sitta et al., 2014). Arguably, this threadworm is reported to be the most neglected helminth universally (Khieu et al., 2014). It is estimated to infect between 100-200 million persons globally, while Bisoffi et al. (2013) suggest that about 370 million persons are affected.

Strongyloidiasis is endemic in tropical and sub-tropical countries, especially low–income and advanced countries like the U.S.A, Spain, Italy and Australia (Beknazarova, Whiley, & Ross, 2016). In Africa, a prevalence rate of less than 1% (Odeniran & Ademola, 2016) and a seroprevalence rate of over 20% have been reported (Amor et al., 2016). Generally, prevalence is documented to be very high in refugees or immigrants. In communities with minimal faecal contamination of soil or water, the prevalence of *S. stercoralis* is very low or rare (Tetteh, 2012). In developing countries, prevalence is also said to be relatively low in urban areas compared to rural communities where sanitation is typically poor (Tetteh, 2012).

Strongyloidiasis is a zoonotic infection caused by *Strongyloides stercoralis & S. fuelleborni* (Varatharajalu & Rao, 2016). Humans, dogs and primates act as definitive hosts of *Strongyloides* (Tetteh, 2012; Odeniran & Ademola, 2016). Both soil-transmitted helminths are established in tropical and sub-tropical regions as well as some temperate regions where sanitary conditions are poor, poverty is widespread, and health care is deficient (Torgerson & Macpherson, 2011; Varatharajalu & Rao, 2016). Several recorded cases indicate that strongyloidiasis is an emerging disease in advanced countries where it was previously non-endemic (Varatharajalu & Rao, 2016). These have been attributed to the emigration of persons from endemic countries. Additionally, these countries have been identified to maintain restricted, pivotal, endemic disease transmission.

Strongyloides stercoralis is distributed worldwide. It accounts for more than 90% of Strongyloidiasis, which is endemic in Africa, Southeast Asia and South America (Odeniran & Ademola, 2016). There is a dearth of information on the disease burden due partly to the difficulties in diagnosis. As such, the burden of *Strongyloides stercoralis* is indeterminate, although Torgerson & Macpherson (2011) suggest it could be significant. *Strongyloides stercoralis* and some STH are reported to be endemic in 138 districts in Ghana, even though there has not been any definitive prevalence assessment (Ministry of Health, 2007). *S. fuelleborni*, on the other hand, is common in nonhuman primates, although cases of human infections have been documented in Papua New Guinea and Central Africa (Ashford, Barnish, & Viney, 1992; Olsen et al., 2009).

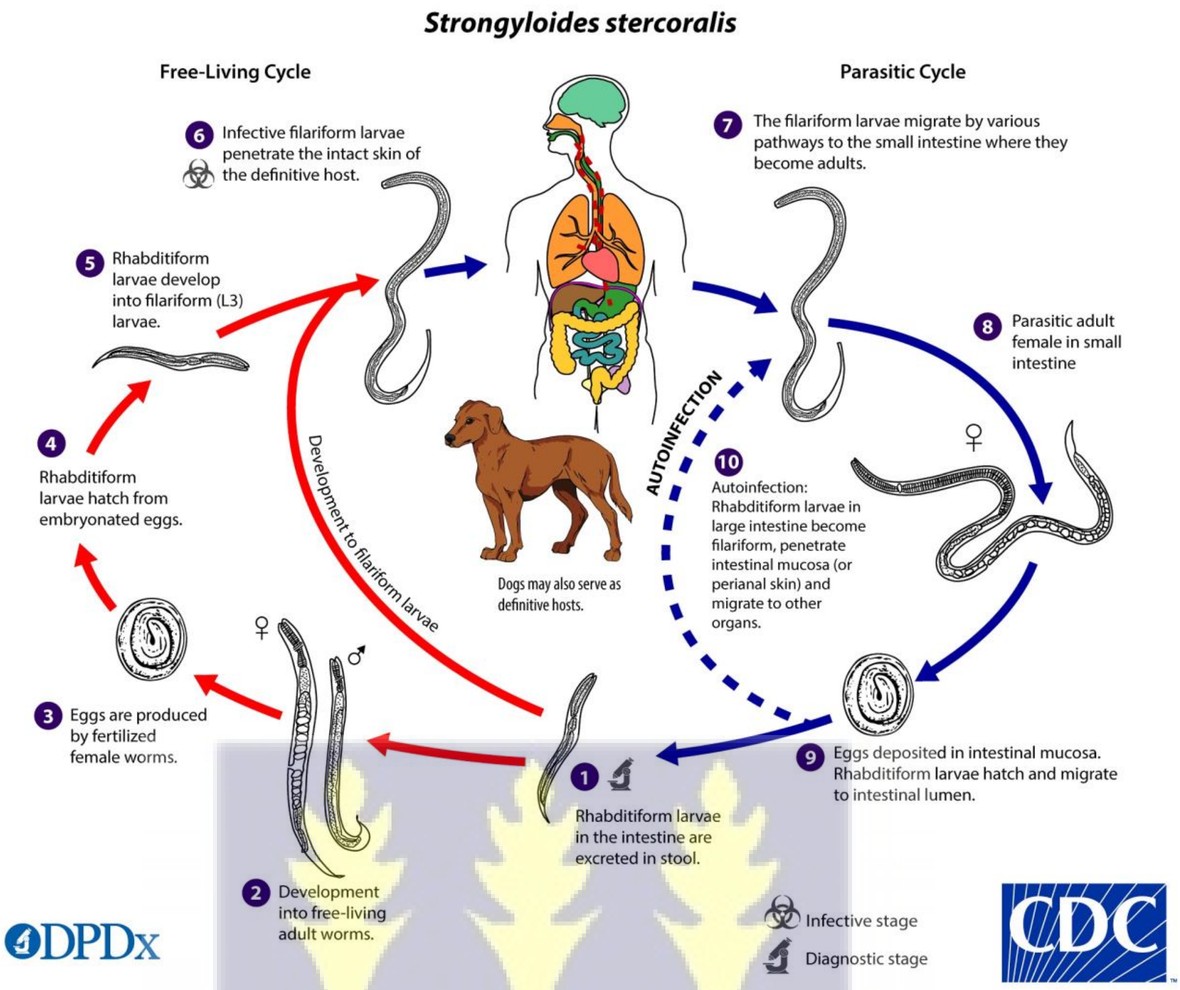

Figure 3:The life cycle of *Strongyloides stercoralis*

Strongyloides stercoralis has a complex life cycle. It has two forms: the parasitic and free-living stages, and this is unique to only this species (Torgerson & Macpherson, 2011; Page, Judd, & Bradbury, 2018). This parasite exhibits an exclusive characteristic: larvae excreted in faeces can give rise to free-living generations of adults and then more infective larvae (Torgerson & Macpherson, 2011). *Strongyloides stercoralis* can cause autoinfection because the female nematode, which is viviparous, can reproduce within the host. This makes it possible for this parasite to stay in infected hosts for several years(Torgerson & Macpherson, 2011; Page et al., 2018).

Transmission of this pathogen is through the filariform larvae entering the skin. In uncomplicated cases, the worm load is observed to be low, so the larvae output is minimal

(Moghaddassani et al., 2011). The eggs of *S. stercoralis* are hardly seen (Page et al., 2018), but when infections are extremely high (hyper infection), the eggs are excreted in the faeces (Varatharajalu & Rao, 2016).

There have been reports of increasing human infections by *Strongyloides* (Paradies et al., 2017). Infections in humans are typically mild and asymptomatic or with just a few symptoms, even though they could be fatal in persons who are immunocompromised and have other pre-existing health conditions (Varatharajalu & Rao, 2016). Chronic infections can stay asymptomatic for long years, and in the view of Sitta et al. (2014), this could be life-threatening in some cases. According to Torgerson and Macpherson (2011), clinical cases of Strongyloidiasis are linked to chronic enteritis, impaired child development, eosinophilia and malabsorption syndrome. This disease is also responsible for diarrhoea and malnutrition (Tetteh, 2012).

It is acknowledged that dogs, cats, and some primates may act as reservoirs of strongyloidiasis. Several research studies have revealed varying prevalence rates of infections in companion animals such as dogs and cats. A prevalence rate of 0.4% *Strongyloides* infection was reported by Ekong et al. (2012) in Jos, Nigeria. Mulugeta et al. (2019) recorded a relatively higher prevalence of *Strongyloides stercoralis* in dogs (2.6%) and their owners (1.5%) in Hossana Town, Ethiopia.

The ability of companion animals to transmit this infection to humans was vague until phylogenetic studies from humans and dogs were published by Jaleta et al. (2017) and Nagayasu et al. (2017). Outcomes from research by Jaleta et al. (2017) suggested that dogs maintain two probably different populations of *Strongyloides*, with one population appearing to be explicit to dogs and the other common to dogs and humans. They concluded that dogs were potential reservoirs for the zoonotic transmission of *S. stercoralis*.

2.5.3 Protozoal Zoonoses/ Protozoonoses

Research on the characteristics of emerging human infections has identified that 10.7% of emerging infectious diseases are caused by protozoa (Jones et al., 2008). Zoonotic protozoa pathogens cause insidious infections; this could be life-threatening for immunocompromised or immunosuppressed individuals (Esch & Petersen, 2013). Humans get infected with protozoa pathogens through contact with contaminated foods, water, infected animals (particularly domestic/companion animals) and the environment.

Several zoonotic protozoan diseases are of public health importance, such as toxoplasmosis, giardiasis, cryptosporidiosis and babesiosis. However, a brief overview is given on these diseases except for the vector-borne protozoan disease, babesiosis.

2.5.3 .1 Toxoplasmosis

Toxoplasmosis is a key zoonotic protozoal infection caused by *Toxoplasma gondii*. This obligate intracellular protozoan parasite affects all endotherms and some fishes (Liu, Wang, Huang, & Zhu, 2015; Odeniran & Ademola, 2016). Since the transmission of this parasite could entail blood (tachyzoites), muscles (bradyzoites) and faeces (sporozoites), it makes it easy for an extensive range of animals to be infected (Odeniran & Ademola, 2016). Naturally, domestic cats are the main definitive hosts, although other mammals such as rodents and dogs are susceptible and could aid in the transmission of this disease in domestic settings (Esch & Petersen, 2013; Mgode et al., 2014; Odeniran & Ademola, 2016).

Toxoplasmosis is distributed globally; approximately 20–90% of persons have had contact with *Toxoplasma gondii* (Abu et al., 2015). Reports indicate that almost 30% of the human population worldwide constantly suffers from this parasite, with prevalence recognised to differ with age, socioeconomic status and climate (Esch & Petersen, 2013; Mgode et al., 2014). Nevertheless, toxoplasmosis is regarded as a neglected disease and has been aimed for public action by the CDC (Centers for Disease Control and Prevention[CDC], 2018).

2.5.3.2 Cryptosporidiosis

This infection is caused by an apicomplexan protozoan responsible for gastrointestinal disease in humans, domestic animals and wildlife (Appelbee, Thompson, & Olson, 2005). Cryptosporidiosis contributes an estimated 8.37 million DALYs based on 2010 data, impacting the Global Burden of Diseases(BOD) considerably(Hotez et al., 2014).

The aetiological agent of Cryptosporidiosis is the *Cryptosporidium* pathogen, an oocyst-forming organism. Generally, two major species affect humans: *Cryptosporidium parvum* and *Cryptosporidium hominis* (Pisarski, 2019). Yet *C. parvum* is described to be extremely infectious in domestic settings. In such environments, *Cryptosporidium* is commonly found in dogs and cats, and both are vital reservoirs of human infections, although infections in these animals usually go unnoticed. In regular faecal examinations of healthy animals, *Cryptosporidia* have been detected, suggesting a subclinical disease state (Scullion & Scullion, 2009). Infected animals usually excrete several millions of cysts or oocysts per day through the passage of faeces, thus massively contaminating the environment. In this situation, humans get infected with the infective oocyst directly through the faecal-oral route or from consuming contaminated water (Macpherson, 2005). According to Shakespeare (2009), an inoculum of not more than 100 encysted organisms could result in clinical infections in humans, which may be more severe in immunocompromised persons.

Cryptosporidium spp. cause diarrhoea infections in many animal species and humans. It is marked by profuse self-limiting watery diarrhoea, abdominal discomfort and cramps, and mild fever for about seven days (Shakespeare, 2009). Such diarrhoea episodes are a significant cause of morbidity and mortality in children below five. This protozoan pathogen is also the cause of what is referred to as the 'travellers' diarrhoea (Tetteh, 2012).

2.5.3.3 Giardiasis

Giardiasis is a disease caused by the protozoa *Giardia duodenalis*, an intestinal flagellate that infects extensive vertebrate hosts (Cacciò & Ryan, 2008). The genus comprises six species: *Giardia agilis*, *G. ardeae*, *G. psittaci*, *G. microti*, *G. muris* and *G. duodenalis(also known as G. lamblia and G. intestinalis)*. They are distinguished from each other based on the morphology and ultrastructure of their trophozoites (Adam, 2000; Cacciò & Ryan, 2008).

Giardia duodenalis is well recognized as a very pathogenic parasitic infection of humans even though it affects other mammals, including companion animals and livestock (Esch & Petersen, 2013; Mekibib & Sheferaw, 2018). A total of eight genotypic assemblages of *G. duodenalis* (assemblages A to H) with different evolutionary lineages have been identified (Li, Wang, Wang, & Zhang, 2017). Humans are infected with assemblages A or B; assemblages C and D are canine-oriented and are found in dogs, whereas F is feline-oriented and therefore infective to cats (Ballweber, Xiao, Bowman, Kahn, & Cama, 2010).

Dogs and cats can also be infected with the zoonotic assemblages AII and rarely B since they are mostly in close contact with humans (Ballweber et al., 2010). The ability of companion animals to carry the strains of *Giardia* that infect humans leads to a cycle of zoonotic transmission of the parasite (Hopkins et al., 1997, cited in Mekibib & Sheferaw, 2018).

2.5.3.4 Vector-borne protozoan diseases

Recently, zoonotic diseases transmitted by vectors such as arthropods pose a significant threat to public health (Jones et al., 2008). They have been known to transmit to vertebrates a wide range of bacteria, helminths, viruses and protozoans (Shaw et al., 2001; de la Fuente et al., 2008). Arthropods have evolved as ectoparasites of wild animals to a larger extent than domestic animals. Important arthropods like ticks, fleas, lice and mites act as reservoirs of infectious diseases and transmit the same (Shakespeare, 2009; Eisen, Kugeler, Eisen, Beard, & Paddock, 2017). They become infected when they feed on the pathogen in the blood or skin of the host. Ticks, for instance, are very important arthropods implicated in several vector-borne diseases, which are also zoonotic.

2.5.3.4.1 Ticks As Agents of Zoonoses

Ticks are ectoparasites of domestic animals and animals in the wild. They are recognised as key vectors of several diseases of public health importance of man and animals (Ficová et al., 2011). Ticks belong to the category of medically important arthropods today, and they markedly influence global health systems by transmitting disease-causing pathogens (Ficová et al., 2011; Eisen et al., 2017). As reported by de la Fuente (2008), these invertebrates are accountable for over 100,000 cases of diseases in humans globally. They are therefore said to be of utmost significance in terms of disease-causing pathogens in both domestic and wild animals but the second to mosquitoes concerning vectors of human illnesses (Shaw et al., 2001; de la Fuente, 2008).

Tick species with an extensive host range have been identified to transmit pathogens to domestic animals and humans (Shaw et al., 2001; Baneth, 2014). Host mobility and climatic conditions affect ticks and the pathogens they transmit (Eisen et al., 2017). Hard ticks are haematophagous, so they attach to their hosts firmly to acquire blood. This event helps in the efficient transmission of infectious agents to their hosts and the spread of infectious agents they carry to various geographical locations through travelling pets (Shaw et al., 2001).

Infections transmitted by ticks are reported to be an emerging health crisis in some animals. For instance, reports show that tick-transmitted infections in dogs are an emerging health issue (Shaw et al., 2001; Baneth, 2014). They are sources of several diseases in dogs found in tropical and semi-tropical regions but now gaining prominence in the cold regions (Shaw et al., 2001). Important tick-transmitted infectious diseases of dogs include ehrlichiosis and babesiosis (Shaw et al., 2001; Bengis et al., 2004). Subclinically infected dogs may act as reservoir hosts for human tick-transmitted infectious pathogens. Shaw et al. (2001) believe that the surge in prevalence of tick-transmitted diseases of companion animals such as dogs and their owners is a result of the rise in accessibility to wildlife habitats and increased contact with reservoir hosts, among other factors.

According to Bown et al. (2006), rodents are also hosts of some *Ixodes* ticks, particularly the larvae and sometimes the nymphs and, in instances of host-specific species, their adults. Rodents help in the enzootic cycles of pathogens such as *Babesia* spp. (Ficová et al., 2011).

2.5.3.4.2 Babesiosis As A Tick-Borne Zoonotic Infection: Aetiology, Transmission and Impact on Human Health

Babesiosis is a tick-borne zoonotic disease caused by the protozoan *Babesia*. *Babesia* is an intraerythrocytic parasite: it infects the red blood cells, invades them and then lyses them (Owusu, 2015; Niriwa, 2018). *Babesia* has a characteristic tetrad configuration, which is either round or pear-shaped (Owusu, 2015). Although the distribution of *Babesia* varies geographically from country to country, it is known to be prevalent in the tropical and sub-tropical regions (Niriwa, 2018). Currently, it has been identified as an emerging health challenge (Akel & Mobarakai, 2017).

Over one hundred *Babesia* species have been identified to infect specific hosts (Owusu, 2015). Initially, five *Babesia* species (*Babesia microti, B. duncani, B. divergens, B. bovis* and *B. venatorum*) were identified to be zoonotic (Niriwa, 2018). However, another new type of *Babesia* (KO1), similar to ovine *Babesia*, was identified to infect humans in Korea (Kim et al., 2007, cited in Niriwa, 2018). There have been other reports of uncharacterised *Babesia* spp. found elsewhere (Owusu, 2015), and this could be due to cross infections.

Babesia has an indirect life cycle: hard ticks act as definitive hosts, while some domestic animals and wildlife serve as reservoir hosts (Niriwa, 2018). Early descriptions of babesiosis in dogs first occurred in Africa, but it is now a global tick-borne infection. According to Schnittger, Rodriguez, Florin-Christensen, & Morrison (2012), dogs are reservoirs from which infected ticks infect many animals (domestic and wild) and humans.

On the other hand, humans are accidental hosts of the *Babesia* parasite. They tend to get infected when bitten by an infected adult tick or nymph. The disease in humans is typically asymptomatic except in immuno-compromised individuals (Owusu, 2015). Symptoms could either be subclinical or severe (Vannier & Krause, 2012).

Infections of *Babesia* have similar symptoms to that of *Plasmodium* (malaria), just as both species share identical morphology (Bloch et al., 2018), making differential diagnosis quite a challenge. Often, human babesiosis has been misdiagnosed as malaria (Olmeda et al., 1997; Arsuaga et al., 2018; Bloch et al., 2018). In the tropical regions where both diseases are widespread, there have been countless occasions of misdiagnosis in the health systems when microscopy is employed. This explains why human babesiosis data are lacking in Africa (Bloch et al., 2018), particularly in Ghana. The variances between *Babesia* and *Plasmodium* are generally undifferentiated except by molecular examination (Niriwa, 2018).

About fifty years after the first human babesiosis was recorded, the epidemiology of *Babesia* has changed from occasional isolated cases to its being endemic in certain countries/states (Hunfeld, Hildebrandt, & Gray, 2008). Cases of human babesiosis have been recorded in the United States, Taiwan, Japan, Europe and Africa (Olmeda et al., 1997; Vannier, Gewurz, & Krause, 2008, Vannier & Krause, 2012). Several cases of babesiosis in Europe have been attributed to *B. divergens*.

In Ghana's case, there is not much information on the disease (Niriwa, 2018), and there has not been any documentation of babesiosis in humans except those reported in animals (Owusu, 2015). Owusu (2015) found *Babesia* infections in a dog (3%) and nine cattle samples (30%) but not any in humans in the Greater Accra region using microscopy and polymerase chain reaction (PCR). She concluded that although no human infections were recorded, the possibility of zoonotic *Babesia* occurring in Accra was undeniable since the parasite was found in cattle and dogs that shared an intimate environment with humans. Similarly, in a cross-sectional study by Niriwa (2018) involving humans, sick dogs and cattle within the Techiman and Kintampo municipalities, 42.3% of dogs were suspected of babesiosis/theileriosis using microscopy, but PCR amplified only 14%. For the sick cattle, 15.9% were positive by microscopy, but 60.6% were amplified and sequenced. In the study, *B. canis* was found in 46.6% of sampled dogs by PCR. In the rural areas of Sao Paulo State, Brazil, O'Dwyer et al. (2009) recorded a prevalence of 8% *Babesia* infections in dogs using PCR.

2.6 Drivers of Zoonotic Diseases

Zoonotic diseases do not emerge or re-emerge unexpectedly, but specific drivers in certain localities play significant roles in their emergence or re-emergence. For instance, the epidemiology of zoonoses, according to Cascio et al. (2011), is intricate and dynamic, and according to Leach et al. (2017), the dynamics of the ecosystem, as well as some other factors, impact disease transmission as they influence the occurrence of animal reservoirs, vectors and their habitats. Generally, the drivers of zoonoses are both immediate and long-term. While the immediate drivers include human behaviour, anthropogenic activities, climatic conditions, ecology and anthropology, the long-term forces comprise political will, business and security interests (Dzingirai et al., 2017).

2.6.1 Human Behaviour

Human behaviour has consistently been acknowledged to influence the emergence of diseases at the human-animal interface. Consequently, it has some bearing on a pathogen's adaptation and spatial distribution, how susceptible a host is to a pathogen, and the exposure and contact rates between the pathogen, reservoir and susceptible hosts (Alexander & McNutt, 2010). Lately, changes in human behaviour are identified to be propelled by rising population figures, technological advancement and agriculture intensification, among others (Jones et al., 2013). Agriculture intensification, for example, promotes encroachment into wildlife habitats resulting in alterations to the ecosystem and creating the avenue for closer interactions between humans and wildlife.

Furthermore, it is recognised that modifications in these behaviours are also creating new ways of disease transmission besides increasing interactions between the human-domestic-wildlife interfaces (Macpherson, 2005; Jones et al., 2013). Studies have shown that these close interactions mostly lead to pathogen spillover and the establishment of novel transmission cycles (Jones et al., 2013). As such increasing contact of human populations with wildlife is predicted to heighten the risks of infections, particularly zoonotic diseases (Karesh et al., 2012; Han et al., 2015).

2.6.2 Anthropogenic Determinants

Due to anthropogenic activities, there have been several changes in disease burdens, distribution, and pathogen types. Jones et al. (2013) believe that the shift from small hunter-gatherer societies to large agricultural communities was linked to the emergence of human infectious diseases, most of which are zoonotic. Unequivocally, anthropogenic activities significantly influence the macro and micro epidemiology of emerging and re-emerging zoonotic diseases (Macpherson, 2005). Activities such as human interferences in virgin or pristine forests support the thriving of wildlife reservoirs near human settlements (Dzingirai et al., 2017).

Furthermore, rapid deforestation and poverty, which are lately increasing interactions between people and infected wildlife, have been recognised as the source of most zoonotic disease epidemics (Dzingirai et al., 2017). As suggested by Cunningham et al. (2017), depletion of biodiversity results in the impairment of the ecosystem service and leads to the emergence of zoonotic pathogens. Likewise, hunting, game ranching, and uncontrolled rearing of domestic animals, as suggested by Daszak et al. (2000), have also led to a rise in the transmission of zoonoses. The emergence of Ebola hemorrhagic fever is believed to be connected to hunting in Gabon and the Republic of Congo (Daszak et al., 2000).

Not only these, but human activities like the improper use of antibiotics in humans and animals have significantly impacted the evolution of pathogens (Alexander & McNutt, 2010). Gilchrist et al. (2007) reported that over 11 million kilograms of antibiotics are used in the livestock production sector, and an estimated 1.4 million kilograms are used for medical purposes per annum in the United States. With such high figures, improper use of antibiotics could increase antibiotic resistance cases, a pending global disaster.

2.6.3 Human-Dominated Landscapes

In general, there are different forms of landscapes and modifications in these various landscapes are envisaged to impact humans' general well-being or health (Patz et al., 2004; Mackenstedt et al., 2015). For example, human-dominated landscapes have been associated with the transmission of several infectious diseases, which sometimes lead to disease outbreaks. By definition, human-dominated landscapes are landscapes heavily dominated by people (350 people per sq. km) (Athreya, Odden, Linnell, Krishnaswamy, & Karanth, 2013). The Urban and peri-urban spaces or areas are typical examples of this landscape.

2.6.3.1 Urbanisation and Peri-urbanisation

The world is becoming more urban daily with records of high human populations (French, Webb, Hudson, & Virgin, 2018). This continuous increase in human populations has caused the development and or expansion of urban areas. According to the United Nations, about 3.9 billion people resided in urban areas as of 2014 (as cited in Neiderud, 2015). People are presented with various benefits in urban areas. In such places, there is good education, well-paid jobs, better health care and easy accessibility to social amenities, among others.

The economic growth or development of countries worldwide has been associated with urbanisation and industrialisation. In the twentieth century, urbanisation was changed, particularly in the developed world (Allender, Foster, Hutchinson, & Arambepola, 2008). The global percentage of the urban populace was 13% in 1900 but eventually increased to

29 % in 1950 (UN, 2006, as cited in Seto, Parnell, & Elmqvist, 2013). All things being equal, the global urban population was predicted to increase to 70%, double the urban population in 2010 (UN, 2010, as cited in Seto et al., 2013). The rise in urbanisation is projected to be higher in Sub-Saharan Africa, with the urban population projected to double to almost 800 million persons by 2030. This burgeoning population in urban areas has resulted in growing concerns about water and food security.

Urbanisation involves physical alterations where a high number of persons live in urban regions (Li et al., 2016). It infers a greater concentration and connectedness of people. Urbanisation is the alterations of natural landscapes to make room for high densities of human populations and structures. Such alterations are termed Human-induced rapid environmental change (HIREC), which is believed to impact significantly animal species (Moule et al., 2016). Significant differences exist in urbanisations across and within countries (Seto et al., 2013). There is no generally accepted definition of what is urban (Neiderud, 2015); as such, there are considerable differences in the classification of what is urban, peri-urban or rural areas among countries and continents (Seto et al., 2013). Most definitions are based on national definitions or characterizations. In some countries, factors like population size, the density of economic activity or the structure of the government are considered in coining these definitions. Based on this, the urban landscape in Europe and North America is usually defined as an area with human masses, having more than fifty (50) per cent of the surface built bounded by other areas, with thirty(30) to fifty(50) per cent built and a total population density greater than ten persons per hectare (Seto et al., 2013).

The Ghana Statistical Service (2014, p.2) defined urbanisation as “the process of growth or increase in the population that is reported to live in localities classified as urban in Ghana”. In Ghana, communities or areas with about five thousand (5,000) persons or more are considered urban. This definition has been described as being too simplistic and fraught with weakness since the make-up of the population of two localities with 5000 or more persons may differ significantly in terms of their socio-economic activities or services (Ghana Statistical Service, 2014).

With all the benefits of urbanisation, this phenomenon is without challenges, although the challenges vary per country. Unfortunately, in many developing countries, rapid urbanisation has led to a surge in urban poverty, evidenced in the poor infrastructures and social and health services that characterize many urban areas (Carvalho-Pereira et al., 2018). The migration of people from rural communities to urban areas has resulted in the creation of peri-urban areas due in part to overcrowding or congestion and all the associated health and social challenges.

Peri-urbanisation is the most conspicuous form of urban growth and urbanisation (Seto et al., 2013). Peri-urban areas develop partly when rural lands are converted to residential use with a blend of urban and rural activities and functions (United Nations Educational Scientific and Cultural Organization(UNESCO), 2014). According to Budiyantini and Pratiwi (2016), this phenomenon continues to occur in fast-growing metropolitan areas. Peri-urban areas have both urban and rural features. In Peri-urbanisation, there are modifications in demography, social and economic structure, and land use, among others (Oduro, Adamtey, & Ocloo, 2015). Peri-urban areas are transition zones from urban to rural with porous and transitory boundaries (UNESCO, 2014). These areas are sometimes described as unstructured areas comprised of low-income citizens or an area claimed to be highly varied. However, a study by Doan and Oduro (2012) revealed that peri-urban zones of Greater Accra were not unstructured (amorphous). Greater Accra Region (GAR) is the smallest in terms of land area but the most urbanised. Many of the peri-urban communities/areas near the Greater Accra Metropolitan Assembly (GAMA), particularly Dodowa, Kasoa, Nsawam and Aburi, are practically linked to Accra and function as dormitory towns.

Urbanisation, due to increased congestion and poor sanitary conditions, has amplified the transmission of infections (Li et al., 2016). Poor sanitary conditions and irregular garbage collection in urban areas continuously provide conducive environments that sustain huge rodent populations (Carvalho-Pereira et al., 2018). According to Kardjadj & Ben-Mahdi (2019), dog-mediated zoonoses in Algeria increased with the unrestrained explosion of household waste dumps, especially in and around urban areas that maintain stray dogs. Furthermore, urbanisation is recognized to influence infectious disease routes in wildlife populations (Alexander & McNutt, 2010).

2.7 Zoonotic Disease Awareness

Awareness of zoonoses influences the maintenance of the life cycle and transmission of zoonotic pathogens to their hosts (Ajat, 2016). Having an understanding of zoonotic diseases is important. Regrettably, many people at risk of zoonosis lack a basic knowledge of diseases that fall under this category and the risk factors involved. For example, usually, there is a lack of awareness in the majority of owners of companion animals about common zoonotic diseases that their animals carry.

A study by Klous et al. (2016) on household practices linked to zoonoses transmission in rural Cambodia showed that 69% of respondents knew about zoonosis, yet only 6% regarded the likelihood of disease transmission between livestock, humans and wildlife. Also, about 65% of households participating in their study could name avian influenza as a zoonotic disease, probably due to the nationwide awareness of influenza in rural Cambodia. They further observed that knowledge of zoonosis influenced household practices such as washing hands before and after cooking and washing hands with soap promptly after handling live animals. Likewise, research by Hundal et al. (2016) in Punjab, India, found that majority of livestock farmers (84.6% and 92.4%) were aware of rabies and bird flu as zoonotic diseases, while about 46%, 32.8% and 4.6% had an awareness of brucellosis, tuberculosis and anthrax respectively. A good number of participants (51.2%) in that study were also aware of the transmission of zoonoses through contact with an infected animal.

In Sub-Saharan Africa, related research by Fèvre et al. (2017) in lake Victoria showed that only 15.1% of respondents were aware of zoonosis. Out of this percentage, 5.6% were able to name anthrax as a zoonotic disease, 8.3 % and 22.9% mentioned brucellosis from sheep and goats and cattle, respectively, whereas 33.1% were aware of rabies from dogs. Similarly, a questionnaire survey to assess dog owners' awareness of zoonotic enteric protozoa by Mekibib and Sheferaw (2018) in Hawassa town, Ethiopia, showed that 76.5% of respondents were not aware of zoonotic parasites. In Maiduguri, Nigeria, Bukar-Kolo et al. (2018) also recorded that most household respondents were unaware of any cat disease. Furthermore, more respondent households never took their cats to veterinary clinics for assessment or vaccination. This was probably influenced by their ignorance of cat diseases.

In Ghana, Amissah-Reynolds et al. (2016) observed that only 24% of dog owners in Mampong, Ashanti Region, had some knowledge of the transmission of zoonotic diseases. However, a higher number of respondents(76%) in the research by Issah et al. (2020) were aware of zoonoses, and 98.7% could mention rabies as a zoonotic disease. Unawareness and lack of knowledge of zoonoses have great implications on surveillance (reporting) and the effective control of such diseases.

2.8 Risk Factors and Population at Risk of Zoonotic Diseases

The degree of human-domestic-wildlife interactions may increase the risk of zoonotic infections worldwide. The risk of zoonotic disease emergence is expected to reach a record high where mammals are in close contact with humans (Cleaveland et al. 2001). Generally, all groups of people are at risk of contracting zoonotic diseases. However, children, the elderly, pregnant women and immunocompromised persons are usually at a higher risk of contracting zoonoses (Burroughs et al., 2002; Ghasemzadeh & Namazi, 2015; Ebani, 2017). For instance, children are at a higher risk of getting infected than adults because of their engagement in behaviours that increase contact with the ground and poor hygiene, to mention a few. As such, they are more prone to ingesting environmental contaminants (Taetzsch et al., 2018).

Again, exposure to zoonotic diseases is fuelled by domestic and occupational activities. Activities like hunting, farming near wildlife habitats, butchering, and consuming wild animals predispose humans to zoonotic diseases. Occupational activities also put people at risk of contracting zoonotic diseases. Typically, veterinarians, herpetologists and zoo workers, pastoralists or livestock keepers, workers at the slaughterhouse, and laboratory research, to mention a few, are occupations highly exposed to zoonotic pathogens due to their frequent contact with animals (Weber & Rutala, 2001; Ebani, 2017; Mangesho et al., 2017).

Other factors like intercontinental travel and trade; high population growth rate; a high number of people with compromised immunity caused by comorbidities; handling and consumption of raw or undercooked food of animal origin; poverty, and close interaction between humans and animals (wildlife and domestic) are some important risk factors of zoonoses (Whitfield & Smith, 2012; Gebreyes et al., 2014; Mangesho et al., 2017;

Cunningham et al., 2017). However, in the view of Cunningham et al. (2017), poverty is a chief risk factor for most zoonotic diseases reported.

Not keeping proper hygiene and improper handling of companion animals are recognised risk factors for companion animal-related zoonotic infections (Whitfield & Smith, 2012; Elieza, 2016). Many people in developing countries who keep companion animals do not care so much about their well-being and most often do not do simple things like regular house feeding, grooming, deworming and vaccinating these animals against infections (Elieza, 2016). Therefore contamination of the environment with faeces of domestic animals, which may be laden with parasites, creates ideal conditions for exposure to zoonotic pathogens (Daniels et al., 2015). Whitfield and Smith (2012) also pointed out that discarding waste generated by companion animals into kitchen sinks; not washing hands after feeding or playing with these animals; sharing a bed, and owners allowing companion animals to kiss or lick them were found to be the cause of several companion animal-related disease outbreaks. It is suggested that insufficient resources and ignorance could be the underlying reason for the owner's indifference and lack of empathy. According to Chomel (2014), common sense, pet and personal hygiene are crucial in preventing transmission of zoonotic infection. Whitfield and Smith (2012) and Ebani (2017) suggest that owners should wash their hands after handling their companion animals or wear gloves when cleaning their cages or changing their water pool to reduce the risks of contracting zoonotic infections.

2.9 Prevention and Control of Zoonoses

Undoubtedly, tackling zoonoses is agreed to be a herculean task. Owing to the vulnerability of the human population to outbreaks and pandemics, there have been calls for an efficient, pre-emptive approach that targets averting the initial emergence or spread of pandemics (Morse et al., 2012). To effectively tackle diseases caused by zoonotic pathogens, much attention must be focused on transmission control, prevention, and reducing disease burden in humans and animals. It demands that all countries develop fundamental capacities to be able to handle disease threats. For this to be actualised, there is the need for early detection and prepared response to zoonotic infections, which are critical steps to effective and efficient control (Mangesho et al., 2017). Africa continues to bear the brunt of most zoonotic disease outbreaks, unlike the advanced countries, probably due to variances in national and regional health systems aimed at detecting and effectively responding to disease threats lacking in most countries.

Because of the increasing zoonotic events recorded for the past two decades, strategies for preventing and controlling zoonoses cannot be overemphasized. Efforts have been made by countries and health organisations like WHO and CDC to reduce the burden of zoonoses and eventually prevent them, yet more needs to be done. So far, most studies into disease outbreaks have been reactive, where surveillance focuses on a broad host range and not proactive (Woolhouse & Gowtage-Sequeria, 2005; Morse et al., 2012). In their rapid response to emerging zoonoses, on some occasions, health organisations become conscious of the complexities of such disease outbreaks (Kamins et al., 2015). Thus identifying major taxonomic groups which are sources of zoonoses, whether emerging or re-emerging, possibly helps to enhance surveillance and interventions (Morse et al., 2012). Promptly identifying, responding to, and controlling public health crises such as epidemics of zoonoses at their source, are crucial to attaining global health security (Salyer et al., 2017; Kelly et al., 2017). Early detection can only be made possible through improved laboratory capacity and surveillance at the animal-human interface.

Though surveillance is critical for swiftly detecting emerging and re-emerging infectious or zoonotic diseases, reports show that many African countries do not have national surveillance strategies (Odeniran & Ademola, 2016). According to Gebreyes et al. (2014), surveillance relies on the accessibility of high-grade analytical and clinical laboratory diagnostic facilities. To recognise effectively and clinically manage zoonoses, factors such as individual healthcare-seeking behaviour, accessibility, accuracy, diagnosis, and treatment availability are also key, as suggested by Zhang et al. (2016).

For some important zoonotic diseases, prevention of infection can only be achieved by practising personal hygiene, proper sanitary conditions, and standard treatment of drinking water (Macpherson, 2005; Esch & Petersen, 2013). Hence the need for the government and all relevant state institutions, particularly in developing countries, to perform their core obligations. Education is also very critical in reducing or preventing zoonotic disease transmissions.

2.10 The One Health Approach

Health is a crucial aspect of human welfare, and it has been recognised that there is some form of continuous interaction among humans, animals, and the environment. Thus, a nation's or country's health may be influenced by the health of the animals present and a healthy environment. The concept of a universal and integrative approach aimed at improving the health and well-being of humans, animals (both domestic and wildlife) and the environment (Leach et al., 2017; Kardjadj & Ben-Mahdi, 2019) have been greatly recommended for some time now. This concept is known as the 'One-health' concept, which is believed to offer the solution to mitigate zoonotic diseases.

The 'One Health' concept was expanded markedly since 2000 (Cunningham et al., 2017), which according to Halliday et al. (2015), was driven by global concerns of zoonoses which had pandemic potential. The concept of one health seeks to improve human, animal and environmental health holistically. This concept acknowledges the coming together of diverse drivers and espouses the close working together of several disciplines (Dzingirai et al., 2017; Cunningham et al., 2017). The One-health concept/approach is multisectoral and multidisciplinary and has been identified as essential for global and national health security. It is worth noting that an integrated approach requiring multi-sectoral collaboration and interdisciplinary partnership has been suggested as the panacea to effectively control or manage the impact of zoonotic diseases (Salyer et al., 2017). Thus, the One Health approach has been proposed to help tackle zoonotic diseases globally (Dzingirai et al., 2017).

It is widely acknowledged that to enhance health security worldwide; every country needs to detect and respond to public health emergencies rapidly (Tappero et al., 2017). To this end, several countries have recognized the relevance of One-health and are integrating this concept/approach in addressing matters of national health security. Many countries are now meticulously identifying and prioritizing zoonotic diseases that are of utmost public health importance through the one health approach (Tappero et al., 2017).

The One Health Zoonotic Disease Prioritization (OHZDP) Tool, created by the CDC, aims at assisting countries in identifying zoonoses of utmost national priority using inputs from human health, the environment, agriculture, and wildlife sectors (Salyer et al., 2017). A country's Zoonotic disease ranking is obtained using an objective and semi-quantitative process. Prioritization of zoonotic diseases can also be done when there is a lack of reliable prevalence data (Salyer et al., 2017). Disease prioritization enables countries to concentrate limited resources on surveillance, response to outbreaks, and capacity building of the laboratories, among others (Angulo et al., 2017; Salyer et al., 2017; Tappero et al., 2017).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The study was conducted in two human-dominated landscapes, urban and peri-urban areas in the Greater Accra Region. Though the smallest of the sixteen (16) regions in Ghana, the region is the second most densely inhabited after Ashanti Region. It recorded about 15.4 % of the total population in the country in the national census in 2000 (Government of Ghana, 2018). Greater Accra is comparatively dry, with temperatures ranging between 20° to 30° Celsius. Annually, this region experiences two rainfall seasons and records between 635 mm and 1,140 mm.

Although no putative definition of what is urban exists, most definitions are based on national definitions or characterizations (Seto et al., 2013). In much the same way, the definition of a peri-urban area varies throughout literature, although peri-urbanization is known to be a conspicuous form of urban growth. Peri-urban areas are usually formed due to the spillover from urban areas and are characterised by a sudden change from the typical rural areas to booming urban settlements. In Ghana, communities or areas with about five thousand (5,000) persons or more are categorized as urban (Ghana Statistical Service, 2014). However, for this research, the minimum population size and the density of socio-economic activities or services carried out by the population were considered.

The Greater Accra region has sixteen (16) districts, with a good number found along the coastline. This region is the most urbanized, with more than 87% of its population residing in urban areas crowded around the Greater Accra Metropolitan Area (GAMA)(Songsore, 2009). The GAMA comprises the Accra Metropolis, Tema municipality and Ga District (Doan & Oduro, 2012). It is referred to as the ‘economic gateway’ to Ghana (Arup & Alliance, 2016).

Legon and Madina, two urban communities in the Greater Accra Region, were purposively selected for the urban category of this study. Legon is found in the Accra Metropolis and falls under the Accra Metropolitan Assembly (AMA). The premier university in the country, the University of Ghana and other prestigious educational institutions like Wisconsin International University College, Presbyterian Boys Secondary School and Ghana Institute of Management and Public Administration (GIMPA) are all located in Legon. In the indigenous Ga language, Legon means 'hill of knowledge'. The University of Ghana campus is commonly referred to as Legon, but for this study, Legon refers to the University of Ghana campus and East Legon. East Legon is one of the most prestigious residential areas in the Greater Accra Region, where some distinguished and affluent persons reside. This area has a vibrant neighbourhood with luxurious apartments, restaurants and shops.

Legon shares boundaries with Madina, the administrative capital of the La Nkwantanang-Madina Municipality. This Municipality is very populous, and per the 2010 Population and Housing Census, it was 2.8% of the total population of the Greater Accra Region (GSS, 2014). It has an average household size of 3.7 persons per household, and the principal economic activities are commerce and services (GSS, 2014).

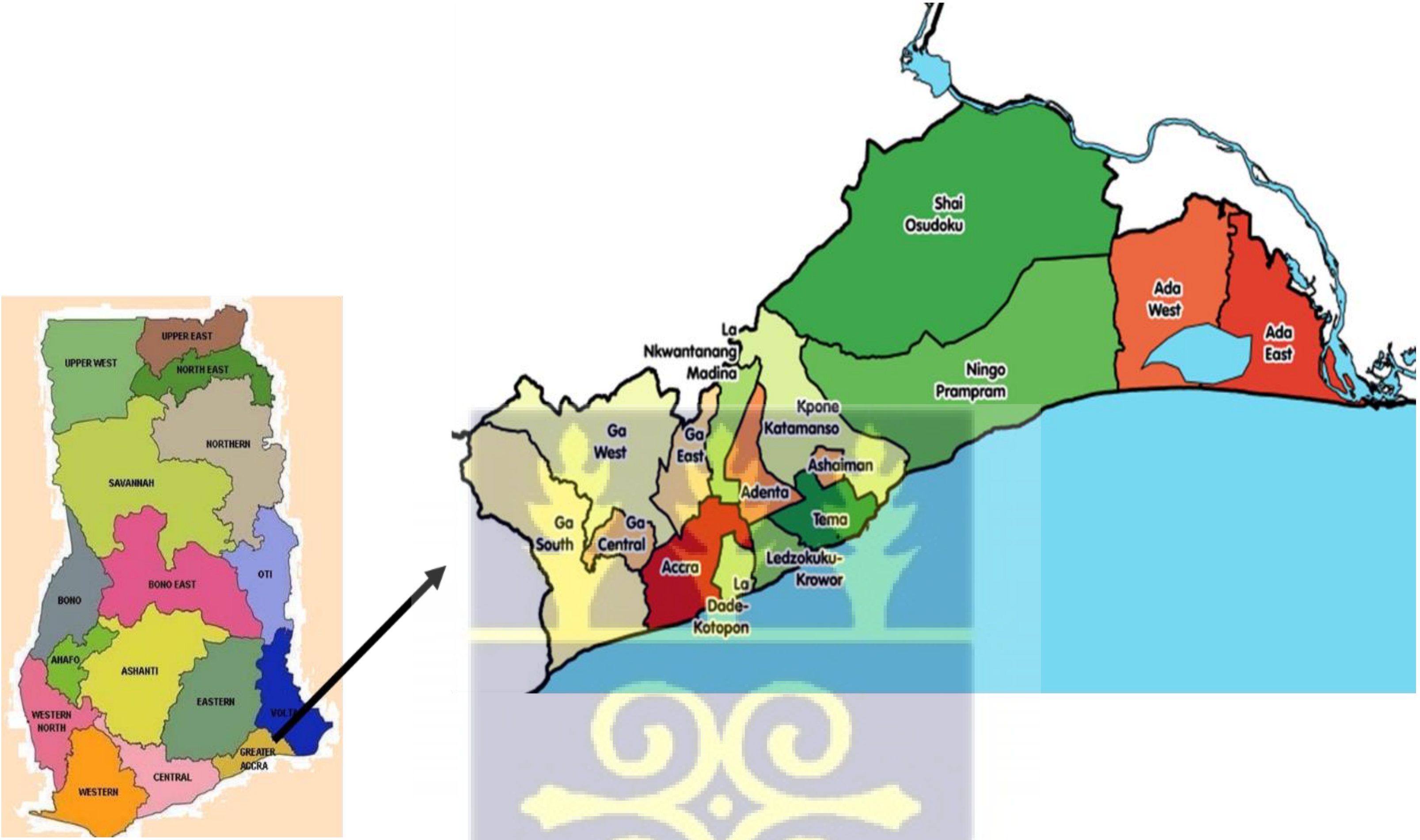

Figure 4: Map showing the 16 regions of Ghana and the districts of the Greater-Accra Region (Zoomed-in Insert).
Source: https://sites.google.com/site/ghanaplacenames/database

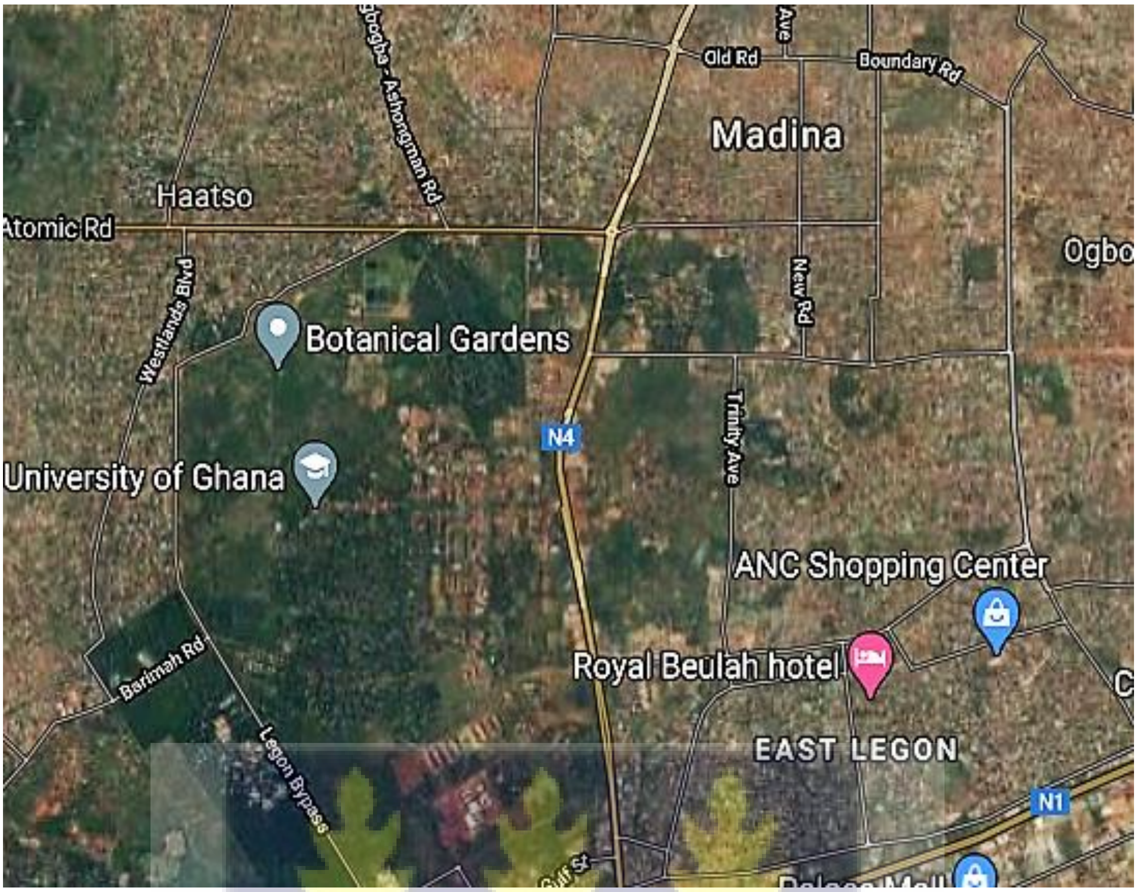

Figure 5: Satellite map showing Legon and Madina
Source: Google map (2020)

For the peri-urban category, Dodowa and its environs were selected based on the fact that these areas were formed by urban spillover and are characterised by land-use changes such as alteration of previously existing agricultural lands and forests to human settlements.

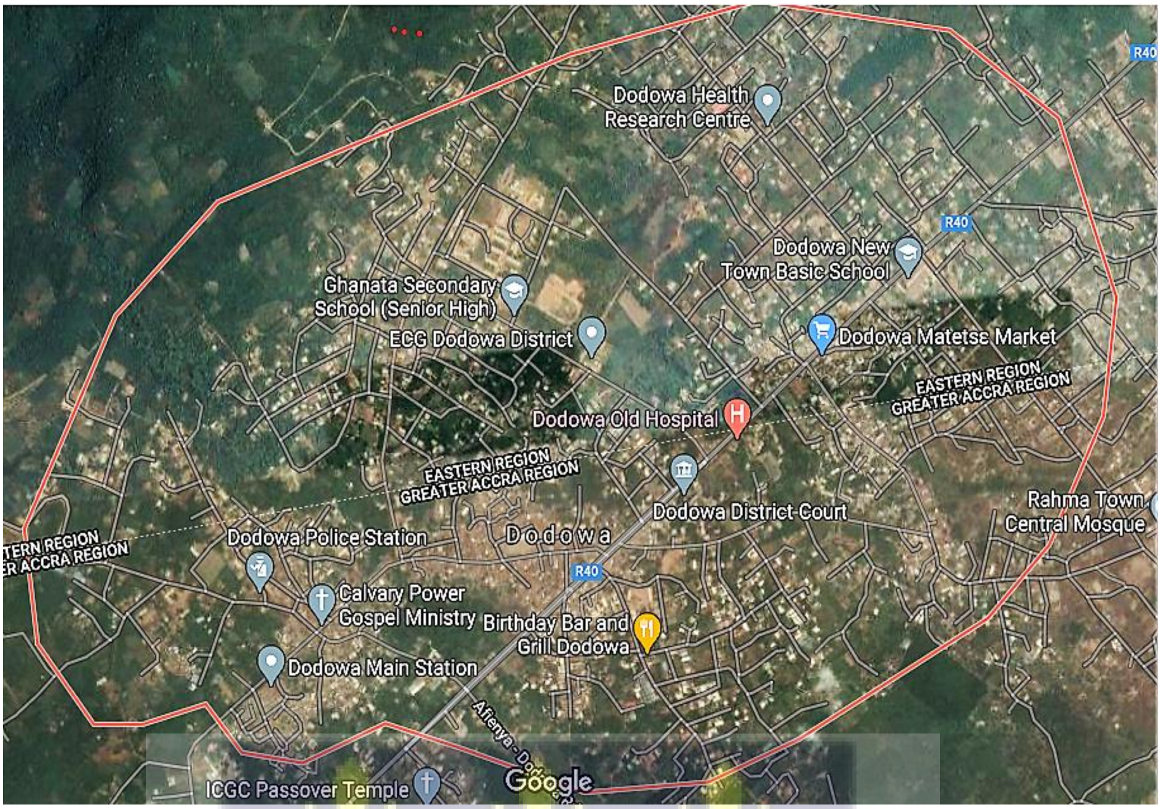

Figure 6: Satellite map showing Dodowa
Source: Google map (2020)

Dodowa is a peri-urban community in the Shai-Osudoku District of the Greater Accra region of Ghana. This district has a total landmass of 969 square kilometres, about 29.84% of the overall land space of this region. Dodowa, the capital of the Shai-Osudoku District, has a population size of about 61 000 (Shai-Osudoku District Assembly, 2018), with an average household size of five (5) (Allabo, 2016). A good number of the inhabitants are categorised as skilled and self-employed.

As part of this research design, veterinary hospitals were selected to collect biological samples. Unfortunately, after the reconnaissance study, there was no functioning veterinary clinic or hospital in the peri-urban category. The Agriculture Department of the Shai Osudoku District assembly, which has a veterinary unit, tried to fill in the gap by providing veterinary services when individuals contacted them. Contrary to the situation in the peri-urban area, there were quite a few veterinary hospitals/clinics in the urban areas. As such, two veterinary hospitals/clinics-the University of Ghana Small Animal Teaching Hospital (UG SATH) and the East Legon Veterinary Centre, were selected using the purposive sampling technique.

University of Ghana Small Animal Teaching Hospital is located off the Atomic-Haasto Road and serves various clients from all over Accra. The hospital offers higher veterinary education and innovative solutions to health-related issues of animals. It was set up to aid researchers in the field of animal science in studying and attaining a significant comprehension of the culture of animals. The mission of UG SATH includes providing exceptional care for pets and serving as a referral centre for pets and veterinarians. It cares for domestic animals (companion animals and pets) that are diseased or wounded and require any kind of treatment.

On the other hand, the East Legon Veterinary Centre (ELVC) is located at Okponglo (East Legon). This veterinary centre provides many services ranging from diagnostics, surgical procedures, wellness examinations and vaccinations to companion animals who predominantly reside in East Legon and its environs.

Additionally, samples were collected from households in selected study areas willing to allow their companion animals to participate in this study. Unfortunately, taking samples from these animals from the households was quite challenging due to the COVID-19 pandemic, which persisted during the sample collection period.

Furthermore, secondary data on human infectious diseases, specifically zoonotic diseases, were obtained from three health institutions in the two human-dominated landscapes. The health institutions were the University of Ghana and the Pentecost Hospitals (urban category) and the Shai-Osudoku District Hospital (peri-urban category) to supplement findings from the animal interface. The University of Ghana Hospital, usually referred to as the Legon hospital, is a quasi-government hospital that was initially set up to cater for the medical needs of students, staff and their dependents. However, it has expanded to cater for the health needs of residents of communities far and near. Currently, the hospital offers both general services and specialist clinics with a 130-bed capacity which consists of a paediatric unit, general wards, maternity, casualty and emergency ward, among others. As part of its core mandate, the hospital seeks to provide outstanding health services to all its patrons from all walks of life.

Conversely, the Pentecost Hospital, situated in Madina, is a mission hospital founded by the Church of Pentecost and is an affiliate of the Christian Health Association of Ghana (CHAG). Formerly, the hospital was known as Alpha Medical Centre but was later changed to its current name. The Pentecost Hospital is the municipal hospital for the La-Nkwantanan-Madina municipality. It provides services in obstetrics and Gynaecology, child health, ophthalmology, accident and emergency services, as well as other relevant services (Ghana Insider, 2020). Comparatively, this hospital has relatively higher patronage, and the patrons are largely from Madina and its environs.

The third hospital, the Shai-Osudoku district hospital, located in Dodowa, is the only major hospital in the Shai-Osudoku district with advanced medical facilities. In 2009, the hospital became a district hospital after its establishment in 1970 as a health post. Presently, the hospital has a 125-bed capacity and offers various clinical services, including accident and emergency, maternity, paediatrics, theatre and trauma, to people from all spheres of life in the district and beyond (Shai-Osudoku District Hospital [SOD], 2019). Furthermore, it is estimated that the hospital serves over 70,000 population and has frequently been used for trials and population-based surveillance in the region (SOD Hospital, 2019).

Zoonotic diseases reported to these hospitals were extracted from unpublished medical records. The data from the University of Ghana Hospital and Pentecost Hospitals were broadly documented in an unprocessed state compared to data from Shai-Osudoku District hospital, which were presented under general or specific diagnosis themes.

Although using secondary data comes with some challenges, this study opted for secondary data on zoonotic diseases reported in the selected hospitals for some specific and important reasons. First, the study could not collect primary data from human participants due to the Covid-19 pandemic and the expensive nature of such an enterprise. Furthermore, it would have made the study more extensive, and that would have spilt over the intended date for completion of this doctoral study. Also, secondary data was convenient because data spanning three years could be sourced from the hospitals.

In searching through the medical records of these hospitals for zoonotic diseases and other related diseases, keywords used included all the zoonotic diseases under consideration (Staphylococcal infections, Toxocariasis, Ancylostomiasis, Strongyloidiasis, Salmonellosis and Babesiosis) as well as some common names such as visceral larva migrans, enteric or typhoid fever. Diseases that were not strictly zoonotic, like enteric fever, were excluded from further inferential analysis. Furthermore, cases such as food poisoning, though most often caused by non-typhoidal *Salmonella* spp., were excluded because the organisms responsible were not indicated.

3.2 Study Design

This cross-sectional study aimed to investigate zoonotic diseases that selected domestic and wild animals could transmit to humans inhabiting the two human-dominated landscapes in the Greater Accra region. It involved fieldwork, laboratory processing of biological samples and questionnaire administration in selected communities within the study. Approval for this study was granted by the University of Ghana- Institutional Animal Care and Use Committee (UG-IACUC) at Noguchi Memorial Institute for Medical Research.

Two non-probability sampling approaches, purposive and convenient sampling techniques, were used in the selection of study areas and study populations. Purposive and convenient sampling techniques are commonly used in clinical research or trials (Patton, 2002; Martínez-Mesa, González-Chica, Duquia, Bonamigo, & Bastos, 2016). These sampling techniques are used to identify and choose knowledge-rich cases of interest in the face of limited resources as well as in the selection of participants of a particular subset based on their availability and accessibility for analytic observational studies (Martin, Meek, & Willeberg, 1987; Patton, 2002; Elfil & Negida, 2017). Most importantly, there existed no reliable data on the population of targeted animals in the study area to serve as a sample frame for the present study. Hence, the use of the non-probability techniques in this study. These techniques were used to obtain an eligible and representative sample size of subjects (dogs and cats) and their owners willing to participate in the research.

The design included the collection of biological samples from companion animals from homes and veterinary hospitals/clinics as well as rodents from the field for processing in the laboratory using molecular methods (Deoxyribonucleic acid (DNA) extraction and Polymerase Chain Reaction (PCR)). Information on awareness and level of knowledge of zoonoses were also assessed using a semi-structured open-ended questionnaire from the owners of the companion animals. Lastly, secondary data on zoonotic diseases presented at three selected health facilities were also obtained and evaluated.

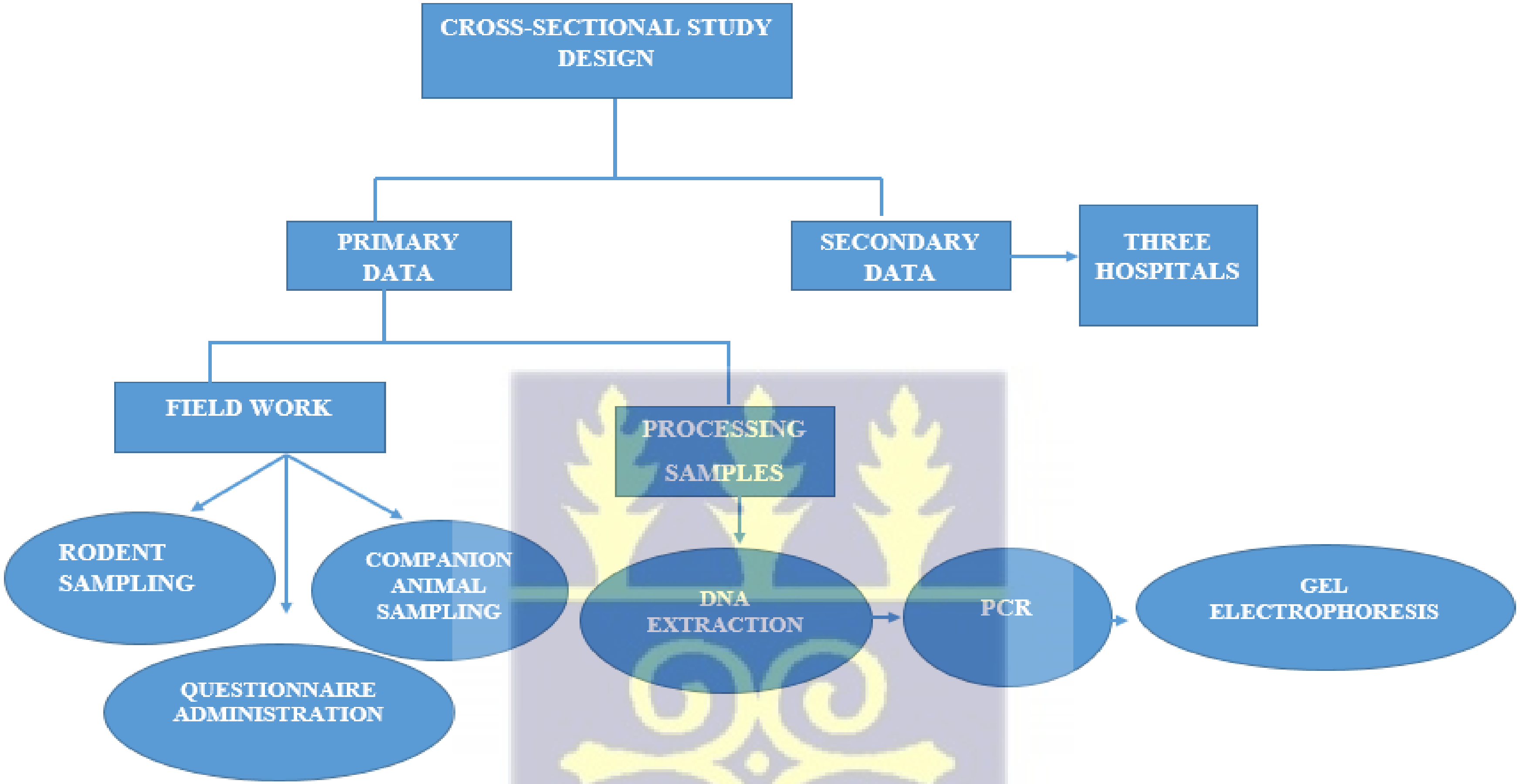

Figure 7: Flow chart of study design

3.3 Sample Size Determination

There has not been any published data yet on the prevalence of shared zoonotic infections among the selected animal species. Therefore, assuming a minimum prevalence of 50%, a sample size of 384 was obtained at a 95% confidence interval using the formula below. This formula is used to calculate sample size, which seeks to measure population prevalence precisely (Naing, Winn, & Rusli, 2006).

$$n = \frac{Z^2 * p(1-p)}{e^2}$$ (Daniel, 1999, cited in Daniel & Cross, 2018)

$$n = \frac{1.96^2 * 0.5(1-0.5)}{(0.05)^2}$$

n=384

Where n is the sample size; Z represents the Z score at a 95% confidence interval which is 1.96; the *p*=minimum estimated prevalence (50%) of zoonotic pathogens potentially transmitted by the three selected animals to humans due to the lack of published data; e=margin of error/absolute error (5%) at 95% confident interval.

3.4 Sample Collection

3.4.1 Rodent sampling/Trapping of Rodents

Four sampling areas were selected in each human-dominated landscape for the trapping of rodents. The Dodowa and Adumaya forests, Dodowa market and Dodowa town were designated sampling areas in the peri-urban category. At the same time, the Legon campus, Madina, Okponglo and Shiashie communities were selected for the urban category. In each sampling area or location, live traps were used.

Live traps are generally employed when protected species, turned-pests, are envisaged to be trapped (Rondinini & Boitani, 2002). In such situations, kill traps cannot be used. As such, for ethical reasons, live traps were selected for this study instead of kill traps. Generally, traps for catching rodents are mostly made of different, box-style wired mesh or traps entirely made with metal (Hice & Velazco, 2013). Examples of all-metal traps include Havahart and Sherman live traps. Most trap designs differ by size, that is, small, medium and large and may have one or two entrances that use the triggering mechanisms: the rodent steps into the trap or pulls with some force leading to its closing (Stryjek, Kalinowski, & Parsons, 2019). In this study, the Sherman live trap was employed. However, it became necessary to augment the trapping with locally made traps during the sampling process due to theft of the Sherman traps and low trapping success. Locally made traps were made from wood and wire or nylon mesh.

Specific numbers of trap lines were set for the trapping of rodents using Sherman's LFA live trap (H.B. Sherman Traps, Inc., Tallahassee, FL) and locally made traps in the sampling sites. At each location, about 50 trap lines were set 10 meters apart. A small amount of bait (a mixture of peanut butter, palm nut and maize flour as shown in Plate 1) was placed in each trap, cautiously labelled (using the code of the sampling site) and placed under logs, near burrows, farmlands, people's homes and dumpsites. Again, each local trap was concealed with vegetation to protect captured rodents from direct sunlight and sometimes rain. All the traps were marked by a surveyor's tape about 0.5 m from the trap in the vegetation. The traps were left overnight and inspected a day after in the morning for three consecutive days. After each daily inspection, the traps were re-baited. Codes and unique numbers of traps containing rodents were recorded in addition to the date of capture. Active traps (traps containing rodents) were recorded and carefully handled according to standard protocol in the appropriate personal protective equipment. The rodents were described using morphometric keys, and any trap found missing, sprung or not triggered was regarded as a misfire. By-catch (capture of non-target species) was also recorded.

Plate 1: A picture of the bait (mixture of peanut butter, palm nut and maize flour) and folded Sherman's live traps (in a bucket) used in trapping rodents
Source: Fieldwork (2019)

3.4.2 Collection of Blood Samples

About one (1) ml of venous blood samples was collected from the study animals into heparinized tubes adhering to standard protocols and procedures for blood collection. Each tube is then appropriately labelled with the sample code and date of collection before transporting to the laboratory.

3.4.2.1 Collection of Blood from the Tail of Rodents

Rodents trapped were each placed in a restraint device with their tails extended. Afterwards, the tail was wiped with 70% ethanol to disinfect it and allowed to dry. A 23G needle attached to a syringe was inserted into a lateral vein about 2-3 cm from the tip of the tail. After that, the plunger was slowly retracted to collect about 1ml of blood. The needle was then removed, and gentle pressure was applied with gauze for 15-30 seconds to stop the blood flow. Afterwards, the animal was released from the restraint device.

3.4.2.2 Collection of Blood from Dogs

The cephalic vein on the foreleg was used to collect blood, taking sterile safety measures (Plate 2). A suitable restrainer (muzzle) was used in restraining the dog and the cephalic vein occluded by positioning the hand underneath the elbow to prevent movement. Slight pressure was then gently applied to fill the vein with blood and become prominent. Subsequently, the site was cleaned with alcohol, and the vein was punctured using a 20G needle to take about 1ml of blood. Afterwards, the puncture site was compressed to stop bleeding, and the dog was released.

Plate 2: Collection of blood from the cephalic vein of a dog

Source: Fieldwork (2019)

3.4.2.3 Collection of Blood from Cats

The cephalic vein (on the forelimb) or medial saphenous vein (on the hindlimb) of the cat was used in the collection of blood depending on the level of cooperation from the cat. First, the cat was restrained, sometimes in lateral recumbency, using towels and, in other cases, by their owners' hands. Then, the pressure was applied to the region of either the cephalic vein (as shown in Plate 3) or the medial saphenous vein to cause the vein to engorge with blood. Subsequently, the site was wiped with 70% alcohol to disinfect it. On some occasions, disinfection of the site was done after the hairs around were shaved. Next, a 22 to 25 gauge needle attached to a 1–or 2 ml syringe was used to collect about 1ml of blood. After the venepuncture, the needle was removed, and pressure was released from the region. Firm digital pressure was applied at the puncture site for several minutes to prevent hematoma formation and then disinfected before the animal was released.

Plate 3: Collection of blood from the cephalic vein of a cat
Source: Fieldwork (2019)

3.4.3 Swabbing for pathogens

Sampling blood from animals, especially cats, was sometimes challenging as they were aggressive, and swabbing of the cloaca was employed. The entire head of each sterile cotton swab was inserted into the cloaca of the cats and gently swabbed. The swabs were then placed into appropriately labelled tubes and transported to the laboratory under cold chain conditions. In the laboratory, these swabs were kept at -20°C before processing at a later date.

3.5 Processing of Biological Samples Using Molecular Techniques

Molecular techniques were further used to identify zoonotic pathogens from samples collected. Deoxyribonucleic acid (DNA) of pathogens was extracted from whole blood and swab samples using DNAzol® and amplified using specific primers for characterising pathogens under consideration.

3.5.1 DNA Extraction of Samples

DNAzol® was used in extracting deoxyribonucleic acid (DNA) from whole blood, cultured blood (for bacterial DNA) and swab samples following manufacturers' protocol.

3.5.1.1 DNA Extraction from Whole Blood

Deoxyribonucleic acid (DNA) from blood was extracted following the manufacturer's protocol (ThermoFisher Scientific). Whole blood samples previously stored at -20°C were allowed to thaw to ambient temperature before they were used. About 200 µl was picked from each EDTA tube and placed in a labelled 2ml Eppendorf tube. One (1) ml of DNAzol was added to each blood, pipetted up and down assiduously to lyse the cells and then washed with 0.9% sodium chloride (NaCl). The cells were pelleted again and resuspended in a single volume of cold (4°C) hypotonic solution [20 mM Tris HCl (pH 8.0), 10 mM EDTA].

Furthermore, the cells were centrifuged at 4,000 rpm for 10 min (4°C) to the pellet, and the supernatant was discarded. Afterwards, 0.5 ml of absolute ethanol per 1 ml of DNAzol was added to precipitate DNA from the homogenate. The solutions were mixed by inverting the Eppendorf tubes gently and reserved at ambient or temperature for about 3min. DNA became noticeable as a cloudy precipitate which was separated by winding with a pipette tip and transferred into a clean Eppendorf tube, after which it was washed double with 1.0 ml of 75% ethanol. With each wash, DNA was suspended in ethanol which was accomplished by upturning the Eppendorf tubes 3-6 times. Subsequently, the tubes were stored perpendicularly for a minute to let the DNA settle at the bottom, and the ethanol was taken out by pipetting. Later, the DNA was air-dried briefly for 15 seconds. Next, the DNA precipitate "was dissolved in 8 mM NaOH by slowly passing the pellet through a pipette tip"(ThermoFisher Scientific, 2019, p.3). A suitable amount of the 8 mM NaOH was added to approach a DNA concentration of 0.2-0.3 µg/µl. The DNA was then stored at 4°C.

3.5.1.2 Preparation and Extraction of Bacterial DNA

As explained by Soumet et al. (1994), bacterial DNA was processed with some modifications. Stored blood samples were thawed to room temperature, after which 100 µl each was picked and inoculated in 900 µl Luria Bertani (LB) broth (Invitrogen 12780-052). The culture was then incubated at 37°C for more than 24 hours in a shaking incubator (100rpm). Afterwards, a millilitre of individual culture was picked and centrifuged for three(3) mins at 13000xg (4°C), after which the resultant pellets were washed twice in 500 µl 1X TAE buffer (Tris, Acetic Acid, and EDTA; pH 8.0), and centrifuged at 13000xg for 3 mins (4°C). The pellets were re-suspended in 200 µl sterile water, boiled for 8 mins, and then stored at -20°C.

3.5.1.3 DNA Extraction from Cotton Swabs

Cloaca swabs kept at -20°C were thawed to room temperature until use, after which 1000 µl of Phosphate Buffered Saline (PBS) was added and vortexed for about 2 minutes. Subsequently, 200µl of the homogenous solutions were picked, and the steps for extracting DNA using DNAzol (as in Section **3.5.1.1**) were followed. Afterwards, 100 µl of the homogenous solution were added to 900µl Luria Bertani (LB) broth (Invitrogen 12780-052), following the steps for bacterial DNA extraction (Section **3.5.1.2)**.

3.5.2 DNA Amplification By Polymerase Chain Reaction

Polymerase Chain Reaction (PCR) was utilized to amplify numerous copies of diminutive DNA fragments using genus-specific and species-specific primers. Further details of the primer sets are listed in Table 1. A direct PCR assay was used for the DNA amplification of some selected pathogens in samples collected using both forward and reverse primers. All PCR reactions were performed in final volumes of 25.0µl containing 7.50µl sterile nuclease-free PCR water, 12.50µl OneTaq® Quick-Load® 2X Master Mix with Standard Buffer (New England Biolabs Inc.), 0.5µl each of forward and reverse primers and 4.0 µl DNA template. Negative controls and PCR reactions without DNA templates were added to each microtiter plate.

Polymerase Chain Reaction (PCR) was carried out using Bio-Rad iCycler Thermal Cycler (Bio-Rad) at these conditions: initial denaturation at 95°C for 2min, final denaturation of 94°C for the 40s, annealing temperature (Table 2) for 1 minute followed by initial extension at 72°C for 3min. This was followed by a final extension at 72°C for 7 minutes and a holding temperature of 4°C.

Table 1: Primer sets used in the amplification of extracted DNA

Genus/ Common Name	Primer	Sequence	Reference
Babesia spp.	PIRO A1 PIRO-B	F: 5'- AGG GAG CCT GAG AGA CGG CTACC- 3' R: 5'- TTA AAT ACG AAT GCC CCC AAC- 3'	Jefferies et al. (2003)
Strongyloides spp.		F: 5′-AAA GAT TAA GCC ATG CATG-3′ R: 5′-GCC TGC TGC CTT CCT TGGA-3′	Dorris et al. (2002)(cited in Sitta et al., 2012)
Toxocara canis	*Tcan1* *NC2*	F: 5′- AGT ATG ATG GGC GCG CCAAT-3′ R: 5′- TAG TTT CTT TTC CTC CGCT-3′	Khademvatan et al. (2013)
Ancylostoma spp.	AncF AncR	F: 5′- CGG GAA GGT TGG GAG TATC-3′ R: 5′- CGA ACT TCG CAC AGC AATC-3′	Hii et al.(2018)
Salmonella spp. (Non-typhoidal)	ttr-6 ttr-4	F:5′-CTC ACC AGG AGA TTA CAA CATGG-3′ R: 5′-AGC TCA GAC CAA AAG TGA CCATC-3′	Malorny et al. (2004)
Staphylococcus spp.	TStaG422 TStag765	F:5′-GGC CGT GTT GAA CGT GGT CAA ATCA-3′ R: 5′-TIA CCA TTT CAG TAC CTT CTG GTAA-3′ NB. I=nucleoside analogue inosine	Martineau et al. (2001)

F=forward primer; R= reverse primer

Table 2: Annealing temperatures of Primers

Pathogen	Annealing Temperature
Bacteria	$53^{\circ}C$
Protozoa	$56^{\circ}C$
Helminth	$57^{\circ}C$

The PCR amplification products were examined by electrophoresis in 1.2% agarose gels stained with 4.0 µl *Ethidium bromide*. The wells of the agarose gels were each loaded with 6.0 µl PCR product and run at 80V for 90 mins. Fluorescence from the DNA-bound *Ethidium bromide* was then visualized under Ultra Violet (UV) Trans-illuminator or Syngene Bio imager (SYNGENE Inc.), and the data was stored for further analysis. For each infectious disease agent, the amplified product of amplicon size was measured using

100 base pair (bp) DNA ladder (New England Biolabs Inc.) at specific bands corresponding to their base pairs.

3.6 Questionnaire Administration

Questionnaires were administered at the selected communities to evaluate participants' awareness and level of knowledge of zoonoses as well as their interactions with these animals to elucidate how these interactions impact their health as a community significantly. An adult member of each household was interviewed with a semi-structured questionnaire in two parts and comprised of four (4) sections: demographics, risk factors and awareness and level of knowledge of zoonotic diseases. The first part of the questionnaires was designed to solicit information on the demographics and vaccination status of the companion animals, the purpose of keeping them and their contact with rodents if any. The other part was on the owners' management of the companion animals and household practices associated with zoonoses transmission to assess potential sources of infection. The questionnaire employed closed and open-ended questions intending to allow the participants to give detailed responses where necessary.

3.7 Ethical Clearance and Informed Consent

The study involved animal and human participants; therefore, ethical clearance (UG-IACUC 009/18-19) was obtained from the University of Ghana-Institutional Animal Care and Use Committee (UG-IACUC) at Noguchi Memorial Institute for Medical Research. After the first year, an annual report was submitted to the UG-IACUC for the continuing review of the protocol, which was also approved.

In addition to the ethical clearance, approval was sought from selected veterinary hospitals/clinics located within study areas to use companion animals brought to their institutions after their owners consented. Again, appropriate community and household entry strategies were also employed in recruiting participants, and informed consent was sought from all the human participants and owners of the animals in households before samples were collected.

3.8 Analysis of Data

Data entry and cleaning were done using Microsoft Excel (2016), and further descriptive and inferential analyses were carried out with IBM Statistical Package for Social Sciences (SPSS version 20). The normality of data was evaluated using normality plots with tests, that is, the Shapiro-Wilk test. The *p*-values for the animal interface data and survey were significant, indicating that both data were not normally distributed. Thus, non-parametric tests were used in the inferential analyses. Descriptive data analyses were done to describe the distribution of sampled animals, the prevalence of zoonotic infections, and demographic characteristics of survey respondents using frequencies, percentages and graphs.

The prevalence of infection was calculated using the formula below

$$\text{Prevalence} = \frac{\text{Number of positive samples}}{\text{Number of samples}} * 100\%$$

For the inferential analyses, the Mann-Whitney *U* test was used to compare the variability between two independent samples, while Chi-square and Kruskal-Wallis H tests were used to assess the statistical significance between two or more independent samples (Laerd Statistics, 2013, 2018). The chi-square test, which is not affected by unequal sample sizes, was also used in cases where sample sizes from the urban and peri-urban areas were unequal (Grace-Martin, 2020). Again, the strength of relationships between dependent and independent variables was evaluated using Spearman’s Rank Correlation.

For the medical records or secondary data, the *p*-value was not significant, indicating that the data was normally distributed. As such, the One-way Analysis of Variance (ANOVA) was used to compare variations between the means of the three health institutions in addition to other descriptive analyses.

At a 95% confidence level, $p<0.05$ was considered statistically significant.

3.9 Limitations/Challenges

The study was not without some challenges; paramount among them was the impact of the COVID-19 pandemic. COVID-19 caused a significant interruption in the delivery timelines of the collection of data and laboratory processing of biological samples. Earlier intentions to check for seasonality of zoonotic disease transmissions were aborted because restrictions and delays made it impossible to collect data at the required periods. Below are some listed challenges that were encountered throughout the pandemic years:

a. There were delays in taking delivery of purchased reagents from suppliers outside the country.
b. Collection of biological samples from companion animals at the household level stalled for about four months when the disease incidence was very high. Many households were unwilling to allow entry into their homes. Human samples could also not be collected.
c. The administration of hardcopy questionnaires during the period of April-June was largely difficult.
d. Due to time constraints, more resources were needed to trap the required sample size of rodents for blood sample collection.

e. There was no access to the laboratory during the lockdown. After the lifting of the lockdown, there was limited access to the laboratory to process biological samples. The shift system put in place at the laboratory caused significant delays.

In addition to the COVID-19 pandemic, using secondary data (medical records) came with some challenges. Because the hospitals had different methods of diagnosing and reporting diseases, many inferential analyses could not be made. Furthermore, data on the total population tested for a particular disease in two health facilities were missing as the records showed only positive cases, so calculating disease prevalence was a great challenge. Efforts to seek clarity proved futile because when the officers in charge of the medical records in these hospitals were probed for further information, they could not help much since they had little to do in generating these records.

Finally, the study could not investigate the transmission of zoonoses in the human-domestic-wildlife interface because biological samples from owners of these companion animals could not be taken due to several challenges such as insufficient resources and the COVID 19 pandemic. In addition, there was no DNA sequencing, so the results from this study cannot be generalized.

CHAPTER FOUR

4.0 RESULTS

4.1 Introduction

This chapter reports on findings from the study. It is divided mainly into two sections, with the first dedicated to the zoonotic diseases potentially transmitted by the selected animals and presented by humans in selected hospitals. In addition to showing the distribution and characteristics of sampled animals, the prevalence of zoonotic diseases under investigation in the households and veterinary institutions in the urban and peri-urban communities are compared. Finally, images of gel-electrophoresis of some PCR products for identifying zoonotic pathogens are also shown.

The second section is on the descriptive characteristics of responses from the questionnaire survey. Some of the variables explored included socio-demographics of respondents, companion animal management and risk factors of zoonoses in the households. Further inferential analysis using cross-tabulation, Mann-Whitney U test and Chi-square are presented. Lastly, the section presents findings on respondents' awareness and level of knowledge of zoonoses as well as the relationships between identified associated/risk factors of zoonotic diseases.

4.2 Potential Transmission of Zoonoses in the two Human-dominated Landscapes

Humans acquire zoonotic diseases via direct or indirect contact with infected animals, that is, domestic and wild animals in domestic and wild settings. Thus, the high prevalence of zoonotic infections in companion animals and rodents could imply the possibility of ongoing zoonotic disease transmission. Hence, this part of the thesis chapter presents findings on zoonotic diseases transmissible by selected domestic and wild animals to humans in the two human-dominated landscapes.

4.2.1 Distribution and Characteristics of Animals

A total of 404 animals comprising 185(45.8%) dogs, 15(3.7%) cats and 204(50.5%) rodents were sampled. In all, 383 blood samples and 21 cotton swabs were taken from these animals. The sampling of companion animals (dogs and cats) were from households in urban and peri-urban areas and two selected veterinary institutions from the urban category. Similarly, rodents were trapped around households and selected sites in human-dominated landscapes. Table 3 shows the distribution of the sampled animals in these two human-dominated landscapes.

The majority, 71.1% of trapped rodents and 81.5% of companion animals (dogs and cats) were from the urban areas in contrast to 28.9% of rodents and 18.5% of companion animals from the peri-urban category (Table 3).

Table 3: Summary of animals sampled in the two human-dominated landscapes

Group	Human-Dominated Landscape		Total
	Urban	**Peri-Urban**	
Wild (Rodents)	145 (71.1%)	59 (28.9%)	204 (100%)
Companion Animals (Dogs & Cats)	163 (81.5%)	37 (18.5%)	200 (100%)
		U=12619.500, Z=-2.348, *p*=0.019	

Overall, one-hundred and fifteen (115) companion animals consisting of 111 (96.52%) dogs and 4(3.48%) cats were sampled from the two veterinary institutions in the urban areas (Table 4). A total of 93.22% of dogs and 6.78% of cats were sampled from the University of Ghana Small Animal Teaching Hospital (UG-SATH). In contrast, all the sampled companion animals from the East Legon Veterinary Clinic were dogs (100%).

Table 4: Distribution of companion animals from the veterinary institutions

Veterinary Institution	Companion Animal		Total
	Dog	Cat	
East Legon Veterinary Centre (ELVC)	56 (100%)	0 (0%)	56 (100.0%)
University of Ghana Small Animal Teaching Hospital	55 (93.22%)	4 (6.78%)	59 (100.0%)
Grand Total	**111 (96.52%)**	**4 (3.48%)**	**115 (100.0%)**

Correspondingly, 74 dogs, 11 cats and 204 rodents were sampled from the households in the urban and peri-urban communities. Of the companion animals, dogs were the dominant species, with the majority (52.7%) from the urban areas compared to 47.3% from the peri-urban areas (Table 5). Similarly, more rodents (71.1%) were trapped in the urban areas compared to the peri-urban areas (28.9%).

Table 5: Summary of companion animals and rodents investigated from the households in the two human-dominated landscapes.

Human-Dominated Landscape	Companion Animals		Animal from Wild
	Dog	Cat	Rodent
Urban (Madina-East Legon)	39 (52.7%)	9 (81.8%)	145 (71.1%)
Peri-Urban (Dodowa & Environs)	35 (47.3%)	2 (18.2%)	59 (28.9%)
Total	**74 (100%)**	**11 (100%)**	**204 (100%)**

For the rodents, 204 individuals of seven (7) species were trapped over one-hundred (120) trap nights using Sherman collapsible live traps, supplemented by locally made traps. The rodents belonged to the genera: *Praomys tullbergi* (n=38, 18.6%), *Arvicanthis niloticus* (n=113, 55.4%), *Rattus rattus* (n=19, 9.3%), *Cricetomys gambianus* (n=5, 2.5%), *Rattus* *norvegicus* (n=18, 8.8%), *Mus musculus* (n=10, 4.9%), *Crocidura olivieri* (n=1, 0.5%) as illustrated in Figure 8.

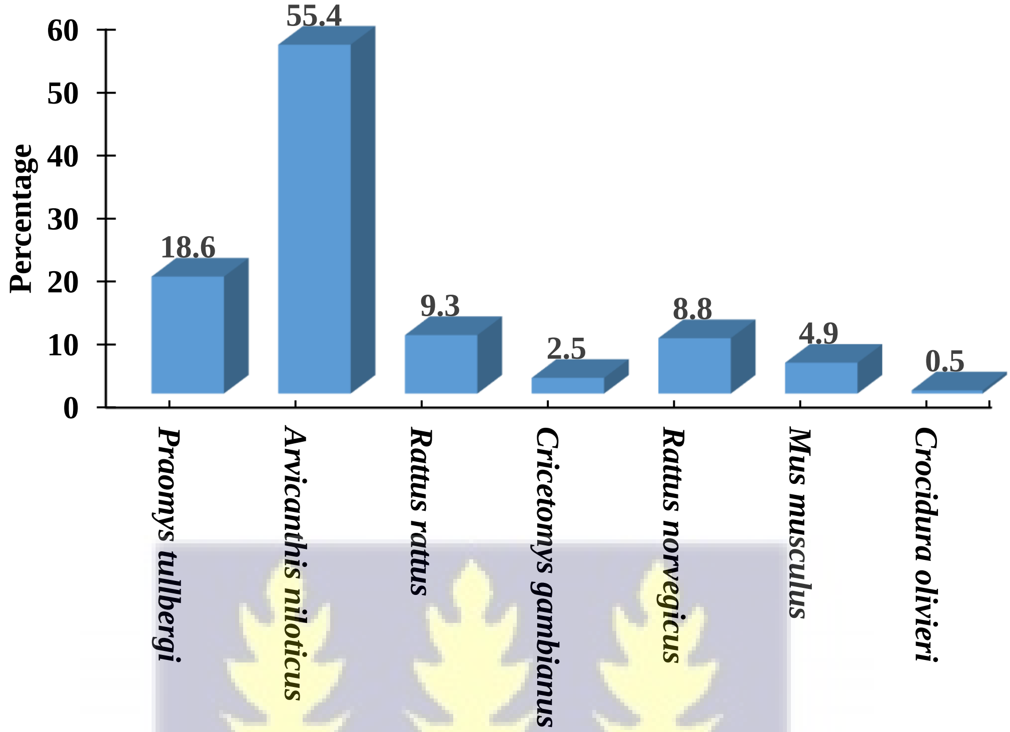

Figure 8: Distribution of trapped rodents

The rodents were distributed between the two human-dominated landscapes. Some species in the urban areas were not trapped in the peri-urban areas and vice versa. Statistically, there was a significant difference between the distributions of rodents in the two human-dominated landscapes (χ^2=180.958, *p<0.001*) (Table 6).

Arvicanthis niloticus was the dominant species trapped in the urban study sites compared to *Praomys tullbergi*, the dominant species from the peri-urban study areas. However, overall, *A. niloticus* was the dominant rodent and *Crocidura olivieri* the least rodent trapped.

Table 6: Distribution of rodents in the human-dominated landscapes

Rodents	Human-ominated Landscape		Total
	Urban	Peri-Urban	
Praomys tullbergi	0 (0.0%)	38 (100.0%)	38 (100.0%)
Arvicanthis niloticus	113 (100.0%)	0 (0.0%)	113 (100.0%)
Rattus rattus	9 (47.4%)	10 (52.6%)	19 (100.0%)
Cricetomys gambianus	5 (100.0%)	0 (0.0%)	5 (100.0%)
Rattus norvegicus	18 (100.0%)	0 (0.0%)	18 (100.0%)
Mus musculus	0 (0.0%)	10 (100.0%)	10 (100.0%)
Crocidura olivieri	0 (0.0%)	1 (100.0%)	1 (100.0%)
			χ^2=180.958, p<0.001

Some images of the trapped rodents in the urban and peri-urban areas are shown in Plate 4 to Plate 7.

Plate 4: *Praomys tulbergi* trapped at Dodowa and surrounding communities
Source: Fieldwork (2020)

Plate 5: *Arvicanthis niloticus* trapped at Legon.
Source: Fieldwork (2020)

Plate 6: *Cricetomys gambianus* trapped on the University of Ghana campus
Source: Fieldwork (2020)

Plate 7: *Rattus rattus* trapped in both urban and peri-urban sampling sites
Source: Fieldwork (2020)

4.2.2 Prevalence of Zoonotic Infections in Animals

Prevalence measures the burden of a disease in a particular population at a specific location and time. This study sought to measure the prevalence of some zoonotic infections to determine their burden and suggest effective methods for their prevention. Hence, the potential transmission of zoonoses was analysed at the animal level where sampled animals were positive for zoonotic pathogen if positive in a single polymerase chain reaction protocol and negative if otherwise. The prevalence of zoonotic infections from the animals studied is illustrated in Figure 9.

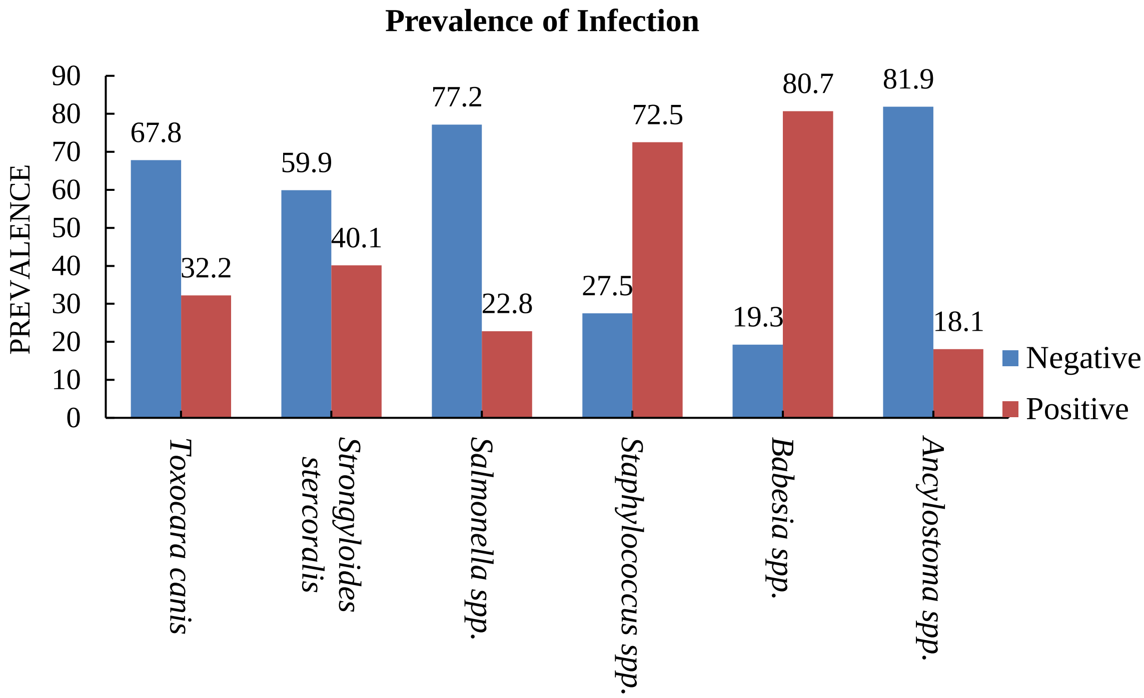

Figure 9: Prevalence of zoonotic infections in targeted animals

The prevalence of *Babesia* spp. was the highest (80.7%), followed by *Staphylococcus* infection (72.5%), and the least was *Ancylostoma* spp. (18.1%). For zoonotic helminths, that is, *T*. canis, *Strongyloides* stercoralis and *Ancylostoma* spp., a prevalence of 30.12 % was recorded.

Human-dominated landscapes signify critical loci for disease transmission and the emergence and re-emergence of several infectious diseases (Hassell, Begon, Ward, & Fèvre, 2017). Thus, the prevalence of zoonotic diseases in this study was analysed in relation to the urban and peri-urban areas. Table 7 shows the prevalence of zoonotic infections in sampled animals between the urban and peri-urban landscapes.

Table 7: Prevalence of zoonotic pathogens in sampled animals in the two human-dominated landscapes

Zoonotic Agent		Human-dominated landscape		Total
		Urban	Peri-Urban	
T. canis	Negative	227 (82.8%)	47 (17.2%)	274 (100.0%)
	Positive	82 (63.1%)	48 (36.9%)	130 (100.0%)
				χ^2=19.160, *p<0.001*
Strongyloides stercoralis	Negative	194 (80.2%)	48 (19.8%)	242 (100.0%)
	Positive	115 (71.0%)	47 (29.0%)	162 (100.0%)
				χ^2=4.545, *p*=0.033
Salmonella spp.	Negative	253 (81.1%)	59 (18.9%)	312 (100.0%)
	Positive	56 (60.9%)	36 (39.1%)	92 (100.0%)
				χ^2=16.151, *p<0.001*
Staphylococcus spp.	Negative	94 (84.7%)	17 (15.3%)	111 (100.0%)
	Positive	215 (73.4%)	78 (26.6%)	293 (100.0%)
				χ^2=5.721, *p*=0.017
Babesia spp.	Negative	67 (94.5%)	11 (5.5%)	73 (100.0%)
	Positive	242 (74.2%)	84 (25.8%)	326 (100.0%)
				χ^2=4.761, *p*=0.029
Ancylostoma spp.	Negative	251 (75.8%)	80 (24.2%)	331 (100.0%)
	Positive	58 (79.5%)	15 (20.5%)	73 (100.0%)
				χ^2=0.436, *p*=0.509

From the table, the highest prevalence was recorded from animals in the urban areas in contrast to those from the peri-urban areas using the Chi-square test.

Also, the Mann-Whitney U test was further used to test for statistically significant differences in the prevalence of zoonotic diseases between the two human-dominated landscapes. The results are presented in Table 8. The table shows a significant difference in the prevalence of *T. canis*, *Strongyloides stercoralis*, *Salmonella* spp., *Staphylococcus* spp and *Babesia* spp. between the two human-dominated landscapes (p<0.05).

Table 8: A comparison of prevalence of zoonotic infections between the two human-dominated landscapes.

Zoonotic Agent	U	Z	*p*
T. canis	11156.5	-4.372	p<0.001
Strongyloides stercoralis	12878.5	-2.129	0.033
Salmonella spp.	11775.5	-4.014	p<0.001
Staphylococcus spp.	12839.0	-2.389	0.017
Babesia spp.	13194.5	-2.179	0.029
Ancylostoma spp.	14240.0	-0.660	0.510

As a result of the close interactions that exist between humans, companion animals and rodents in our communities, the relationship between the prevalence of infection between the households and veterinary institutions was also analysed using cross-tabulation. Cross-tabulation was used to help identify patterns or trends. In addition, the Pearson Chi-Squared test was used to check for observed differences, as shown in Table 9.

Table 9: Prevalence of zoonotic infections in sampled animals from households and veterinary institutions

Zoonotic Agent		Prevalence (%)		Total
		Households	Veterinary Institutions	
Toxocara canis	Negative	205 (74.8%)	69 (25.2%)	274 (100.0%)
	Positive	84 (64.6%)	46 (35.4%)	130 (100.0%)
				χ^2=4.507, *p*=0.034
Strongyloides stercoralis	Negative	201 (83.1%)	41 (16.9%)	242 (100.0%)
	Positive	88 (54.3%)	74 (45.7%)	162 (100.0%)
				χ^2=39.355, *p<0.001*
Salmonella spp.	Negative	225 (72.1%)	87 (27.9%0	312 (100.0%)
	Positive	64 (69.6%)	28 (30.4%)	92 (100.0%)
				χ^2=0.227, *p*=0.634
Staphylococcus spp.	Negative	83 (74.8%)	28 (25.2%)	111 (100.0%)
	Positive	206 (70.3%)	87 (29.76%)	293 (100.0%)
				χ^2=0.789, *p*=0.374
Babesia spp.	Negative	76 (97.4%)	2 (2.6%)	78 (100.0%)
	Positive	213 (65.3%)	113 (34.7%)	326 (100.0%)
				χ^2=31.847, *p<0.001*
Ancylostoma spp.	Negative	239 (72.2%)	90 (27.8%)	331 (100.0%)
	Positive	50 (68.5%)	22 (31.5%)	73 (100.0%)
				χ^2=0.405, *p*=0.525

The chi-squared tests (χ^2) revealed significant differences existed in the prevalence of *T. canis*, *Strongyloides stercoralis* and *Babesia* spp. between the households and veterinary institutions. These three infections were higher in sampled animals from the households compared to the veterinary institutions.

The Mann-Whitney U test was also used to compare the prevalence of infection between households and veterinary institutions. At a 95% confidence interval, the prevalence of *T. canis*, *Strongyloides stercoralis* and *Babesia* varied significantly between households and veterinary institutions (Table 10).

Table 10: A comparison of the prevalence of infections between households and veterinary institutions using the Mann-Whitney U test

Zoonotic Agent	**U**	**Z**	***p***
Toxocara canis	14800.5	-2.120	0.034
Strongyloides stercoralis	10984.5	-6.266	$p<0.001$
Salmonella spp.	16251.5	-0.476	0.634
Staphylococcus spp.	15891.0	-0.887	0.375
Babesia spp.	12536.5	-5.636	$p<0.001$
Ancylostoma spp.	16169.0	-0.635	0.525

Further analysis was also done to determine which of the sampled animals was the most infected and with which zoonotic agent. Consequently, the result is shown in Table 11.

In all, a total of 130 animals were positive for *T. canis* infections and out of this number, the majority were recorded in dogs (56.29%), followed by rodents (42.3%) and then cats (1.5%). Similarly, out of the total 162 positive cases of *Strongyloides stercoralis*, 69.8% were from dogs, 29.6% from rodents and the least was recorded in 0.6% of sampled cats.

Table 11: Prevalence of zoonotic infections among the sampled animals using cross-tabulations

Zoonotic Agent		Prevalence (%)			Total
		Dog	**Cat**	**Rodent**	
T. canis	Negative	112 (40.9%)	13 (4.7%)	149 (54.4%)	274 (100.0%)
	Positive	73 (56.2%)	2 (1.5%)	55 (42.3%)	130 (100.0%)
					χ^2=9.480, *p*=0.009
Strongyloides stercoralis	Negative	72 (29.8%)	14 (5.8%)	156 (64.5%)	242 (100.0%)
	Positive	113 (69.8%)	1 (0.6%)	48 (29.6%)	162 (100.0%)
					χ^2=64.206, *p<0.001*
Salmonella spp.	Negative	144 (46.2%)	9 (2.9%)	159 (51.0%)	312 (100.0%)
	Positive	41 (44.6%)	6 (6.5%)	45 (48.9%)	92 (100.0%)
					χ^2=2.630, *p*=0.269
Staphylococcus spp.	Negative	48 (43.2%)	5 (4.5%)	58 (52.3%)	111 (100.0%)
	Positive	137 (46.8%)	10 (3.4%)	146 (49.8%)	293 (100.0%)
					χ^2=0.569, *p*=0.752
Babesia spp.	Negative	12 (15.4%)	2 (2.6%)	64 (82.1%)	78 (100.0%)
	Positive	173 (53.1%)	13 (4.0%)	140 (42.9%)	326 (100.0%)
					χ^2=38.924, *p<0.001*
Ancylostoma spp.	Negative	146 (44.1%)	13 (3.9%)	172 (52.0%)	331 (100.0%)
	Positive	39 (53.4%)	2 (2.7%)	32 (43.8%)	73 (100.0%)
					χ^2=2.143, *p*=0.342

Again, out of 293 animals positive for *Staphylococcus*, the majority were recorded in rodents (52.3%) and then 46.8% of dogs(Table 11). There were only 92 positive cases of *Salmonella* infection, with the majority of cases found in rodents (48.9%) followed by 44.6% in dogs and 6.5% in cats. Three hundred and twenty-six (326) positive cases of babesiosis were also recorded, with 53.1% found in dogs. Equally, the highest positive cases of Ancylostomiasis were in 53.4% % of dogs, followed by 43.8% of sampled rodents, as shown in Table 11.

Using the Kruskal Wallis test, statistically significant differences in the prevalence of zoonotic infections were assessed among the three sampled animals, and the results are presented in Table 12. The differences in the prevalence of *T. canis*, *Strongyloides stercoralis* and *Babesia* were statistically significant among the sampled animals.

Table 12: A comparison of prevalence of zoonotic pathogens among sampled animals.

Zoonotic Agent	*H*	*p*
T. canis	9.456	0.009
Strongyloides stercoralis	64.047	*p*<0.001
Salmonella spp.	2.623	0.269
Staphylococcus spp.	0.568	0.753
Babesia spp.	38.827	*p*<0.001
Ancylostoma spp.	2.138	0.343

Further post hoc test was done with Dunn's test to identify where the difference in the prevalence of *T. canis, S. stercoralis,* and *Babesia* spp existed between the groups of animals.

Table 13: Post Hoc Dunn's Test

Pairwise-comparison	Test statistic	Std. error	Std. Test statistic	*p*	Adjusted *p* values
Cats-Rodents	-27.527	25.276	-1.089	0.276	0.828
Cats-Dogs	52.775	25.365	2.081	0.037	0.112
Rodents-Dogs	25.247	9.592	2.632	0.008	0.025

Using the adjusted *p*-value of the Dunn's test, differences in the prevalence of *T. canis*, *S. stercoralis* and *Babesia* spp. were observed between rodents and dogs (*p*=0.025)(Table 13).

In analysing the prevalence of zoonotic infections in the animals, some tested negative for all the zoonotic diseases investigated, but 94.8% were infected with at least one. Overall, 13.9% of the animals had a single or mono-zoonotic infection, while 80.9% were co-infected with two to six infections. Table 14 shows the level of infection in the sampled animals**.**

Table 14: Level of Zoonotic infection in studied animals

Level of Infection		**Frequency**	**Percentage (%)**
No Infection		21	5.2
Single/Mono infection		56	13.9
	Two pathogens	110	27.2
	Three pathogens	117	29.0
Co-infection	Four pathogens	70	17.3
	Five pathogens	28	6.9
	Six pathogens	2	0.5
Total		**404**	**100.0**

4.2.3 Infectious and Zoonotic Diseases in the Human Interface

Concerning the secondary data accessed from the three health facilities, records on some infectious and zoonotic diseases are presented in this section. Additionally, findings of zoonoses reported by the different age groups are shown.

4.2.3.1 Infectious Diseases recorded by the Health Institutions

From the peri-urban category, salmonellosis, diseases caused by *Salmonella* spp., were the most reported at the Shai-Osudoku District Hospital for the three years under consideration (Table 15). This was followed by helminthiasis or intestinal helminthiasis; the least was staphylococcal infections. Although *Toxocara* or visceral larva migrans are also grouped as helminth infections, per the medical records of the Shai-Osudoku District Hospital, these were not included under the group 'helminthiasis'. Similarly, *Staphylococcus aureus* or staphylococcal infections were also separated from septicemia due to *S. aureus* and other specified *Staphylococcus* sp. Regarding the individual years, helminthiasis/intestinal helminthiasis was the highest documented infection in 2018, closely followed by salmonellosis. However, this changed in the following years (2019 and 2020) as salmonelloses were recorded as the leading infection (Table 15).

Table 15: Summary of infections documented by the Shai-Osudoku District Hospital (SODH) from 2018 to 2020.

Infectious Diseases	Frequency of infection/Year			Total
	2018	**2019**	**2020**	
Salmonellosis	55	254	126	435
Toxocara/Visceral Larva migrans	4	11	5	20
Helminthiasis/Intestinal helminthiasis	56	96	39	191
S. aureus/Staphylococcal infections	11	2	1	14
Septicemia due to *S. aureus* and other specified *Staphylococcus* sp.	28	3	0	31
Strongyloidiasis	12	11	0	23
Hookworm	1	0	0	1
Total	**166**	**377**	**171**	**714**

In the case of the Pentecost Hospital, information was only available for two of the infectious diseases under consideration: helminthiasis/worm infestation and Typhoid fever. From Table 16, a total of 208 positive cases of typhoid fever and 270 helminth infections were documented over the three years. At a cursory look at the table, positive cases of typhoid fever increased from 2018 to 2020. On the other hand, positive cases of helminthiasis decreased from 108 in 2018 to 60 in 2020.

Table 16: Summary of infections reported at the Pentecost Hospital (PH) from 2018 to 2020.

Infectious Diseases		Frequency of infection /Year			Total
		2018	2019	2020	
Typhoid fever	positive	14	62	132	208
	negative	83	168	231	482
Total		**97**	**230**	**363**	**690**
Helminthiasis/Worm infestation	positive	108	102	60	270
	negative	660	945	190	1795
Total		**768**	**1047**	**250**	**2065**

In contrast to the records from the Shai-Osudoku District Hospital and the Pentecost Hospital, the medical records from the University of Ghana Hospital revealed somewhat high staphylococcal infections (Table 17). Similar to the two hospitals, positive cases of salmonellosis were also the highest.

From Table 17, staphylococcal infections dropped drastically from 146 in 2018 to only 47 positive cases in 2020. In the same way, there was a decline in salmonellosis from 196 in 2018 to 104 in 2020.

Table 17: Summary of infections documented by the University of Ghana Hospital (UGH) from 2018 to 2020

Infectious Diseases	Frequency of infection /Year			Total
	2018	2019	2020	
Staphylococcus infections	146	148	47	341
Salmonellosis	196	174	104	474
Helminthiasis	6	19	4	29
Hookworm infection	2	0	0	2
Toxocara/Visceral larva migrans	0	1	0	1
Total	**350**	**342**	**155**	**847**

Unique to the U.G hospital, the medical records had in detail the different staphylococcal infections, which showed that in 2018 alone, 44% (64/146) of the staphylococcal infections presented were skin infections. Similarly, in 2019 and 2020, 91.2 % (135/148) and 38% (37/97) of staphylococcal infections in that order presented at the hospital were also skin infections.

4.2.3.2 Zoonotic Infections recorded by the hospitals

Per medical records from the health institutions, salmonelloses included typhoid and paratyphoid fevers caused by *Salmonella typhi* and *Salmonella paratyphi*, which are not zoonotic. Therefore, these two pathogens were excluded from zoonotic diseases recorded by the hospitals. Furthermore, all zoonotic diseases were grouped under bacterial and parasitic/helminthic zoonoses, as shown in Tables 18 and 19.

Table 18: Zoonotic bacterial infections presented at the hospitals

Hospital	Zoonotic Agent	Frequency of Infection/Year			Total
		2018	2019	2020	
SODH	*Salmonella enteritidis*	4	5	15	24
	S. aureus/other Staphylococcal infections	39	5	1	45
	Total	**43**	**10**	**16**	**69**
UGH	*Salmonella enteritidis*/ other *Salmonella* infections	5	0	2	7
	Staphylococcal infections	146	148	47	341
	Total	**151**	**148**	**49**	**347**

SODH: Shai-Osudoku District Hospital UGH: University of Ghana Hospital

From Table 18, UGH recorded the highest zoonotic bacterial infections for all the three years investigated. However, the total positive cases decreased markedly from 151 in 2018 to 49 in 2020. Besides, in comparing data from the two hospitals, SODH recorded the highest cases of *Salmonella enteritidis* compared to UGH (Table 18). A one-way analysis of variance (ANOVA) was conducted to examine mean differences in reported zoonotic bacterial diseases in the selected health institutions from 2018 to 2020. No statistically significant differences were observed across the three years (p>0.05) (Appendix C1).

Similarly, one-way ANOVA was conducted to ascertain if there were variations in reported zoonotic bacterial infections across the health facilities. From Appendix C1, there was no statistically significant difference in cases of *Salmonella enteritidis* (p>0.05). However, a statistically significant difference was observed for Staphylococcal infections (F (2, 6) =9.103, p=0.015) across the hospitals. A post hoc test, Fisher's Least Significant Difference (LSD), was then computed to determine where the statistically significant difference exists, and the results are presented in Appendix C1. From the multiple comparison test, there was a statistically significant mean variation in staphylococcal infections between the University of Ghana Hospital (M=113.67, SD=57.74) and the Shai Osudoku district hospital (M=15.00, SD=20.881), Mean difference=98.667, p=0.014) (Appendix C1). This result shows that more cases of staphylococcal infections were reported at the University of Ghana hospital compared to the Shai Osudoku District Hospital.

Concerning helminthic zoonoses (Table 19), the UGH documented the least total cases of helminthic zoonotic infections in all three years. Conversely, the SODH had the highest records of *Toxocara* and *Strongyloides* infections, while PH recorded the highest helminthic cases.

Table 19: Parasitic/Helminthic zoonotic infections presented at the hospitals

Hospital	Zoonotic Agent	Frequency of Infection/Year			Total
		2018	**2019**	**2020**	
SODH	*Toxocara*/VLM	4	11	5	20
	Helminthiasis/intestinal helminthiasis	56	96	39	191
	Strongyloidiasis	12	11	0	23
	Hookworm	1	0	0	1
	Total	**73**	**118**	**44**	**235**
PH	Helminthiasis/worm infestation	**108**	**102**	**60**	**270**
UGH	*Toxocara*/VLM	0	1	0	1
	Helminthiasis	6	19	4	29
	Hookworm infection	2	0	0	2
	Total	**8**	**20**	**4**	**32**

In comparing cases of parasitic/helminthic zoonoses between the hospitals, a One-Way ANOVA analysis showed statistically significant differences between the hospitals and recorded cases of Toxocariasis (F=8.66, p=0.017) and helminthiasis (F=9.395, p=0.014)(Appendix C1). Furthermore, the multiple comparison test (LSD) showed a statistically significant difference in helminthiasis between Pentecost (M = 90.00, SD = 26.15) and University of Ghana Hospitals (M = 9.67, SD = 8.14), Mean $_{\text{Difference}}$ = 80.33, p =. 0.005. This shows that significantly more cases of helminthiasis were reported at the Pentecost Hospital than at the University of Ghana hospital over the three years.

Also, there was a statistically significant difference in helminthiasis between Shai Osudoku (M = 63.67, SD = 26.26) and University of Ghana Hospitals (M = 9.67, SD = 8.14), Mean $_{\text{Difference}}$ = 54.00, p =. 0.029) as shown in Appendix C 1. This indicates that more helminthic cases were recorded by the Shai- Osudoku District Hospital than at the University of Ghana Hospital.

4.2.3.3 The Age-distribution of cases of Zoonotic Disease

The age distribution of cases of zoonotic diseases among the three health institutions was examined and presented in Table 20 to Table 22.

Examining the age-distribution of zoonotic diseases presented to the SODH, helminthiasis and intestinal helminthiasis were the most reported in 2018, followed by strongyloidiasis and then staphylococcal infections (Table 20).

Table 20: Distribution of zoonotic diseases by the different age groups documented by the Shai-Osudoku District Hospital from 2018-2020.

		Frequency of infection/Year				
Year	**Age group**	***S. enteritidis***	**Toxocariasis/ Visceral larva migrans**	**helminthiasis/ intestinal helminthiasis**	**Staphylococcal *infection***	**Strongyloi-diasis**
	<18	2	4	26	11	3
	18-30	0	0	11	0	3
	31-40	1	0	8	0	6
2018	41-50	1	0	2	0	0
	51-60	0	0	4	0	0
	61+	0	0	5	0	0
	Total	**4**	**4**	**56**	**11**	**12**
	<18	4	11	40	2	4
	18-30	1	0	19	0	3
	31-40	0	0	6	0	2
2019	41-50	0	0	13	0	1
	51-60	0	0	6	0	1
	61+	0	0	12	0	0
	Total	**4**	**11**	**96**	**2**	**11**
	<18	6	5	23	1	3
	18-30	3	0	7	0	3
	31-40	2	0	4	0	6
2020	41-50	3	0	3	0	0
	51-60	1	0	2	0	0
	61+	0	0	0	0	0
	Total	**15**	**5**	**39**	**1**	**12**

With regard to records from the Pentecost Hospital, the highest positive cases of helminthiasis were recorded in the age groups below 18 years. Comparatively, positive helminthic cases were noted to decrease with an increase in age (Table 21).

Table 21: Distribution of positive cases of helminthiasis reported by the different age groups at the Pentecost Hospital during the three years.

Year	Age group	Frequency of Helminthiasis/ worm infestation
2018	<18	60
	18-30	17
	31-40	14
	41-50	5
	51-60	9
	61+	3
	Total	**108**
2019	<18	45
	18-30	25
	31-40	19
	41-50	4
	51-60	4
	61+	5
	Total	**102**
2020	<18	21
	18-30	17
	31-40	8
	41-50	7
	51-60	3
	61+	4
	Total	**60**

From the University of Ghana medical records, most cases of staphylococcal infections were presented by persons less than 18 years (Table 22). In 2018 and 2020, there were no records of Toxocariasis or visceral larva migrans. Similarly, there was no record of non-typhoidal salmonellosis (caused by *S. enteritidis* and other *Salmonella* infections) in 2019 as compared to 2018 and 2020.

Table 22: Distribution of zoonotic diseases by the different age groups documented by the University of Ghana Hospital from 2018-2020.

		Frequency of infection/ Year				
Year	**Age**	**Staphylococcal infections**	***Salmonella enteritidis*/ other *Salmonella* infections**	**Helminthiasis**	**Hookworm infection**	***Toxocara*/ Visceral larva migrans**
2018	<18	110	1	2	1	0
	18-30	25	3	3	1	0
	31-40	7	0	1	0	0
	41-50	1	0	0	0	0
	51-60	2	0	0	0	0
	61+	1	1	0	0	0
	Total	**146**	**5**	**6**	**2**	**0**
2019	<18	110	0	7	0	1
	18-30	25	0	5	0	0
	31-40	8	0	2	0	0
	41-50	4	0	2	0	0
	51-60	1	0	2	0	0
	61+	0	0	1	0	0
	Total	**148**	**0**	**19**	**0**	**0**
2020	<18	30	1	0	0	0
	18-30	14	0	1	0	0
	31-40	1	0	1	0	0
	41-50	0	0	1	0	0
	51-60	1	0	1	0	0
	61+	1	1	0	0	0
	Total	**47**	**2**	**4**	**0**	**0**

4.2.4 Gel Electrophoresis of Polymerase Chain Reaction(PCR) Products

Molecular techniques were used to investigate the presence or otherwise of zoonotic pathogens in biological samples. After DNA extraction, polymerase chain reactions were carried out, and the products were further analysed using gel electrophoreses. The images are shown in this section of the chapter.

The molecular weight marker or the DNA ladder, denoted by M (Lane M), was used to detect the approximate sizes of the molecules run on the gel. Negative controls (without templates) were used in the absence of positive controls that proved challenging to get.

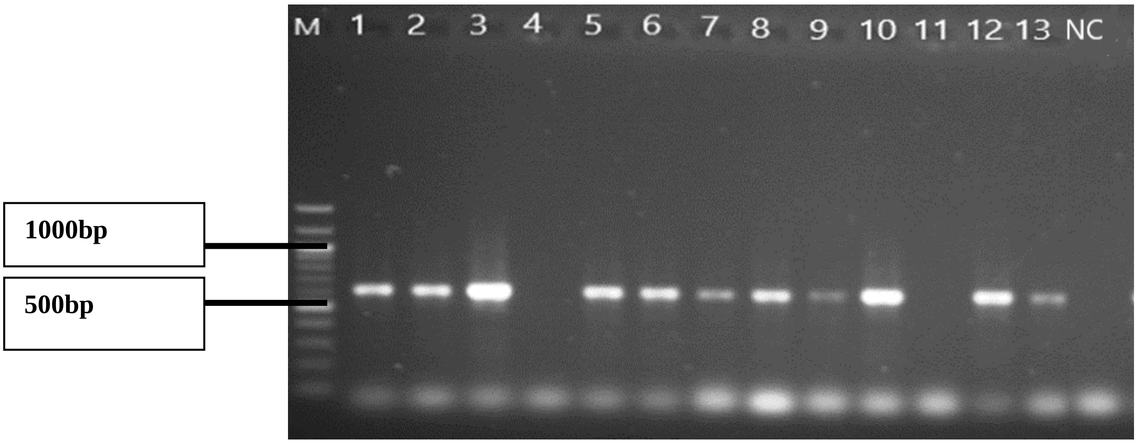

Figure 10: Agarose gel (1.2%) of amplified PCR products for identifying *Toxocara canis*.
(**Lane M**= 100bp ladder, **Lane NC**= negative control, **Lanes** 1-3, 5-10, 12-13 tested positive, **Lanes** 4 and 11 tested negatives).

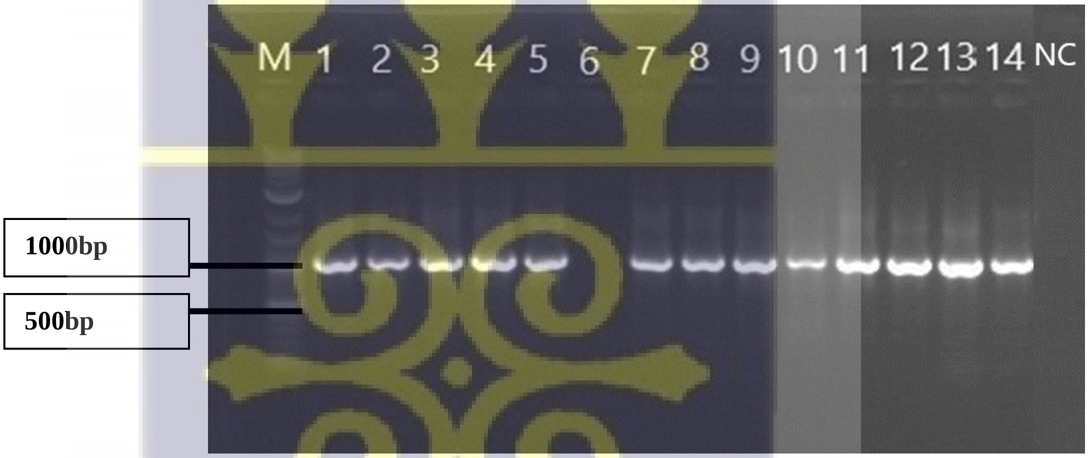

Figure 11: Agarose gel (1.2%) of amplified PCR products for identifying *Strongyloides stercoralis*
(**Lane M**= 100bp ladder, **Lane NC**= Negative control, **Lane 1-5,7-14** tested positive, **Lane 6** tested negative).

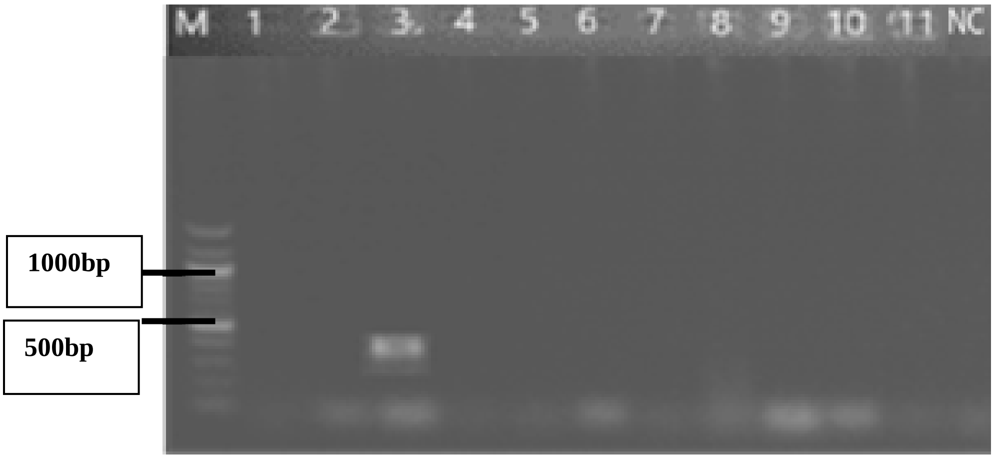

Figure 12: Agarose gel (1.2%) of amplified PCR products for identifying *Salmonella* spp.
(**Lane M**= 100bp ladder, **Lane NC**= negative control, **Lane 3** tested positive**, Lane 1-2, 4-11** tested negative).

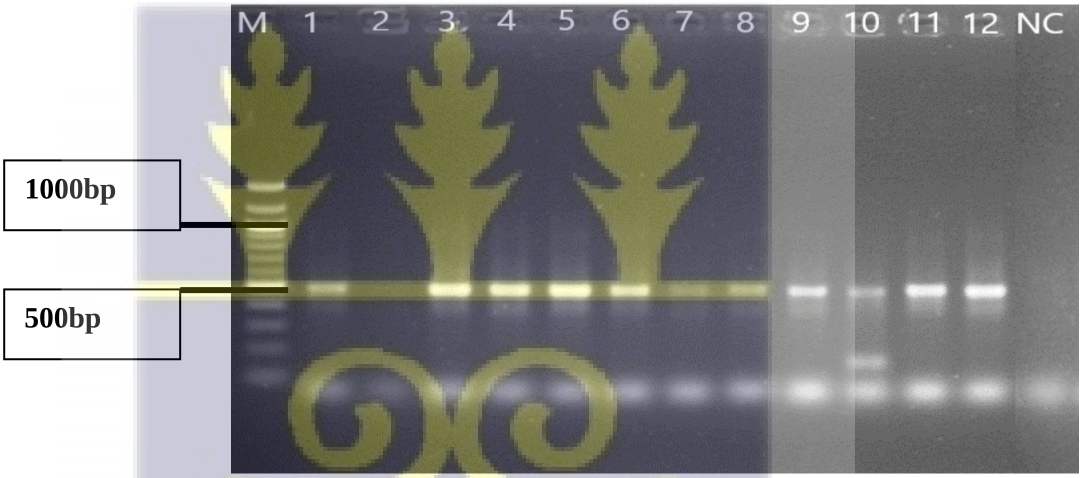

Figure 13: Agarose gel (1.2%) of amplified PCR products for identifying *Staphylococcus* spp.
(**Lane M**= 100bp ladder, **Lane NC=**negative control, **Lane 1, 3-12** tested positive**, Lane 2** tested negative).

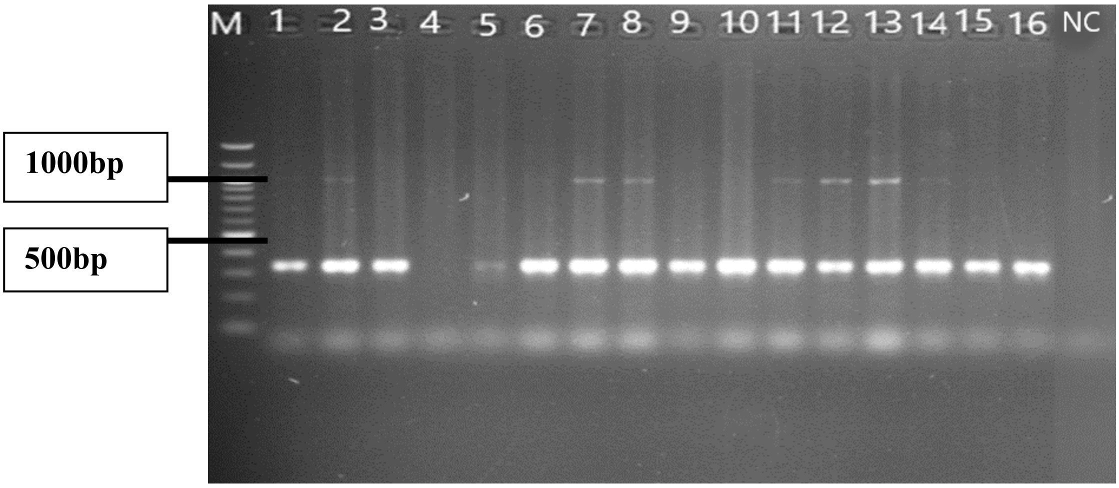

Figure 14: Agarose gel (1.2%) of amplified PCR products for identifying *Babesia* spp.
(**Lane M**= 100bp ladder, **Lane NC=** Negative control, **Lane 1-3** and **5-16** tested positive, Lane 4 tested negative).

Figure 15: Agarose gel (1.2%) of amplified PCR products for identifying *Ancylostoma* spp.
(**Lane M**=100bp ladder, **Lane NC**=Negative control, **Lane 3, 9, 12-14** tested positive).

4.3 Risk factors, Awareness and Knowledge of Zoonoses

The second section of this chapter focused on gathering relevant information on human-domestic animal interactions that predispose humans to zoonotic diseases and how these interactions could form transmission pathways. With the use of semi-structured questionnaires, the awareness, knowledge and risk factors of zoonotic diseases were identified and presented.

4.3.1 Socio-Demographic Characteristics of Respondents

Two hundred and thirty (230) respondents filled and returned the administered questionnaires. Summary information of the socio-demographic characteristics of the respondents is illustrated in Table 23. From the table, the proportion of males was 58.8%, with only 41.2 % females.

Table 23: Descriptive Characteristics of Respondents from the Survey.

Variable	Response	Frequency	Percentage (%)
Sex of respondent	Male	133	58.8
	Female	93	41.2
Age of respondent	<18	7	3.2
	18-30	81	36.8
	31-40	62	28.2
	41-50	41	18.6
	51-60	28	12.7
	61+	1	0.5
Educational level	No formal Education	2	0.9
	Basic/Primary	7	3.2
	Junior High School	19	8.6
	Secondary/High School	46	20.7
	Tertiary	148	66.7
Size of Household	<4	47	21.4
	4-6	119	54.1
	7-9	42	19.1
	>10	12	5.5
Human-dominated landscape	Urban	150	65.2
	Peri-urban	80	34.8

More than 36% of respondents were 18-30 years old, followed by 28.2% within 31-40 years and the least (0.5%) above 61 years (Table 23). Also, 66.7% of the respondents had tertiary education, 20.7% Secondary/High school, and 0.9% had no formal education. In all, 99.1% of them had some form of formal education. There was no statistically significant difference between sex and age of respondents (U=5635, p=0.810) in contrast to a statistically significant difference found between sex and educational level of respondents (U=5100, p=0.046) (Appendix C3).

The impact of household structure or size of household on disease transmission has been reported, and this factor cannot be overstated. As such, this study sought to evaluate how this characteristic influenced disease transmission in the two human-dominated landscapes. From the survey, over 54% of respondents had a household size of 4-6 persons, followed by 21.4% with a household size of fewer than four persons. The largest household size (more than ten persons) was reported by 5.5% of the respondents in the survey(Table 23).

Out of the overall number of respondents who participated in the survey, the majority (65.4%) were from the urban landscape, specifically the Legon-Madina study areas and 34.6% were from the peri-urban areas. In comparing the size of households between the two human-dominated landscapes, no statistically significant difference existed between their medians (U=5113.50, p=0.379) (Appendix C3). However, there were significant associations between the different household sizes in the two human-dominated landscapes using cross-tabulation (χ^2=8.089, df =3, p=0.044) (Appendix C4).

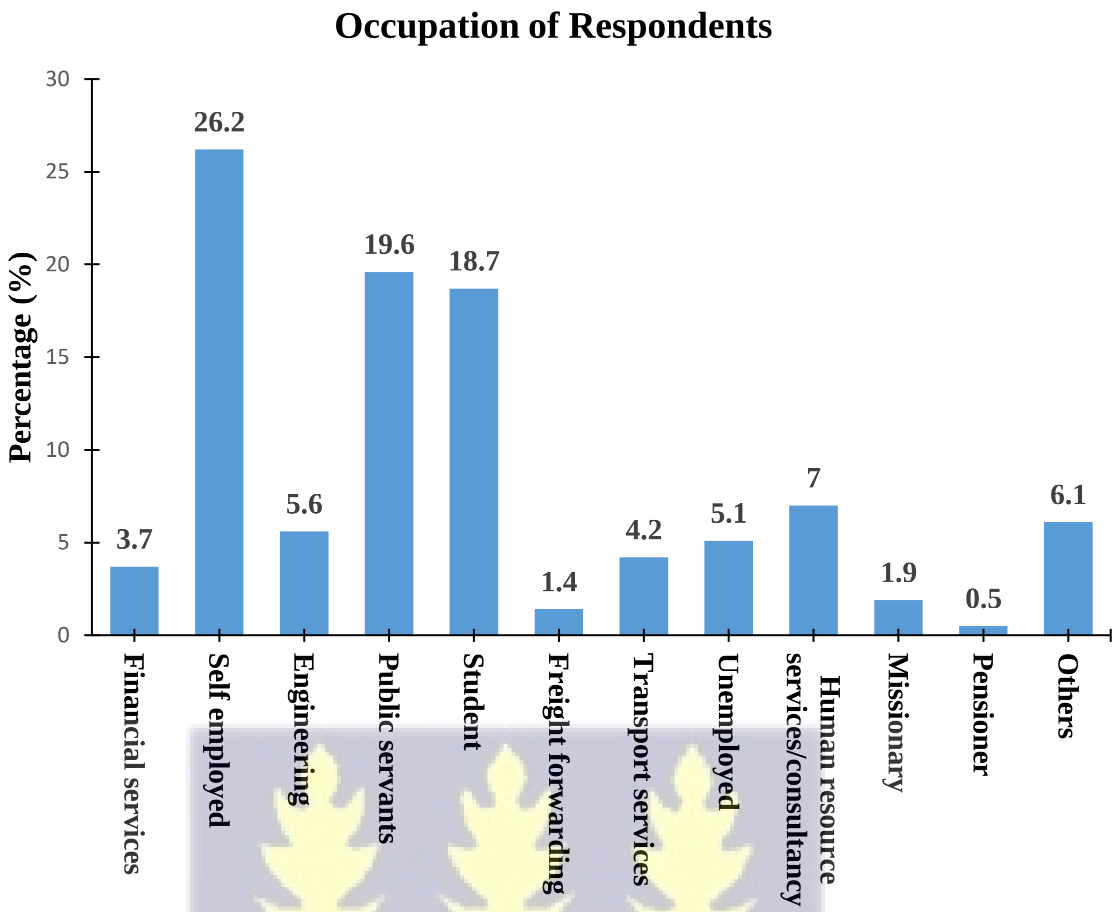

Figure 16: Occupation of respondents of the survey

As illustrated in Figure 16, a good number of respondents were self-employed (26.2%), followed by public servants (lecturers/teachers and medical officers), who accounted for 19.6% of the total sample size. Among the respondents, students at various levels of education were 18.7%, while 5.1% were unemployed.

4.3.2 Companion Animal Management

The relationship between humans and some animals, termed companion animals or pets, has existed for several centuries. People keep these animals for several reasons and have developed a preference for some kind over others. In this study, dogs were the commonest companion animals kept by households. From the survey, 54.4% of respondents had dogs, whereas 24% kept cat(s), and 21.7% owned both dog(s) and cat(s)(Figure 17).

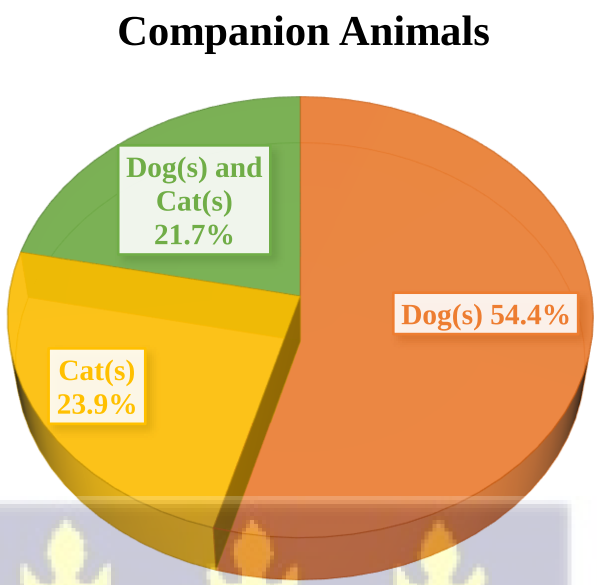

Figure 17: Distribution of companion animals owned by respondents

From the survey, educational level (χ^2=27.638, *df* =8, *p*=0.001) and occupation (χ^2=55.492, df=22, *p<0.001*) were significantly associated with preference for a companion animal (Appendix C4). The majority of respondents who had tertiary education owned dogs (59.5%), while 24.3% and 16.2% kept both animals and solely cats, respectively (Appendix C4). Equally, over 41% and 21% of respondents with secondary/ senior high school qualifications kept dogs and cats, respectively, while 37% owned both animals. From Appendix C4, none of the respondents with no formal education kept cats. Similarly, there existed a significant association between the size of the household and preference for companion animals (χ^2=14.543, *df* =6, *p*=0.024). Again, the data showed that the largest household sizes preferred dogs (50%), and this was also observed in all the other household sizes (Appendix C4).

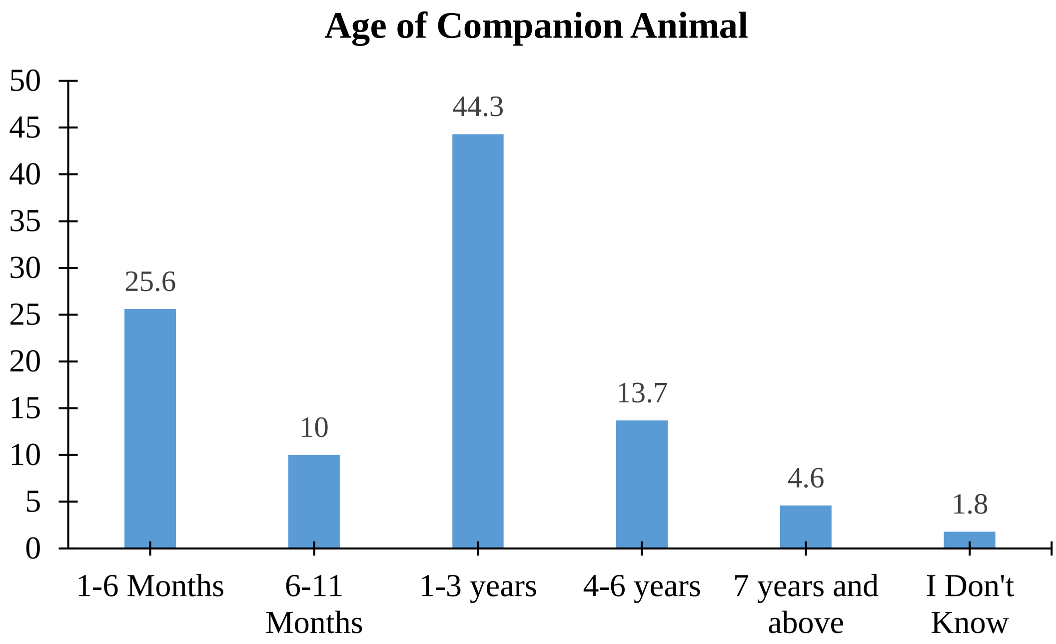

Figure 18: Age of at least one companion animal owned by a respondent

The survey also asked respondents to give the age or ages of their companion animals. Figure 18 shows the age of at least one companion animal. From the figure, a majority (44.3%) of the companion animals were between the ages of 1-3 years. Remarkably, 1.8 % of owners of these companion animals could not tell their ages.

As part of the objectives, this study sought to collect relevant data on the domestic-human interactions comprising how households catered well for their companion animals by engaging in activities like deworming and vaccinating their animals. Again, the study gathered information on the primary reason for keeping these animals which directly or indirectly influences how well the animals are given proper veterinary care (Table 24).

Table 24: Summary of companion animal ownership and management by respondents

Variable	Response	Frequency	Percentage (%)
Do you deworm your pets?	Yes	138	61.1
	No	88	38.9
If yes, how many times do you deworm your pet(s)	Once every month	33	25.2
	Once every three months	54	41.2
	Three times a year	20	15.3
	Other	24	18.3
When was the last time you vaccinated your pet(s)?	Never	79	36.2
	< 3 months	49	22.5
	<12 months	64	29.4
	> 12 months	22	10.1
	I do not know	4	1.8
Reasons for keeping Pet	Companionship/part of the family	72	33.8
	Security/Protection	53	24.9
	Hunting	13	6.1
	Commercial purposes/Breeding	6	2.8
	Health purposes	3	1.4
	Security and Commercial purposes	9	4.2
	Hunting & Companionship	4	1.9
	Security and Companionship	39	18.3
	Others	8	3.8
	No special reason	6	2.8

The survey showed that over 61% of the respondents dewormed their pets, while 38.9% had never dewormed their animals (Table 24). Although vaccination of companion animals is critical in avoiding several preventable infectious diseases and transmission of the same to their owners (humans), sadly, 36.2 % of respondents had never vaccinated their animals (Table 24). A majority (51.9%) had their animals vaccinated less than a year ago, which was quite good. However, 10.1% of respondents vaccinated their animals over a year ago, indicating that their animals were at risk of infectious or zoonotic diseases and transmission to their owners. In all, 54.3% of respondents who had vaccinated their pets had vaccination cards as proof (Appendix C2). There was no association between household size and frequency of vaccinating companion animals (p>0.05) as well as the frequency of deworming companion animals(p>0.05), as shown in Appendix C4.

Undoubtedly, many people have several reasons for keeping companion animals. In this survey, a high proportion of respondents, that is, 33.8%, kept companion animals for the primary purpose of companionship or as part of the family, followed by 24.9% and 18.3% who cited security/protection and security and companionship, respectively (Table 25). From the data, only 1.4 % kept companion animals for health reasons, while 3.8% kept these animals for other reasons such as spiritual protection against spiritual attacks.

Table 25: Relationship between the kind of companion animal and reasons for keeping them

Reasons For Keeping Pets	Dogs	Cats	Dogs & Cats	Total
Companionship/part of the family	28 (38.9%)	26 (36.1%)	18 (25.0%)	72 (100.0%)
Security	41 (77.4%)	4 (7.5%)	8 (15.1%)	53 (100.0%)
Hunting	5 (38.5%)	6 (46.2%)	2 (15.4%)	13 (100.0%)
Commercial purposes	6 (100.0%)	0 (0.0%)	0 (0.0%)	6 (100.0%)
Health purposes	1 (33.3%)	0 (0.0%)	2 (66.7%)	3 (100.0%)
Security & Commercial purposes	5 (55.6%)	0 (0.0%)	4 (44.4%)	9 (100.0%)
Hunting & companionship	0 (0.0%)	2 (50.0%)	2 (50.0%)	4 (100.0%)
Security & Companionship	26 (66.7%)	1 (2.6%)	12 (30.8%)	39 (100.0%)
Others	4 (50.0%)	4 (50.0%)	0 (0.0%)	8 (100.0%)
No special reason	0 (0.0%)	6 (100.0%)	0 (0.0%)	6 (100.0%)
Total	**116 (54.5%)**	**49 (23.0%)**	**48 (22.5%)**	**213 (100.0%)**
				χ^2=75.711, *p<0.001*

All the respondents who reported spiritual protection against spiritual attacks owned a cat. Some companion animals were also kept for hunting purposes; the dogs for hunting in the forest or bush and the cats for hunting rodents. It was also observed that almost all the dogs used for hunting were from Dodowa. From Table 25, keeping only dogs was the most preferred by respondents in this study. Most respondents owned only dogs for security (77.4%) and security and companionship (66.7%). It was also observed that cats were mainly kept for no particular reason, companionship/part of the family and hunting of rodents.

Using the Mann-Whitney U test, the reasons respondents had for keeping companion animals/pets had no statistically significant effect on deworming the animal (U=4438.0, p=0.130)(Appendix C3). However, there existed a significant association between reasons for keeping companion animals and the last time the animals were vaccinated (χ^2=98.281, df=36, $p<0.001$)(Appendix C4). Lastly, there was a statistically significant relationship between the kind of companion animal owned and the reason for keeping such animal (χ^2=75.711, df=18, $p<0.001$), as shown in Table 25.

4.3.3 Risk of Zoonotic Diseases associated with Companion Animal Management

In keeping companion animals, owners may become exposed to zoonotic infections when proper care management systems are not in place. Consequently, the entire household and anyone in the immediate environment may be at risk. As such, sections of the questionnaires elicited responses from the respondents to gather information on some associated factors linked to keeping companion animals. A summary of some of these factors is presented in Table 26.

Table 26: Summary of associated/risk factors of zoonotic diseases identified from the survey

Variable	Response	Frequency	Percentage (%)
Do you allow your dog/cat outdoor at will?	Yes	129	57.1
	No	97	42.9
Do you feed your dog/cat yourself?	Yes	221	96.1
	No	9	3.9
If yes, how often?	Throughout the day	108	48.6
	Sometimes in a day	104	46.8
	Occasionally	10	4.5
If your answer is No or Sometimes in a day, do the pet(s) look for food outside the house?	Yes	55	44.0
	No	70	56.0
Does your dog/cat share the same plate/bowl with the household?	Yes	2	0.9
	No	225	99.1
Where do you wash your dog/cat food and water bowls?	At the tap outside	75	37.3
	Outside/compound of the house	103	51.2
	Kernel	1	0.5
	Kitchen sink/Kitchen	9	4.5
	Bathroom	2	1.0
	Garden	2	1.0
	Inside the house	1	0.5
	No washing	8	4.0
What do you use to wash their food and water bowls?	Soap and sponge	148	74.7
	Just water	20	10.1
	Just sponge	15	7.6
	Parazone /Disinfectant	2	1.0
	Water and sponge	8	4.0
	Broom and soap/water	5	2.5
Do you wash your hands after feeding your pet(s)?	Yes	211	95.5
	No	10	4.5

Table 26 (continued)

Variable	Response	Frequency	Percentage (%)
If yes, when do you wash your hands after feeding your pet(s)?	Immediately after	180	88.7
	After a while	12	5.9
	when going to eat or do something else requiring hand washing	11	5.4
If No, why?	Hands do not touch the bowl	2	40.0
	I use surgical gloves	1	20.0
	I wash my hands when going to eat or do something else requiring hand washing	2	40.0
Do you share the same bed with your dog/cat?	Yes	11	4.8
	No	192	83.8
	Sometimes	26	11.4
Do you allow children in the house to play with the dog/cat?	Yes	150	70.1
	No	64	29.9
After the children play with the pets, do you supervise them to wash their hands before eating/drinking?	Yes	107	66.0
	No	47	29.0
	Sometimes	8	4.9
I keep pets away from sleeping in food preparation areas	Disagree strongly	13	6.9
	Disagree	17	9.0
	Neutral	28	14.8
	Agree	56	29.6
	Agree strongly	75	39.7

From the survey, over 57% of respondents allowed their dogs/cats outdoors, while most fed their pets at home (96.1%). Nevertheless, about 44% of these animals looked for food outside the house (Table 26). Contrary to reports elsewhere, only 0.9% of the respondents shared the same plate or bowl with their companion animal. Again, 1.0% and 4.5 % of respondents reported washing the food/water bowl in the bathroom and kitchen sink/kitchen, respectively. Also, a relatively high number of the food/water bowls were washed outside or on the compound of the house (51.2%), followed by washing at the tap outside (37.3%) (Table 26). In addition, a high proportion of the respondents (74.7%) also washed their companion animals' food and water bowls with soap and a sponge. Interestingly 2.5% used broom and soap/water to achieve this purpose. Almost all the respondents (95.5%) washed their hands after feeding their pets, although only 88.7% of this number washed immediately.

The responses revealed that 4.8% of the respondents share the same bed with their animals, whereas 11.4% only do so sometimes. Over 70% of households with children allowed them to play with their dogs or cats, but only 66.0% were supervised to wash their hands before eating or drinking.

4.3.4 Risk of Zoonoses Associated with Rodents

Several zoonoses have their source from wildlife, so wildlife has been identified as the origin of many emerging infectious diseases. Rodents are typical examples of animals from the wild. Although they are very relevant to the ecosystem yet they are known reservoirs of several zoonotic diseases. In Ghana, they are common around human settlements and cause many destructions of food and household items. Dogs and cats prey on rodents, which could result in the transmission of zoonotic pathogens they carry to these companion animals. Table 27 shows responses from participants of the survey on the contact of their companion animals with rodents.

Table 27: Summary information of companion animals' contact with rodents

Variable	Response	Frequency	Percentage (%)
Do you see rodents in your immediate environment?	Yes	123	53.5
	No	107	46.5
Do rodents cause destruction in your home?	Yes	47	20.9
	No	162	72.0
	I do not know	16	7.1
Is there a history of contact of your dog/cat with rodents recently?	Yes	119	52.4
	No	89	39.2
	I do not know	19	8.4
Have you ever seen your dog/cat eating any rodents before?	Yes	98	43.0
	No	120	52.6
	I do not know	10	4.4
If yes, how often does this happen?	Very often	16	17.8
	Not often	40	44.4
	Rarely	34	37.8

Respondents were asked if they see rodents in their immediate environment; 53.5% responded in the affirmative, although only 20.9% reported that rodents caused destruction in their homes (Appendix C2). Equally, 52.4% said there had been a recent history of contact of their companion animals with rodents. Forty-three per cent (43%) had also seen their dogs/cats eating rodents in the past, with 17.8% and 44.4% describing this phenomenon as very often and not often, respectively. Again, 37.8% of the respondents reported that this rarely occurred (Table 27).

4.3.5 Relationship Between Associated/Risk Factors of Zoonoses in the Human-Dominated Landscapes

The relationship between two or more associated/risk factors and how these factors influence potential zoonotic disease transmission was assessed using Spearman's Rank correlation Coefficient and cross-tabulation. In addition, the significance of the relationships was tested at a 95% confidence interval.

The Spearman's rank correlation coefficient is usually used to determine the strength and direction of the monotonic relationship between two-ranked variables (Laerd Statistics, 2018). From Table 28, there was a significant positive association between educational level and owners' frequency of vaccinating pets (r_s=0.254, p<0.001) and knowledge of causes of zoonoses (r_s=0.141, p=0.049).

Table 28: Summary of significant associations between some variables using Spearman's rank correlation.

Factor		Rs	*p*
Educational level	Frequency of vaccinating a pet	0.254	p<0.001
	Knowledge of sources of zoonoses	0.141	0.049
Frequency of deworming pets	Reasons for keeping pets	-0.203	0.011
	Prevention of zoonotic diseases	-0.350	p<0.001
Frequency of Vaccinating pets	Prevention of zoonotic diseases	-0.260	0.001
Reasons for keeping a pet	Where do you feed your dog?	-0.222	0.009

0.20-.39 ="weak" ; 0.40-.59= "moderate"; 0 .60-.79 ="strong" ; 0.80-1.0= "very strong" (source: https://www.statstutor.ac.uk/resources/uploaded/spearmans.pdf)

In contrast, there was a significant negative association between the frequency of deworming pets and reasons for keeping pets (r_s=-0.203, p=0.011) as well as knowledge of prevention of zoonotic diseases (r_s=-0.350, p<0.001) (Table 28). Similarly, the frequency of vaccinating pets was negatively correlated with knowledge of the prevention of zoonotic diseases (r_s=-0.260, p=0.001), while reasons for keeping a pet were also negatively correlated with place for feeding dog (r_s=-0.222, p=0.009). In all, the strength of the various associations was weak.

In addition to the Spearman Rank Correlation Co-efficient, cross-tabulation was similarly used to show relationships between associated factors/variables measured in the two human-dominated landscapes.

The outcome revealed that 57.1% (129/226) of respondents allowed their companion animals outdoors. Of this percentage, over 67% were from the urban areas compared to 32.6% from the peri-urban areas. Likewise, 44% (55/125) of companion animals, 63.6% from the urban and 36.4% from the peri-urban areas, looked for food outside the house. Again, 61.1% (138/226) of the respondents dewormed their pets, while 38.9% (88/226) did not. Of those who dewormed their pets, 63.8% and 36.2% lived in the urban and peri-urban areas, respectively(Table 29). Also, out of 53.5% (123/230) of respondents who saw rodents in their immediate environment, the majority (65.9%) were from urban areas. Furthermore, 60.2% of respondents who had seen their companion animals eating rodents were from the urban category (Table 29).

Table 29: A summary of associated/risk factors of zoonoses between the two human-dominated landscapes

Factor		Human-dominated landscape		Total
		Urban	Peri-Urban	
Do you allow your dog/cat outdoor at will?	Yes	87 (67.4%)	24 (32.6%)	129 (100.0%)
	No	61 (62.9%)	36 (37.1%)	97 (100.0%)
Total		**148 (65.5%)**	**78 (34.5%)**	**226 (100.0%)**
				χ^2=0.508, *df*=1, *p*=0.476
Do the pet(s) look for food outside the house?	Yes	35 (63.6%)	20 (36.4%)	55 (100.0%)
	No	51 (72.9%)	19 (27.1%)	70 (100.0%)
Total		**86 (68.8%)**	**39 (31.2%)**	**125 (100.0%)**
				χ^2=1.220, *df*=1, *p*=0.269
Do you deworm your pet(s)?	Yes	88 (63.8%)	50 (36.2%)	138 (100.0%)
	No	58 (65.9%)	30 (34.1%)	88 (100.0%)
Total		**146 (64.6%)**	**80 (35.4%)**	**226 (100.0%)**
				χ^2=0.108, *df*=1, *p*= .743
When was the last time you vaccinated your pet(s)?	Never	50 (63.3%)	29 (36.7%)	79 (100.0%)
	< 3 months	26 (53.1%)	23 (46.9%)	49 (100.0%)
	<12 months	45 (70.3%)	19 (29.7%)	64 (100.0%)
	> 12 months	13 (59.1%)	9 (40.9%)	22 (100.0%)
	I do not know	4 (100.0%)	0 (0.0%)	4 (100.0%)
Total		**138 (63.3%)**	**80 (36.7%)**	**218 (100.0%)**
				χ^2=6.053, *df*=4, *p*= .195
Do you see rodents in your immediate environment?	Yes	81 (65.9%)	42 (34.1%)	123 (100.0%)
	No	69 (64.5%)	38 (35.5%)	107 (100.0%)
Total		**150 (65.2%)**	**80 (34.8%)**	**230 (100.0%)**
				χ^2=0.047, *df*=1, *p*=0.828
Is there a history of contact of your dog/cat with or rodent recently?	Yes	70 (58.8%)	49 (41.2%)	119 (100.0%)
	No	65 (73.0%)	24 (27.0%)	89 (100.0%)
	I do not know	15 (78.9%)	4(21.1%)	19 (100.0%)
Total		**150 (66.1%)**	**77 (33.9%)**	**227 (100.0%)**
				χ^2=6.119, *df*=2, *p*=0.047

Table 29 (continued)

Factor		Human-dominated landscape		Total
		Urban	Peri-Urban	
Have you ever seen your dog/cat eating any rodents before?	Yes	59 (60.2%)	39 (39.8%)	98 (100.0%)
	No	85 (70.8%)	35 (29.2%)	120 (100.0%)
	I do not know	6 (60.0%)	4 (40.0%)	10 (100.0%)
Total		**150 (65.8%)**	**78 (34.2%)**	**228 (100.0%)**
				χ^2=2.864, *df*=2, *p*=0.239
How concerned are you about contracting zoonotic diseases?	Very concerned	77 (60.2%)	51 (39.8%)	128 (100.0%)
	concerned	19 (62.5%)	6 (37.5%)	16 (100.0%)
	Not so concerned	30 (68.2%)	14 (31.8%)	44 (100.0%)
	Not concerned at all	17 (77.3%)	5 (22.7%)	22 (100.0%)
	Total	**134 (63.8%)**	**76 (36.2%)**	**210 (100.0%)**
				χ^2=2.843, *df*=3, *p*=0.417

Using the chi-square test of independence, there was not enough evidence to suggest associations between these factors and the two human-dominated landscapes except for an association between the history of contact of pets with rodents (Table 29).

4.3.6 Awareness and Level of Knowledge of Zoonotic Diseases

Having awareness and some knowledge of zoonotic diseases is very important. Unfortunately, most people, such as households that keep domestic animals and are at risk, may lack the essential awareness or knowledge of such diseases. Therefore, this study sought to assess the awareness and the level of knowledge of the respondents on zoonotic diseases.

From Table 30, 69.1% had heard of zoonotic diseases, but only 3% reported ever being diagnosed with any of such diseases. When these respondents were asked what zoonotic disease they were diagnosed with, 40% reported not having any idea; however, 40% reported having been diagnosed with tick fever. All persons diagnosed with tick fever owned dogs (Appendix C4). Most respondents (81.1%) believed that zoonotic diseases could be prevented.

Table 30: Awareness and level of knowledge of zoonotic diseases by respondents

Variable	Response	Frequency	Percentage (%)
Have you ever heard of "zoonotic diseases?"	Yes	159	69.1
	No	71	30.9
Have you ever been diagnosed with a zoonotic disease?	Yes	7	3.0
	No	203	96.7
What zoonotic disease were you diagnosed with?	No idea	2	40.0
	Malaria	1	20.0
	Tick fever	2	40.0
In your opinion, can zoonotic diseases be prevented?	Yes	163	81.1
	No	2	1.0
	Do not know	36	17.9
Do you know of any diseases that people could contract from rodents?	Yes	50	24.3
	No	156	75.7
I think I have a high level of knowledge about zoonotic diseases	Disagree strongly	31	14.0
	Disagree	51	23.1
	Neutral	74	33.5
	Agree	47	21.3
	Agree strongly	18	8.1
Animals can share the same bacteria, viruses and parasites with me	Disagree strongly	21	9.9
	Disagree	13	6.1
	Neutral	25	11.7
	agree	86	40.4
	Agree strongly	68	31.9
Rodents cannot transfer any disease to me	Disagree strongly	24	25.5
	Disagree	23	24.5
	Neutral	15	16.0
	Agree	9	9.6
	Agree strongly	23	24.5

Statically, there was no significant difference in having heard of zoonotic diseases (awareness) between respondents from the urban and peri-urban areas (U=5460, p=0.160)(Appendix C3).

Out of the total 230 respondents interviewed on their knowledge of zoonoses, 39.2% could tell that these diseases were transmitted from animals to humans, and 11.2 % said it was deadly. In contrast, 5.6% said it was a disease transmitted by touching an animal and not washing your hands (Figure 19). Conversely, 12.6% had just heard about it and did not know much. Interestingly, 11.9% of respondents said they only knew that cats' fur causes cough, while 14.7% had no idea what the disease was about, as shown in Figure 19.

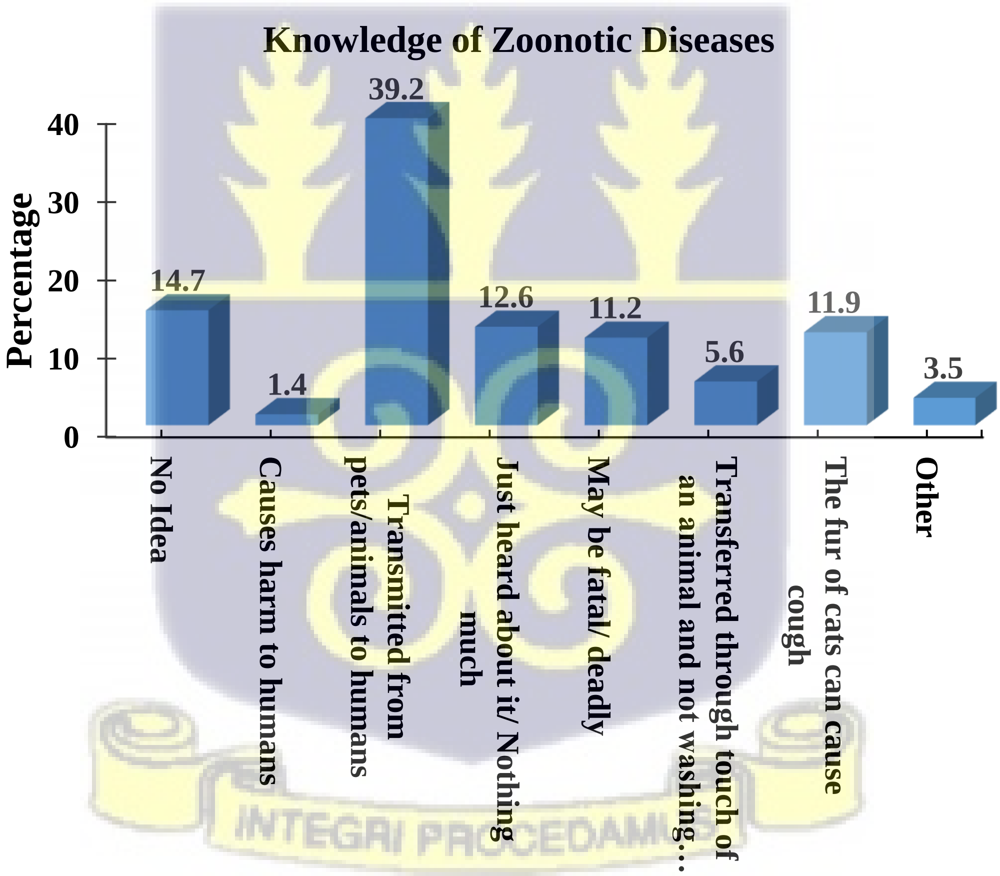

Figure 19: Respondent's knowledge of zoonotic diseases

Respondents mentioned a few zoonotic diseases, which are illustrated in Figure 20. From Figure 20, a good number (37.3%) of the respondents could readily mention rabies as a zoonotic disease, whereas 24.3% could not name any, although they were aware of it. Between the two human-dominated landscapes, there was no significant difference in respondents' ability to name some zoonotic diseases they know of (U =3078.5, p=0.696) (Appendix C3).

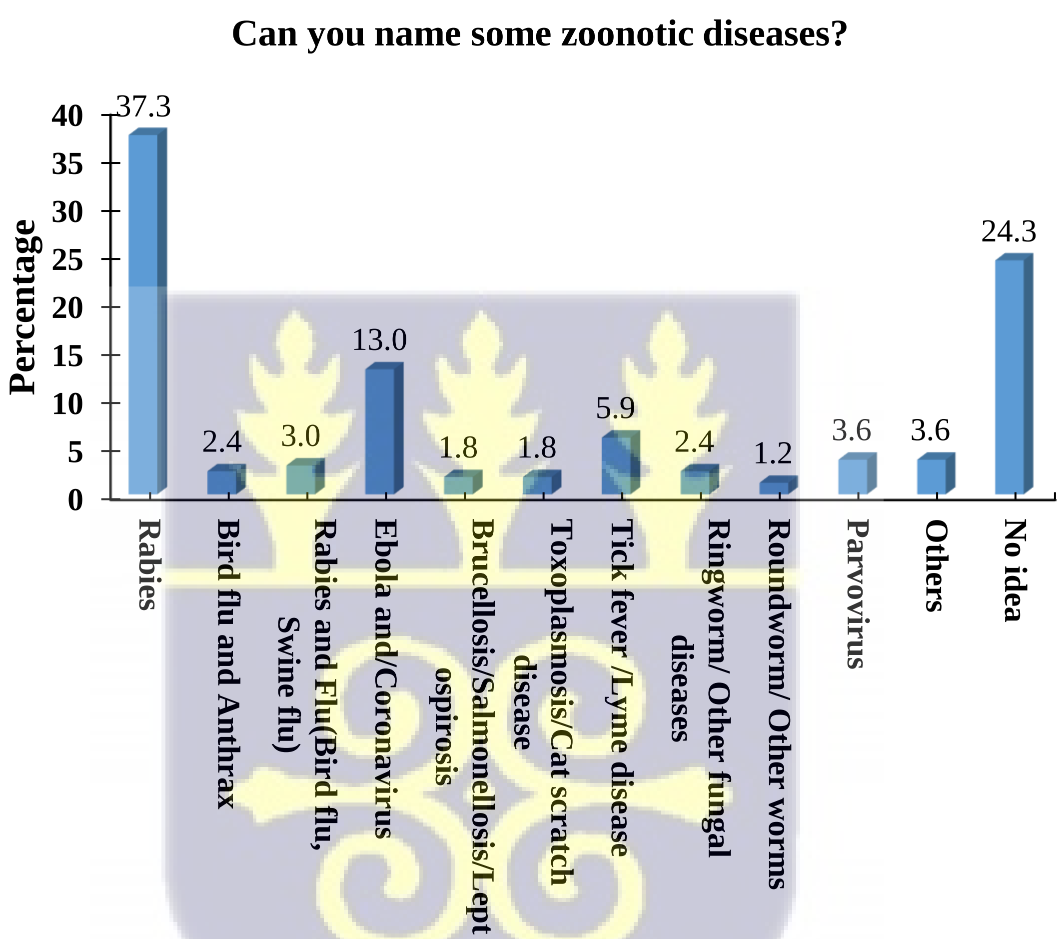

Figure 20: Zoonotic diseases named by respondents in the survey

Again, when they were asked to rate their level of knowledge of zoonotic diseases using the Likert scale, 29.4% agreed to have a high level of knowledge, 37.1% disagreed, and 33.5% were neutral/indifferent (Appendix C2). Using the Mann-Whitney U test, the difference in the level of knowledge of zoonoses between respondents in the two human-dominated landscapes was not significant (U=4858.5, *p*=0.157) (Appendix C3).

From the survey, 42.3% of the respondents agreed that rodents could transmit diseases to them, but only 24.3% were aware of diseases that people could contract from rodents (Appendix C2). When probed to name some of these diseases, 19% mentioned rabies, 16.7% named Ebola, while the majority (others, 23.8%) cited diseases like rashes, allergic reaction, typhoid and cholera, as shown in Figure 21. There was no significant difference in respondents' ability to name diseases from rodents between the two human-dominated landscapes (U=196, *p*=0.606) (Appendix C3).

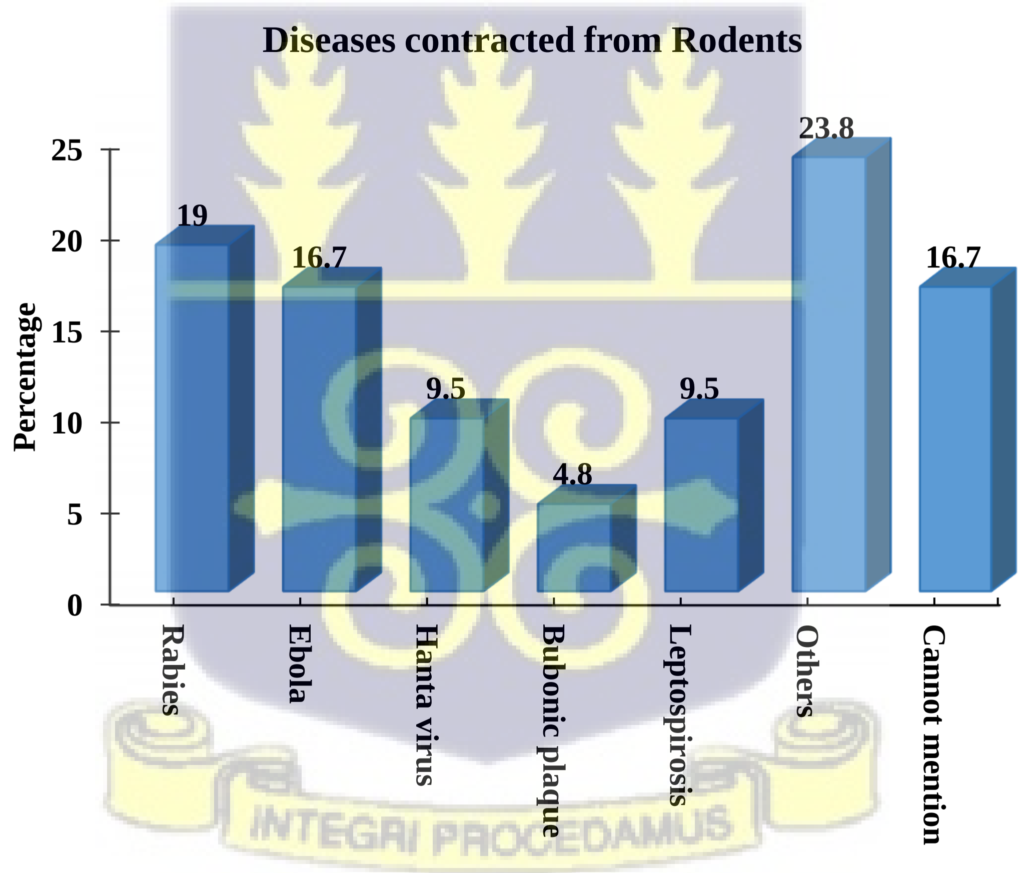

Figure 21: Diseases contracted from rodents as mentioned by the respondents

CHAPTER FIVE

5.0 DISCUSSION

The study set out to explore the potential transmission of zoonotic diseases across the human-domestic-wildlife interface in two human-dominated landscapes and gather information on how households create favourable conditions that facilitate the transmission of such diseases and their impact on sustainable health. The results were divided into two sections, with the first focusing on assessing the prevalence of zoonotic diseases in selected sampled animals and humans. In contrast, the other part evaluated participants' awareness and level of knowledge of zoonoses through the questionnaire survey. Thus, this chapter discusses these findings in relation to these two sections.

In total, 404 animals were sampled, comprising 49.5% companion animals from households and veterinary institutions and 50.5% rodents from the wild. Most of this total number were from the urban landscape, Legon and Madina, whereas 23.76% were from Dodowa and its environs categorised in this study as the peri-urban landscape. Overall, the prevalence of zoonotic infections varied among the sampled species ranging from 18% to 81%. Babesiosis was the highest zoonotic infection recorded, while Ancylostomiasis was the least. For zoonotic soil-transmitted helminths comprising *T.* canis, *Strongyloides* and *Ancylostoma* spp., a prevalence rate of 30.12% was recorded.

Furthermore, data from the study showed that 80.9% of animal species were co-infected with multi-zoonotic pathogens. The prevalence of the various zoonotic infections investigated in sampled animal species was diverse. Therefore, further discussions were along that tangent.

Of the three animals examined, dogs were the dominant species infected with babesiosis, followed by rodents and the least prevalence rate was observed in cats. The prevalence of babesiosis recorded in dogs (53.1%) in this study was significantly higher than what was recorded by O'Dwyer et al. (2009), Owusu (2015) and Baah (2019), which were 8%, 3% and 7.7% respectively. With such high prevalence, babesiosis, a protozoan zoonotic disease from ticks, suggests that half of the dog population was infested with tick species. It implies that these dogs may not be adequately taken care of by their owners, as was identified from the survey accounting for such high tick infestation resulting in relatively high babesiosis. Furthermore, 42.9% of rodents testing positive for *Babesia* species may pose an increased risk of recurrent *Babesia* infections in companion animals who feed on these rodents nearly often and their owners. These findings could also allude to the fact that human babesiosis transmission may be ongoing in such households because of the close interaction between dogs and their owners. However, because of the similarities in the clinical presentation of *Babesia* infections and malaria (*Plasmodium falciparum*), misdiagnosis and under-reporting might result in the lack of data on human babesiosis in the country (Owusu, 2015).

The second highest prevalence rate was *Staphylococcus* infection. This zoonotic bacterial disease can readily be transmitted from one species to another, from animals to humans and vice versa. Reports show that most zoonoses are caused by bacterial agents (Han et al., 2016; Ebani, 2017). Generally, rodents are known natural hosts of *Staphylococcus* (Mrochen et al., 2018), so the relatively high number testing positive for *Staphylococcus* infections was not out of place. However, this data indicates that, first of all, *Staphylococcus* infection could be transmitted to humans directly by these rodents as they contaminate food in storage, utensils and many more (Bonwitt et al., 2017). Secondly, the transmission may be indirect when companion animals feed on these rodents and consequently infect their owners with the infection (Goni et al., 2018). It could also mean that rodents might be reservoirs of methicillin-resistant *Staphylococcus* (Ge et al., 2019). If so, companion animals that come into contact with these infected rodents in their environments can also become colonised and infected by MRSA (Mrochen et al., 2018; Ge et al., 2019). Without a doubt, such a situation could complicate matters, although in this study, due to lack of funds and other COVID-19-related issues, no sequencing was carried out for further confirmation.

Strongyloidiasis, the third-highest zoonotic infection recorded, is also a disease of primary public health importance because this infection is shared between humans and dogs. Therefore, cross-infection is probable even though there seems to be no available data. This data is consistent with the assertion that animals with unlimited out-of-door access could be prone to continuous exposure to *S. stercoralis* (Paradies et al., 2017). In contrast to other studies by Ekong et al. (2012) and Mulugeta et al.(2019), which reported a prevalence of 0.4% and 2.6%, respectively, the prevalence of infection in dogs (69.8%) in this present study was high

Data on human strongyloidiasis in Africa and Ghana are mostly lacking because humans are typically asymptomatic (Varatharajalu & Rao, 2016). Even when symptomatic, the symptoms are often general (non-specific), leading to misdiagnosis in our health facilities or underreporting. Generally, soil-transmitted helminth infections like *S. stercoralis* can be prevented by wearing shoes when walking on soil and avoiding contact with faecal matter (CDC, 2020) since transmission is through the filariform larvae entering the skin. In most communities in Ghana, the faecal matter of dogs and cats is left unattended in the environment. So human infections are more likely when good personal and environmental hygiene practices are not observed.

Toxocariasis, a regularly reported disease in children, gained much attention in recent years due to increased cases in some parts of the world (Woodhall et al., 2014; Chen et al., 2018). In these cases, dogs and cats were implicated in the disease transmission (Holland, 2015; Chidumayo, 2018) because children ingested either the ova or oocyst of this parasite excreted into the environment. Even until now, cases are reported regularly in certain parts of the globe. In this study, the prevalence of *Toxocara canis* infection in selected animal species was 32.2%, with a high proportion of positive cases recorded in dogs. Comparatively, the prevalence of *T. canis* infection in this research was higher than the 4.5%, 29.4% and 9.8% prevalence reported by Nijsse et al. (2016), Smout et al. (2018) and Ayinmode et al. (2016) elsewhere in that order. This data supports the view that *T. canis* is a common and relevant helminth of dogs (Johnson et al., 2015; Amissah-Reynolds et al., 2016). Additionally, because rodents are intermediate hosts of this parasite (Shakespeare, 2009), there is the likelihood of enzootic transmission of *Toxocara canis* in these infected animals, increasing human exposure to this parasite. Furthermore, *T. canis* in cats suggests cross-species transmission, confirming Spickler's report (2016).

Furthermore, comparing the prevalence of *Toxocara* in dogs to other studies conducted in Ghana by Johnson et al. (2015)(5.8%), Amissah-Reynolds et al. (2016) (18%) and Baah (2019)(40%), this is much higher perhaps due to the use of PCR in this study or rather a surge in *Toxocara* infections in selected communities. A possible increase in *Toxocara* infections could be attributed to the fact that these animals feed or sleep on the ground. Because this pathogen is a soil-transmitted helminth, they become infected in any *Toxocara*-infested environment (Nijsse et al., 2016). Unfortunately, Toxocariasis has not received much attention in Ghana, so a high prevalence of infected dogs documented in this present study coupled with *T. canis* infected cats merits swift attention to avert any possible disease outbreak. Again, since cats are not natural hosts of *T. canis*, possible cross-infection may be ongoing in study sites which merits further investigation.

The study also revealed that 22.8% of sampled animals were positive for *Salmonella* spp. In all, 49.8% of rodents and 44.6% of dogs tested positive. *Salmonella* colonises many animals, and studies show they are commonly distributed in domestic and wild animals who maintain the animal-to-animal cycle through the faecal-oral route (PAHO, 2001). For instance, dogs, cats and rodents get infected by ingesting infected faeces from the environment. Subsequently, shedding the parasite by dogs and cats causes diseases in humans living in the same household. According to Sanchez et al.(2002), the estimated prevalence of *Salmonella* spp. in normal dogs could range from 1%-36%. However, the high prevalence in dogs and rodents suggests the environment may be contaminated with *Salmonella* spp. from infected animals and the possible ongoing human salmonellosis.

Zoonotic hookworm diseases are transmitted from infected animals to humans through contact with excreted parasite eggs that contaminate the environment. Thus, the role of animals in this disease transmission to humans cannot be overstated and therefore merit some investigation. In this study, 18.1% of animals were positive for *Ancylostoma* spp. Comparatively, the prevalence rate in dogs(53.4%) was lower than what was reported by Ortega-Pacheco et al. (2015) (70.8%) and Smout et al. (2018)(91.8%) but higher in contrast to studies carried out in Ghana by Johnson et al. (2015) and Amissah-Reynolds et al. (2016) where prevalence reported were 46.8% and 16.9% respectively. Having over half of the dog population sampled in this study testing positive and Johnson et al. (2015) also recording a relatively high rate in the Greater Accra Region suggests that owned dogs in the region may not be given good veterinary care in terms of regular deworming. Thus, persons who live in households and communities where these animals are present may be at a higher risk of zoonotic hookworm infections(Ngui et al., 2012).

With regard to zoonotic diseases presented in the three health facilities, salmonellosis and helminthiasis were the highest infectious diseases recorded in that order. Even though *Salmonella typhi* and *S. paratyphi* are not zoonotic, the high frequency suggests possible active transmission, which could eventually lead to disease spillover as these parasites are constantly evolving mechanisms to survive and expand their host range (Wiedemann et al., 2015).

Although mortality associated with helminthiasis is generally low, this disease impacts heavily on the physical and mental health of the affected, especially children's growth. Therefore, the high record of helminthiasis, a common infection usually reported in poor communities' merits attention. Altogether, the medical records pointed out a relatively high occurrence of helminth infections in urban and peri-urban communities. With almost all helminths pathogenic to humans identified as zoonotic (Taylor et al., 2001; Ayinmode et al., 2016), findings from the animal interface and the medical records support the assertion by Ekong et al. (2012). According to them, there is a direct link between the prevalence of zoonotic helminth infections in humans and the occurrence of such in animals in that same area.

Regarding individual parasitic worm infections, data from the two hospitals, namely, the University of Ghana(U.G) and the Shai-Osudoku District Hospitals, varied considerably. This could be attributed to economic, social and environmental factors (Heymann, 2006) and the different diagnostic techniques used. For instance, there was a single positive case of toxocariasis at the U.G hospital for the entire 3-year period, whereas the Shai-Osudoku District Hospital recorded 20 positive cases. Relatively, patrons of the U.G hospital are more economically sound and may not be predisposed to these soil-transmitted infections compared to patrons of the Shai-Osudoku District Hospital. In much the same way, the diagnostic method used in both hospitals and the level of knowledge of the laboratory personnel could influence the detection and reporting of the disease.

Besides, some zoonotic infections in humans cause marginal or no clinical manifestations. Others like toxocariasis can lead to severe complications, especially when *Toxocara canis* migrate through the human body. Regardless of the low number of positive cases, the importance of this disease cannot be overemphasized. In the University of Ghana and Pentecost hospitals, cases of toxocariasis were found in ages below 18. This data substantiates the fact that juveniles are often vulnerable to this infection due to their contact (while playing) with soil contaminated with the parasite (Taetzsch et al., 2018; Chen et al., 2018) from infected dogs and cats (Holland, 2015; Chidumayo, 2018). In like manner, cases of strongyloidiasis for the three years were also low, and the majority of the cases were in ages below 18 years which again support the fact that children are very vulnerable to many soil-transmitted helminth infections. Even though *Strongyloides stercoralis* is reportedly endemic in 138 districts in Ghana (Ghana Health Service, 2007), this did not reflect in the hospital records.

In the case of hookworm infections, both the Shai-Osudoku district hospital and the U.G hospital had separate medical records of one and two positive cases, respectively. However, because the three hospitals had diseases grouped under helminthiasis, it may include some hookworm and *Strongyloides* infections. For example, results of whole blood counts of some patients of the Pentecost Hospital suspected to have helminth infections showed low haemoglobin levels, characteristic of persons suffering from hookworm infections.

As observed from the three hospitals, there were no records of tick fever or babesiosis, which could be due to one of two reasons. Usually, humans are accidental hosts of this parasite and get infected when bitten by an infected adult tick or nymph. However, records on human babesiosis in Africa and Ghana, in particular, are often non-existing because this infection shares similar morphology and clinical presentations as malaria. So it is often misdiagnosed as malaria. Therefore, the lack of data could be due to misdiagnosis or because persons suffering from this disease may not report at the hospitals but rather treat it as a malaria infection at home.

Continuous changes in various landscapes occurring worldwide are identified to play significant roles in the epidemiology of zoonotic diseases (Patz et al., 2004; Mackenstedt et al., 2015). For instance, changes in human-dominated landscapes such as the urban and peri-urban landscapes are reported elsewhere to be associated with various infectious disease outbreaks as these places play major routes in disease transmission. Thus, one specific objective of this study was to investigate which human-dominated landscape best support potential zoonotic disease transmission. As such, animal distribution and zoonotic prevalence data from the study were analysed between the two human-dominated landscapes (urban and peri-urban areas), and the results were discussed in tandem.

Animals from the wild have been implicated in many zoonotic disease epidemiology. Rodents directly or indirectly impact human health and the economy by sustaining various pathogen transmission cycles. They are reservoirs to many diseases and play significant roles in transmitting those diseases by maintaining infections mainly in endemic areas and thus a considerable risk to sustainable health. In the present study, 204 individual rodents from 7 genera were trapped. Some of these species are major agricultural pests with extensive distributions in Ghana and Africa. From the data, the distribution of the various rodents between the two human-dominated landscapes was statistically significant. Two rodents, *Arvicanthis niloticus* and *Praomys tulbergi*, were the dominant species found in the urban and peri-urban areas, respectively, suggesting that *A. niloticus* and *P. tulbergi* might be the commonest species found in the Legon-Madina and Dodowa areas respectively.

It is quite interesting to note that most of the trapped rodents were from the urban areas compared to the peri-urban areas that have a combination of rural and urban characteristics. One reason for the low numbers of rodents in the peri-urban areas may be due to the continued hunting of rodents in these areas. The survey indicated that most of the dogs sampled from the peri-urban areas were mainly used for hunting in the Dodowa and Adumaya forests and the bushes around. In the view of Meerburg et al. (2009), these peri-urban rodents serve as a connexion between wildlife and humans, resulting in the exposure of humans to zoonotic pathogens that circulate in the natural ecosystem. Conversely, a possible explanation for the high numbers in the urban areas may be human behaviour which creates conducive environments such as unsanitary conditions and poor waste management practices. Such conditions cause rodents to thrive and reproduce at unprecedented rates corroborating the works by Costa et al. (2015) and Panti-May et al. (2016).

Similarly, more companion animals were sampled from the urban communities probably because of the high socioeconomic status of persons found in these areas and also no sampling from a veterinary clinic at Dodowa at the time of data collection. Initially, the study proposed to collect and compare data from selected veterinary clinics in the two human-dominated landscapes, but this proved unsuccessful due to the absence of a functional veterinary clinic in Dodowa. Enquiries at the Shai-Osudoku Department of veterinary services clarified that most of the residents who owned these companion animals did not seem concerned about the health of their animals and did not bother taking them to the veterinary. As such, it was not a profitable venture, hence the unavailability of a veterinary clinic. In the absence of a veterinary clinic run by the district veterinary department (due to lack of infrastructure), the few who cared enough about their companion animals took them elsewhere or employed the services of veterinary officers who visited their homes. Contrary to the situation at Dodowa, there were many veterinary clinics owners of companion animals could patronise. From the data gathered at these two institutions, dogs were the most familiar animals brought in by their owners.

Likewise, the highest prevalence of zoonotic infections was from animals sampled from the selected urban areas. Of the total positive cases of the six zoonotic diseases examined, the majority were recorded in animals from urban areas. Statistically, there were significant differences ($p<0.05$) in the prevalence of *T. canis*, *S. stercoralis* and *Babesia* among the sampled animal species in contrast to significant differences found in the prevalence of *T. canis, S. stercoralis, Salmonella* spp., *Staphylococcus* spp. and *Babesia* spp. between the urban and peri-urban areas.

Furthermore, in comparing the prevalence of zoonotic infections between the households and veterinary institutions, there were statistically significant differences in the prevalence of *T. canis, S. stercoralis* and *Babesia* infections. It suggests that more animals from the households than the veterinary institutions were positive for these infections. Both *T. canis* and *S. stercoralis* are soil-transmitted helminths; therefore, the data suggest that the infective larvae of these worms are commonly found in the environment where these animals frequently come into contact. Also, the data points to the fact that proper care of these animals, like regular deworming and grooming of companion animals, may be lacking.

Primarily, the data indicate that selected animal species are hosts to zoonotic diseases of significant public health to humans. Furthermore, considering the findings of Taylor et al. (2001), where 35% of zoonotic diseases were identified to be transmitted through direct contact and 61% via indirect contact, the relatively high prevalence in companion animals and rodents suggest that the human population are highly exposed to zoonotic pathogens. This may have triggered possible zoonoses transmission in the human-dominated landscapes, as indicated by the medical records. However, the findings suggest that the urban areas best support potential zoonotic disease transmission. Therefore, the presence and frequency of these animals will possibly affect disease pressure in humans (Mackenstedt et al., 2015; Salyer et al., 2017), even though the impact will also be affected by other factors.

In the second section of the study, which was about specific objectives 4 and 5, a total of 230 respondents were surveyed. From the survey, most of the respondents were males, and this was expected because some zoonoses-related surveys conducted in some African countries and particularly in Ghana, mainly report male respondents to be in the majority (Ohemeng et al., 2018; Awuni et al., 2019; Issah et al., 2020; Namusisi et al., 2021). Even though a study by Bukar-Kolo et al. (2018) showed that females or women tend to keep companion animals more than their male counterparts, that was not observed in this study. Furthermore, the dominant age group recorded were the ages of 18-30 years. A possible explanation for this young age could be because they may be charged to take care of these companion animals or simply because they prefer to own them for various reasons. The data from the veterinary institutions also confirmed this observation. However, in a related study by Ayim-Akonor, Krumkamp, May, & Mertens (2020), the dominant age group was 20-29.

Data from the survey also showed that most respondents had formal education, with a majority having tertiary education as their highest educational level. In contrast, less than one per cent had no formal education. In a similar study by Namusisi et al. (2021) in Uganda, low educational levels of participants were documented, with only 18.7% having had secondary education while 19.5% had no formal education. Similarly, in the study by Ohemeng et al.(2018), 15.9% of the participants were also without formal education.

Because of the strong interactions among households, the size or structure of the household is considered important in disease transmission studies, especially in diseases transmitted directly (House & Keeling, 2009; Endo, Uchida, Kucharski, & Funk, 2019). According to House and Keeling (2009), large households are more likely to be infected because many members may bring infection from somewhere else. From the study, a higher proportion of respondents had a household size of four to six persons, and 5.5% had a household size of more than ten persons. The implication of this data on sustainable health cannot be overstated. Even if one person contracts an infectious disease, the possibility of transmitting it to other household members is likely to be very high, with far-reaching consequences for the entire community.

Additionally, most of the respondents were from urban areas, which was not out of place because the populations at both Legon and Madina are among the highest in the Greater

Accra Region (GSS, 2014). Again, residents from these urban areas mostly keep companion animals compared to their peri-urban counterparts, which was a criterion for selecting persons to be part of the survey. Statically, there was no significant difference in the household sizes between the two human-dominated landscapes, although significant associations were observed using a chi-square analysis.

Having companion animals has existed for centuries, and these animals have become integral to many households. People keep these animals for several purposes, such as for companionship, protection or security, among other reasons. The purpose or reason influences the preference of companion animals. In this study, most respondents owned only dogs, which supports the findings from Issah et al.(2020). Again, data from the survey revealed that most owners of companion animals in Ghana preferred dogs which is consistent with findings from Amissah-Reynolds et al. (2016), Baah (2019) and Issah et al. (2020). The second preferred companion animal is the domestic cat, even though keeping this animal has been met with several superstitions and myths in some African countries (Bukar-Kolo et al., 2018). Nevertheless, some owners prefer them to dogs mainly because of the hunting of rodents (Serpell, 2013).

Of the many reasons for keeping companion animals in this research, companionship or being part of the family and security or protection were ranked high. In all, a high number of respondents owned dogs for security purposes, substantiating findings by Johnson et al. (2015) and Baah (2019), where 70% and 90.2% of dogs in the Greater Accra region were used for security purposes. Unlike the western world where a good number of these animals are kept for health purposes, only 1.4% of animals surveyed in this study were for that reason. Nearly all the dogs sampled from the peri-urban areas were used for hunting, consistent with the view of Kardjadj & Ben-Mahdi (2019). Interestingly, most of the peculiar reasons for keeping cats were superstitious-based, which supports reports by Bukar-Kolo et al. (2018). Even though there was no significant association between deworming companion animals and reasons for keeping these animals, a significant association was observed between the various reasons for keeping companion animals and the type of companion animal.

In comparing the association between some measured variables and socio-demographic characteristics, the educational level of respondents had a bearing on the preference for companion animals, which was statistically significant. Respondents with tertiary education owned the highest number of companion animals, preferably dogs. Also, household size was associated with a preference for companion animals, with larger households preferring to keep dogs, probably for security purposes.

Data from the study suggest that some of the companion animals are well catered for or given good veterinary care. Most respondents had dewormed and vaccinated their animals within 12 months, which is commendable. It implies that such respondents were less at risk of contracting helminthic infections from their animals.

The importance of vaccination can never be overemphasized, even though cost-related issues in this country are glaring. However, vaccination is indispensable because humans are always in contact with companion animals. According to the survey, the majority of respondents had dewormed and vaccinated their pets within a year. Though Baah (2019) recorded a lower percentage of dewormed dogs (37.2%) in his research, Awuni et al. (2019), on the other hand, recorded a higher percentage (52.7%) of vaccinated dogs in their study.

The fact that close to 39% and 36.2% of respondents had never dewormed or vaccinated their animals suggests that such animals may trigger future zoonoses transmission and outbreaks. Research by Bukar-Kolo et al. (2018) in Nigeria also revealed that none of the sampled cats had ever been vaccinated. In Ghana, a parallel study by Amissah-Reynolds et al. (2016) at Mampong reported that 46% of dogs had never been dewormed. These findings are worrisome because these animals are potential carriers of infectious diseases and, therefore, are likely to significantly impact zoonoses transmission in these respective communities.

The prevention of zoonoses cannot be accomplished without awareness and knowledge by all the relevant stakeholders. Every effective control strategy hinges on an accurate understanding of the disease. Thus, this study investigated respondents' awareness and level of knowledge of zoonoses. The results showed that a high proportion of the respondents were aware of zoonotic diseases, which are consistent with findings from Klous et al. (2016), lower than those reported by Issah et al. (2020) but relatively higher than reported by Fèvre et al. (2017) in Lake Victoria. Though a good number of respondents were aware of the disease, only 39.2% could correctly tell what the disease was all about. Nevertheless, nearly all believed that zoonoses could be prevented, which is laudable. Again, when asked to name some zoonotic diseases, the majority mentioned rabies as a zoonotic disease, quite similar to findings by Issah et al. (2020) and Hundal et al. (2016) but divergent from the research outcome by Klous et al. (2016), where 65% of respondents named avian influenza. The researcher attributed this to a nationwide awareness creation during their research. Participants called diseases like rabies, Ebola and coronavirus, anthrax and bird flu, among others. When respondents were asked to rate their level of knowledge about zoonotic diseases, a few claimed to have a high level.

Furthermore, only 3% claimed to have been diagnosed with a zoonotic disease. Nevertheless, a majority (40%) could not tell what condition they were diagnosed with, but 40% said they were infected with tick fever. The survey revealed that respondents who alleged to have been diagnosed with tick fever kept dogs in their homes.

In the case of diseases contracted from rodents, many of the respondents were unaware of such. Although the majority agreed people could contract diseases from rodents, only a few knew about some of these diseases. When asked to name some of these diseases, the majority (23.8%) mentioned illnesses that were not zoonotic, indicating that they lack knowledge of the subject matter.

It was envisaged that over 90% of respondents having formal education could imply good knowledge about zoonotic diseases. However, this study found no significant difference between educational level and respondent level of knowledge. Furthermore, between the two human-dominated landscapes, there were no significant differences in the awareness of zoonotic diseases, the ability to mention some examples and the respondents' level of knowledge.

The study also investigated zoonoses' associated or risk factors in these two human-dominated landscapes. The data suggest that most companion animals and their owners were highly exposed to zoonoses because most owners allowed their animals out at will. However, nearly all of them claimed (96.1%) feeding them. Also, about 44% of sampled companion animals looked for food outside their homes which implies these animals were predisposed to zoonoses from other infected animals in the community.

In contrast to owners of companion animals in the western world, less than one per cent of the respondents shared the same plate with their animals, placing them at a higher risk of getting infected. Commendably, just a few did not wash their animals' food and water bowls even though respondents who did so used all kinds of materials ranging from a broom to soap and sponge. Another risk factor assessed was the sharing of a bed with companion animals. The data revealed that only a few respondents shared a similar bed with their animals. In the view of Whitfield and Smith (2012), this could lead to zoonotic disease outbreaks.

The data also showed that many households had children who played with dogs and cats, but only 66% supervised these children to wash their hands before consuming anything. According to Whitfield and Smith (2012), not washing hands after feeding or playing with these animals was responsible for many companion animal-related disease outbreaks in the past. Hence, the need to practice good handwashing hygiene to avoid infections.

In measuring the relationship between the variables, there were significant associations between quite a few. Some relationships showed positive direction while others were negative. The positive and significant correlation between educational level and frequency of vaccinating companion animals shows that owners with higher education are more likely to vaccinate their companion animals as often as required. Also, the higher the educational level of respondents, the more knowledgeable respondents are about the sources of zoonoses; an indication that respondents with high education are better placed to identify sources of zoonoses and therefore capable of preventing them. Conversely, the negative association between the frequency of deworming pets and knowledge of zoonoses prevention implies that persons with high knowledge of zoonoses prevention may not necessarily deworm their companion animals as often as required, which has grave implications for sustainable health. In addition, the frequency of deworming pets found to be negatively associated with the reason for owning a pet suggests that the purpose for keeping these animals influences the frequency at which their owners deworm them.

The results also showed that respondents who have heard or were aware of zoonotic diseases believed such could be prevented, as observed in the significant positive association recorded. The negative correlation between respondents' awareness and high knowledge of zoonoses indicates that a high understanding entailed more than just being aware of the disease.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This last chapter is dedicated to the concluding remarks on the objectives of the thesis and its contribution to knowledge. Some recommendations and policy directions are also presented.

6.2 Conclusions

The present study revealed the prevalence of *Toxocara canis, Strongyloides stercoralis*, *Salmonella* spp., *Staphylococcus* spp., *Babesia* spp. and *Ancylostoma* spp. across the two human-dominated landscapes studied. The results prove the existence of zoonotic infections circulating among companion animals and animals in the wild that are pathogenic to humans. Notably, the overall prevalence of zoonotic diseases varied among the sampled animal species, with a more significant proportion of dogs being positive for *T. canis*, *Staphylococcus* spp., S. *stercoralis*, *Babesia* spp. and *Ancylostoma* spp. whereas a higher prevalence rate of *Salmonella* spp. was recorded in rodents. These findings from the animal interface and the medical records from the human interface indicate that there are possible ongoing transmissions of zoonoses, especially helminthiasis, in these communities.

Furthermore, the study established that the urban areas best support the potential transmission of zoonotic diseases compared to the peri-urban areas. This is because higher infection prevalences were recorded in animals from the urban areas indicating that persons living in such areas are at a higher risk of zoonotic diseases, considering the high potential of zoonotic transmissions in those communities.

The survey also showed that companion animals (both dogs and cats) were mainly kept for companionship or as part of the family. However, of the two companion animals, dogs were the most preferred and predominantly owned simply because of their relevance in providing protection or security for their owners.

Again, a high proportion of the respondents were aware of zoonotic diseases and could readily mention rabies as a zoonotic disease. Nevertheless, many were unaware of zoonotic diseases that one could contract from rodents, and a good number also lacked knowledge on the subject matter. There were also indications from this study that people with high education pay more attention to vaccinating their animals, and persons more concerned about contracting zoonotic diseases observed good practices to avoid being infected. Therefore, since every effective control strategy pivots on accurate knowledge, much attention must be directed to educating the populace on the importance of zoonotic diseases to their health, security and economy.

In conclusion, the findings of this study strongly suggest that human exposure to zoonotic diseases as a result of their close contact with companion animals and rodents is relatively high since most of these animals were co-infected with more than one zoonotic pathogen. Again, the data from the health facilities and the fact that the zoonotic pathogens investigated are capable of crossing species barriers indicate potential active transmission of zoonotic pathogens across the human-domestic-wildlife interface, especially in urban communities. Moreover, the lack of knowledge of zoonoses and the risky behaviours of owners of companion animals predisposing them to infections calls for urgent and proactive surveillance and strategies for the prevention and control of zoonoses using the one health approach.

6.3 Recommendations

The findings from this study brought to bear some research topics that could be explored to give a better comprehension and conclusiveness of zoonoses transmission across the human-domestic-wildlife interface in the country. The following suggestions could be considered in future investigations.

1. There should be the inclusion of primary data from the human population during the collection of biological samples from domestic and some wild animals commonly found around human settlements to draw a better link between zoonoses transmission pathways across these interfaces.
2. An extensive study should be carried out in the other regions of the country using larger sample sizes to provide relevant information and make better inferences.
3. More zoonotic pathogens must be investigated in these populations and amplified gene products from gel electrophoreses sequenced to give conclusive reports.

In addition, there is an urgent need for constant and effective public health education and awareness creation campaigns on zoonoses among the general public using the One-health approach.

6.4 Contribution to Knowledge

A few works have been published on the potential transmission of zoonoses in Ghana and, in many instances, across the human-domestic interface or human-wildlife interface. However, this present study brings to the fore a relatively inclusive picture of potential zoonoses transmission across the human-domestic-wildlife interface in two human-dominated landscapes, that is, the urban and peri-urban communities. To the best of my knowledge, this study is the first of its kind in Ghana.

Again, most previous studies used non-molecular techniques to assess zoonotic disease prevalence. Conversely, in this study, the use of molecular techniques, which are more robust, was employed, thus making it a good baseline study.

Furthermore, findings from this study add to the literature on zoonotic disease transmission of companion animals and rodents in Ghana.

6.5 Policy Direction

This study highlights the limited knowledge of persons at high risk of zoonoses. It stresses the urgent need for continuous and effective public health education and awareness campaigns on zoonotic diseases among the general public using a one-health approach. To forestall any future zoonotic disease outbreak, all relevant stakeholders, including policymakers, must be engaged to bring out a comprehensive but feasible plan for the surveillance, identification or diagnosis and control of zoonotic diseases.

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APPENDICES

APPENDIX A: ETHICAL CLEARANCE FROM INSTITUTIONS

Appendix A1: Ethical clearance from the University of Ghana Institute of Animal Care and Use Committee (IACUC)

/

UNIVERSITY OF GHANA

University of Ghana Institutional Animal Care and Use Committee (UG-IACUC)

Phone:
Email: UG-IACUC@ug.edu.gh

P.O. Box LG 581
Legon, Accra
Ghana

Office Location: Department of Animal Experimentation Building, Noguchi Memorial Institute for Medical Research (NMIMR), University of Ghana

29th April, 2021

ETHICAL CLEARANCE
(UG-IACUC 009/18-19)

Title of Protocol: Transmission of zoonoses between the human-domestic-wildlife interface across twohuman-dominated landscapes and its implication on sustainable health

Principal Investigator: Linda Ama Owusuaa Amoah

Your protocol for an amendment was presented to the University of Ghana Institutional Animal Care and Use Committee (UG-IACUC) for a full board review and the following actions have been taken subject to the conditions and explanation provided below:

On Agenda for: An Amendment

UG-IACUC Action: Approved

Expiry Date: 17th January, 2022

Reporting: Annually

Signature of Chairperson
Prof. Major (Rtd.) George A. Asare

INTEGRI PROCEDAMUS

Appendix A2 : Ethical clearance from Accra Regional Health Directorate, Ghana Health Service

In case of reply the number and date of this letter should be quoted.

My Ref. No. **GHS/GARHD/001/21**

Your Ref. No.

GHANA HEALTH SERVICE
Your Health - Our Concern

GHANA HEALTH SERVICE
REGIONAL HEALTH DIRECTORATE
GREATER ACCRA
P. O. BOX 184
ACCRA

Tel: +233-0302-234225/226203
Mobile: 0208140751
E-mail: c_brako@yahoo.com

23rd June, 2021

THE MEDICAL SUPERINTENDENT
SHAI OSUDOKU DISTRICT HOSPITAL
DODOWA

RE: PERMISSION TO ACCESS DATA FROM SHAI OSUDOKU DISTRICT HOSPITAL – LINDA AMA OWUSUAA AMOAH

Kindly find attached a letter dated 21st June, 2021 from the Principal Supervisor of the Department of Animal Biology and Conservation Science of the University of Ghana with the above subject matter for your information and necessary support.

Thank you.

DR. (MRS.) CHARITY SARPONG
REGIONAL DIRECTOR OF HEALTH SERVICE
GREATER ACCRA

Cc: Acting Deputy Director, Clinical Care

APPENDIX B: RESEARCH INSTRUMENT/QUESTIONNAIRE

RESEARCH INSTRUMENT

Background

The study is part of a study by Linda A. O. Amoah, a student of the Department of Animal Biology and Conservation Science, the University of Ghana on the "**Transmission of Zoonoses Between the Human-Domestic-Wildlife Interface Across Two Human-Dominated Landscapes and Its Implication on Sustainable Health**".

She would like to seek your thoughts by asking you a few questions on zoonotic diseases. Your participation is voluntary and you may at any point decide to withdraw from this exercise if you find it necessary. We would appreciate any assistance you can give to her to enable her complete this study. We assure you that your responses will remain confidential. Any further questions or clarifications on the study may be addressed to Prof. Langbong Bimi on **024 352 1393** or Dr Benjamin Y. Ofori on **020 174 9574**. Thank you.

Consent

"I have read or have had someone read all of the above regarding participation in this research to me, and I am willing to give my consent to participate in the study. However, I have not waived any of my rights as a research participant by signing this consent form."

____

Initials of participant

____ _______________________

Signature or mark of participant Date

____

Name of Interviewer

____ _______________________

Signature or mark of interviewer Date

A. SOCIO-DEMOGRAPHIC CHARACTERISTICS

1. Sex of respondent. a. Male b. Female
2. Age of respondent……………………………….
3. Educational level a. No formal education b. Basic/Primary c. Junior High School d. Secondary/ High School e. Tertiary f. Higher Education
4. Occupation………………………………………
5. Locality………………………………………….
6. How long have you been staying in this locality? ....
7. How would you describe the area in which you live? a. Rural b. Urban c. Peri-urban
8. How many are you in the house/ size of the household? ....

B. CONTACT WITH PETS/COMPANION ANIMALS

1. Do you keep pets? a. Yes b. No
   - If yes, what pet(s) do you keep?
     a.……………………b…………………………
2. How many are your pets? ……………………
3. How old is your pet? a. 1-6 months b. 6-11 months c. 1-3 years d. 4-6 years e. 7 years and above.
   (If there are multiple pets, list the ages of the rest)
4. Do you deworm your pet(s)? a. Yes b. No
   - If yes, how many times do you deworm your pet(s)? A. once every month b. once every three months c. three times a year d. other, specify………………...
5. When was the last time you vaccinated your pet(s)? a. Never b. < 3 months c. <12 months d. > 12 months.
6. Do you have a vaccination card for your pet(s)?
   ……………………………………………
7. What is your reason for keeping pets?
   ....
   …………………………………………………………………………………

C. RISK FACTORS OF ZOONOTIC DISEASES

1. Do you allow your dog/cat outdoor at will?
2. Do you feed your dog/cat yourself? a. Yes b. No
   - If yes, how often? a. throughout the day b. sometimes in a day c. Occasionally d. never
   - If your answer is **No** or **Sometimes in a day**, do the pet(s) look for food outside the house. a. Yes b. No

3. If you feed your pets, where in your house do you feed them? a. Dog .... b. Cat.................
4. Does your dog/cat share the same plate or bowl with the household? a. Yes b. No
   - If yes, why?...
   ....
5. Where do you wash your dog/cat food and water bowls? …………………………………
6. What do you use to wash their food and water bowls? ……………………………………
7. Do you wash your hands after feeding your pet(s)? a. Yes b. No
   a. If yes, when do you wash hands after feeding your pet(s)? a. immediately after b. after a while c. when going to eat or do something else requiring handwashing
8. Do you share the same bed with your dog/cat? a. Yes b. No c. Sometimes
   - Explain your answer...
   ……………………………………………………………………………………………
9. Do you allow children in the house to play with the dog/cat? a. Yes b. No
10. After the children play with the pets, do you supervise them to wash their hands before eating/drinking? a. Yes b. No

D. CONTACT WITH RODENTS

1. Do you see rodents in your immediate environment? a. Yes b. No
2. Do rodents cause destruction in your home? a. Yes b. No
   - If yes, state some destructions caused by these animals?
   ……………………………………………………………………………………………
   ……………………………………………………………………………………………I
   s there a history of contact of your dog/cat with rodent(s) recently? a. Yes b. No
3. Have you ever seen your dog/cat eating any rodent before? a. Yes b. No
   - If yes, how often does this happen? a. Very often b. Not often c. Rarely d. Never

AWARENESS & LEVEL OF KNOWLEDGE

1. Have you ever heard of "zoonotic diseases"? a. Yes b. No
2. What do you know about these diseases?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
………………………

3. Can you name some zoonotic diseases you know of?
   ....
   ....
   ....……………………………………………………………………………

4. Have you ever been diagnosed with a zoonotic disease? a. Yes b. No
5. What zoonotic disease were you diagnosed with?..

6. What do you think are some of the causes of zoonotic diseases? .... ………………………………………………………………………………………I n your opinion, can zoonotic diseases be prevented? a. Yes b. No c. Don't know
   - If yes, how can it be prevented? ……………………………………………………
7. How concerned are you about contracting zoonotic diseases? a. very concerned b. concerned c. not so concerned d. not concerned at all
8. Do you know of any diseases that people could contract from rodents? a. Yes b. No
   - If yes, name any two: ……………………………………………………………… ………………………………………………………………………………

Using the scale: **Agree strongly (5)**; **Agree (4)**; **Neutral (3)**; **Disagree (2)**; **Disagree strongly** (1), indicate your agreement or otherwise with the following statements by ticking or circling the corresponding rate/number

Sn.	**Item**	**Responses**				
		1	**2**	**3**	**4**	**5**
10.	I think I have a high level of knowledge about zoonotic diseases					
11.	Animals can share the same bacteria, viruses and parasites with me					
12.	I am concerned about getting zoonotic disease					
13.	I just hope for the best when it comes to trying to avoid contracting a zoonotic disease					
14.	I keep pets away from sleeping in food preparation areas					

APPENDIX C: DATA ANALYSES

Appendix C1: Inferential Statistics using One-way ANOVA analysis

Mean comparison of reported zoonotic bacterial diseases from the health institutions

Zoonotic diseases	Heath facility	N	Mean	Std. Deviation	ANOVA
Salmonella enteritidis	Shai Osudoku District hospital	24	8	6.08	*F*= 3.52, *p*=0.098
	Pentecostal hospital	0	0	0	
	University of Ghana hospital	7	2.33	2.517	
S.aureus/Staphylococcal infection	Shai Osudoku District hospital	45	15	20.881	*F*= 9.103, *p*=0.015
	Pentecostal hospital	0	0.00	0.00	
	University of Ghana hospital	341	113.67	57.74	

The level of significance is set at 0.05.

Mean comparison of reported helminth zoonotic diseases from the health institutions

Zoonotic diseases	Heath facility	N	Mean	Std. Deviation	ANOVA
Toxocariasis Visceral larva migrans	Shai Osudoku District hospital	20	6.67	3.79	*F*= 8.66, *p*=0.017
	Pentecostal hospital	0	0.00	0.00	
	University of Ghana hospital	1	0.33	0.58	
helminthiasis intestinal helminthiasis	Shai Osudoku District hospital	191	63.67	29.26	*F*= 9.4, *p*=0.014
	Pentecostal hospital	270	90.00	26.15	
	University of Ghana hospital	29	9.67	8.14	
Strongyloidiasis	Shai Osudoku District hospital	23	7.67	6.66	*F*= 3.98, *p*=0.079
	Pentecostal	0	0.00	0.00	

	University of Ghana hospital	0	0.00	0.00	
Hookworm	Shai Osudoku District hospital	1	0.33	0.577	*F*= 0.6, *p*=0.579
	Pentecostal	0	0	0	
	University of Ghana hospital	2	0.67	1.16	

The level of significance is set at 0.05.

Post hoc pairwise comparison of zoonotic bacterial diseases from the health institutions

Dependent variable	Health facility	Health facility	Mean Difference (I-J)	Std. Error	Sig.
Salmonella enteritidis	Shai Osudoku District Hospital	Pentecostal Hospital	8.000*	3.103	0.042
		University of Ghana	5.667	3.103	0.118
	Pentecostal Hospital	Shai Osudoku District hospital	-8.000*	3.103	0.042
		University of Ghana	-2.33	3.103	0.481
	University of Ghana	Shai Osudoku District hospital	-5.667	3.103	**0.118**
		Pentecostal Hospital	2.33	3.103	0.481
S. aureus/ Staphylococcal infection	Shai Osudoku District hospital	Pentecostal Hospital	15.00	28.946	0.623
		University of Ghana	-98.667*	28.946	**0.014**
	Pentecostal Hospital	Shai Osudoku District hospital	-15.000	28.946	0.623
		University of Ghana	-113.667*	28.946	**0.008**
	University of Ghana	Shai Osudoku District hospital	98.667*	28.946	**0.014**
		Pentecostal Hospital	113.667*	28.946	0.008

***The mean difference is significant at 0.05 level**

Post hoc pairwise comparison of helminth zoonotic diseases from the health institutions

Toxocariasis/ Visceral larva migrans	Shai Osudoku District hospital	Pentecostal Hospital	6.667*	1.8	0.010
		University of Ghana	6.333*	1.805	0.013
	Pentecostal Hospital	Shai Osudoku District hospital	-6.667*	1.805	0.010
		University of Ghana	-0.333	1.805	0.860
	University of Ghana	Shai Osudoku District hospital	-6.333*	1.805	0.013
		Pentecostal Hospital	0.333	1.805	0.860
Helminthiasis intestinal helminthiasis	Shai Osudoku District hospital	Pentecostal Hospital	-26.33	18.895	0.213
		University of Ghana	54.000*	18.895	0.029
	Pentecostal Hospital	Shai Osudoku District hospital	26.333	18.895	0.213
		University of Ghana	80.333*	18.895	0.005
	University of Ghana	Shai Osudoku District hospital	-54.000*	18.895	0.029
		Pentecostal Hospital	-80.333*	18.895	0.005
Strongyloidiasis	Shai Osudoku District hospital	Pentecostal Hospital	7.667	3.139	0.05
		University of Ghana	7.667	3.139	0.05
	Pentecostal Hospital	Shai Osudoku District hospital	-7.667	3.139	0.05
		University of Ghana	0.000	3.139	1.00
	University of Ghana	Shai Osudoku District hospital	-7.667	3.139	0.05
		Pentecostal	0.00	3.139	1.00
Hookworm	Shai Osudoku District hospital	Pentecostal Hospital	0.33	0.609	0.604
		University of Ghana	-0.33	0.609	0.604
	Pentecostal Hospital	Shai Osudoku District hospital	-0.333	0.609	0.604
		University of Ghana	-0.667	0.609	0.315
	University of Ghana	Shai Osudoku District hospital	0.333	0.609	0.604
		Pentecostal Hospital	0.667	0.609	0.315

Mean comparison of zoonotic bacterial diseases from 2018-2020

Zoonotic diseases	Years	N	Mean	Std. Deviation	ANOVA
Salmonella enteritidis	2018	9	3.0	2.646	*F= 0.457, p=0.653*
	2019	5	1.667	2.887	
	2020	17	5.67	8.145	
S.aureus/Staphylococcal infection	2018	185	61.67	75.593	*F= 0.381, p=0.699*
	2019	153	51.00	84.042	
	2020	48	16.00	26.851	

The level of significance is set at 0.05.

Mean comparison of helminth zoonotic diseases from 2018-2020

Zoonotic diseases	Years	N	Mean	Std. Deviation	ANOVA
helminthiasis	**2018**	**170**	**56.67**	**51.00**	*F=0.592., p=0.583*
	2019	217	72.33	46.29	
	2020	103	34.33	28.29	
Toxocariasis/Visceral larva migrans	2018	4	1.33	2.31	*F=0.375., p=0.702*
	2019	12	4.00	6.08	
	2020	5	1.67	2.89	
Hookworm	2018	3	1	1	*F=3.0, p=0.125*
	2019	0	0	0	
	2020	0	0	0	
Strongyloidiasis	2018	12	4	6.928	*F=0.502, p=0.629*
	2019	11	3.67	6.351	
	2020	0	0.00	0.00	

The level of significance is set at 0.05.

Appendix C2: Descriptive Characteristics

Do you have a vaccination card for your pet(s)?

	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	121	52.6	54.3	54.3
No	97	42.2	43.5	97.8
Don't know	5	2.2	2.2	100.0
Total	223	97.0	100.0	

Some destructions caused by rodents?

	Frequency	Percent	Valid Percent	Cumulative Percent
Destroy Food Items/Vegetables	26	11.3	55.3	55.3
Contaminate Stored Foods	4	1.7	8.5	63.8
Chew Household Items	6	2.6	12.8	76.6
They Defecate Around	4	1.7	8.5	85.1
Urinate On Cooking Utensils	1	.4	2.1	87.2
Others	6	2.6	12.8	100.0
Total	47	20.4	100.0	

I think I have a high level of knowledge about zoonotic diseases

	Frequency	Percent	Valid Percent	Cumulative Percent
Disagree strongly	31	13.5	14.0	14.0
Disagree	51	22.2	23.1	37.1
Neutral	74	32.2	33.5	70.6
agree	47	20.4	21.3	91.9
Agree strongly	18	7.8	8.1	100.0
Total	221	96.1	100.0	

Do you know of any diseases that people could contract from rodents?

	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	50	21.7	24.3	24.3
No	156	67.8	75.7	100.0
Total	206	89.6	100.0	

Appendix C3: Inferential Statistics (Using Mann-Whitney U tests)

Sex and age of respondents

Sex of respondent	N	Mean Rank	Sum of Ranks
Male	129	110.32	14231.00
Female	89	108.31	9640.00
Total	218		

Test Statistics[a]	Age of respondent
Mann-Whitney U	5635.000
Wilcoxon W	9640.000
Z	-.241
Asymp. Sig. (2-tailed)	.810

Sex of respondents and educational level

	Sex of respondent	N	Mean Rank	Sum of Ranks
Educational level	Male	129	104.53	13485.00
	Female	91	118.96	10825.00
	Total	220		

Test statistics	Educational level
Mann-Whitney U	5100.000
Wilcoxon W	13485.000
Z	-1.997
Asymp. Sig. (2-tailed)	.046

Size of household of respondents between the human-dominated landscapes

	How would you describe the area in which you live	N	Mean Rank	Sum of Ranks
Size of Household	Urban	144	108.01	15553.50
	Peri-urban	76	115.22	8756.50
	Total	220		

Test Statistics	Size of Household
Mann-Whitney U	5113.500
Wilcoxon W	15553.500
Z	-.879
Asymp. Sig. (2-tailed)	.379

Reasons for keeping pets and deworming pets and r

	Do you deworm your pet(s)?	N	Mean Rank	Sum of Ranks
Reasons for Keeping Pet	Yes	133	109.63	14581.00
	No	76	96.89	7364.00
	Total	209		

Test Statistics[a]	Reasons For Keeping Pet
Mann-Whitney U	4438.000
Wilcoxon W	7364.000
Z	-1.512
Asymp. Sig. (2-tailed)	.130

Awareness of zoonotic diseases between the human-dominated landscapes

	How would you describe the area in which you live	N	Mean Rank	Sum of Ranks
Have you ever heard of “zoonotic diseases”	Urban	150	119.10	17865.00
	Peri-urban	80	108.75	8700.00
	Total	230		

Test Statistics	Have you ever heard of “zoonotic diseases”?
Mann-Whitney U	5460.000
Wilcoxon W	8700.000
Z	-1.404
Asymp. Sig. (2-tailed)	.160

Ability to name zoonotic diseases between the two human-dominated landscapes

	How would you describe the area in which you live	N	Mean Rank	Sum of Ranks
Can you name some zoonotic diseases you know of?	Urban	112	83.99	9406.50
	Peri-urban	57	86.99	4958.50
	Total	169		

Test Statistics	Can you name some zoonotic diseases you know of?
Mann-Whitney U	3078.500
Wilcoxon W	9406.500
Z	-.391
Asymp. Sig. (2-tailed)	.696

Level of knowledge about zoonotic diseases between the two human-dominated landscape

	How would you describe the area in which you live	N	Mean Rank	Sum of Ranks
I think I have a high level of knowledge about zoonotic diseases	Urban	146	106.78	15589.50
	Peri-urban	75	119.22	8941.50
	Total	221		

Test Statistics	I think I have a high level of knowledge about zoonotic diseases
Mann-Whitney U	4858.500
Wilcoxon W	15589.500
Z	-1.415
Asymp. Sig. (2-tailed)	.157

Ability to name zoonotic diseases contracted from rodents in the two human-dominated landscapes

	How would you describe the area in which you live	N	Mean Rank	Sum of Ranks
Ability to name zoonotic diseases from rodents	Urban	24	22.33	536.00
	Peri-urban	18	20.39	367.00
	Total	42		

Test Statistics	If yes, name any two
Mann-Whitney U	196.000
Wilcoxon W	367.000
Z	-.516
Asymp. Sig. (2-tailed)	.606

Appendix C4: Cross tabulation and Chi-square analysis

Crosstabulation on size of household between the two human-dominated landscapes

Human-dominated landscape		SIZE OF HOUSEHOLD				Total
		<4	4-6	7-9	>10	
Urban	Count	28	87	24	5	144
	% Human-dominated landscape	19.4%	60.4%	16.7%	3.5%	100.0%
Peri-urban	Count	19	32	18	7	76
	% Human-dominated landscape	25.0%	42.1%	23.7%	9.2%	100.0%
Total	Count	47	119	42	12	220
	% Human-dominated landscape	21.4%	54.1%	19.1%	5.5%	100.0%

Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.089[a]	3	.044
Likelihood Ratio	7.975	3	.047
Linear-by-Linear Association	1.347	1	.246
N of Valid Cases	220		

Educational level and preference of companion animal

Educational level	If yes, what pet(s) do you keep?			Total
	Dog(s)	Cat(s)	Dog(s) and Cat(s)	

No formal Education	2	0	0	2
	100.0%	0.0%	0.0%	100.0%
Basic/Primary	1	6	0	7
	14.3%	85.7%	0.0%	100.0%
Junior High School	11	6	2	19
	57.9%	31.6%	10.5%	100.0%
Secondary/High School	19	17	10	46
	41.3%	37.0%	21.7%	100.0%
Tertiary	88	24	36	148
	59.5%	16.2%	24.3%	100.0%
Total	121	53	48	222
	54.5%	23.9%	21.6%	100.0%

Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	27.638[a]	8	.001
Likelihood Ratio	26.549	8	.001
Linear-by-Linear Association	.007	1	.934
N of Valid Cases	222		

Occupation and preference of companion animal

Occupation	If yes, what pet(s) do you keep?			Total
	Dog(s)	Cat(s)	Dog(s) and Cat(s)	
Accounting, Auditing and other financial services	3	0	5	8
	37.5%	0.0%	62.5%	100.0%
Self employed	32	22	2	56
	57.1%	39.3%	3.6%	100.0%
Engineering	8	0	4	12
	66.7%	0.0%	33.3%	100.0%
Public servants	18	10	14	42
	42.9%	23.8%	33.3%	100.0%
Student	21	5	14	40
	52.5%	12.5%	35.0%	100.0%
Shipping and forwarding/Freight forwarding	3	0	0	3
	100.0%	0.0%	0.0%	100.0%
Transport services	7	0	2	9

	77.8%	0.0%	22.2%	100.0%
Unemployed	3	6	2	11
	27.3%	54.5%	18.2%	100.0%
Administration/Human resource/consultancy	9	4	2	15
	60.0%	26.7%	13.3%	100.0%
Missionary/Pastor	4	0	0	4
	100.0%	0.0%	0.0%	100.0%
Pensioner	1	0	0	1
	100.0%	0.0%	0.0%	100.0%
Others	10	1	2	13
	76.9%	7.7%	15.4%	100.0%
Total	119	48	47	214
	55.6%	22.4%	22.0%	100.0%

Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	55.492[a]	22	.000
Likelihood Ratio	65.208	22	.000
Linear-by-Linear Association	1.542	1	.214
N of Valid Cases	214		

Size of household and preference for companion animal

Size of Household		If yes, what pet(s) do you keep?			Total
		Dog(s)	Cat(s)	Dog(s) and Cat(s)	
<4	Count	29	13	5	47
	% within Size of Household	61.7%	27.7%	10.6%	100.0%
4-6	Count	58	35	26	119
	% within Size of Household	48.7%	29.4%	21.8%	100.0%
7-9	Count	27	2	13	42
	% within Size of Household	64.3%	4.8%	31.0%	100.0%
>10	Count	6	3	3	12
	% within Size of Household	50.0%	25.0%	25.0%	100.0%
Total	Count	120	53	47	220
	% within Size of Household	54.5%	24.1%	21.4%	100.0%

Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	14.543[a]	6	.024
Likelihood Ratio	18.000	6	.006
Linear-by-Linear Association	1.203	1	.273
N of Valid Cases	220		

Household size and frequency of deworming companion animals

		Frequency of deworming pets				Total
		Once every month	Once every 3 months	three times a year	Other	
Size of household	<4	5	9	7	3	24
		20.8%	37.5%	29.2%	12.5%	100.0%
	4-6	18	27	7	11	63
		28.6%	42.9%	11.1%	17.5%	100.0%
	7-9	8	15	6	4	33
		24.2%	45.5%	18.2%	12.1%	100.0%
	>10	1	2	0	2	5
		20.0%	40.0%	0.0%	40.0%	100.0%
	Total	32	53	20	20	125
		25.6%	42.4%	16.0%	16.0%	100.0%

Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.551[a]	9	.580
Likelihood Ratio	7.469	9	.588
Linear-by-Linear Association	.001	1	.976
N of Valid Cases	125		

Household size and frequency of vaccinating pet

		When was the last time you vaccinated your pet(s)?					Total
		Never	< 3 months	<12 months	> 12 months	I don't know	
Size of Household	<4	15	11	13	5	0	44
		34.1%	25.0%	29.5%	11.4%	0.0%	100.0%
	4-6	43	25	30	13	4	115
		37.4%	21.7%	26.1%	11.3%	3.5%	100.0%

	7-9	11	10	15	2	0	38
		28.9%	26.3%	39.5%	5.3%	0.0%	100.0%
	>10	4	1	5	1	0	11
		36.4%	9.1%	45.5%	9.1%	0.0%	100.0%
		73	47	63	21	4	208
		35.1%	22.6%	30.3%	10.1%	1.9%	100.0%

Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.803[a]	12	.720
Likelihood Ratio	10.587	12	.565
Linear-by-Linear Association	.046	1	.830
N of Valid Cases	208		

Zoonotic disease and Pet ownership

		What pet(s) do you keep?			Total
		Dog(s)	Cat(s)	Dog(s) and Cat(s)	
Have you ever been diagnosed with a zoonotic disease?	Yes	5	1	1	7
		71.4%	14.3%	14.3%	100.0%
	No	107	54	42	203
		52.7%	26.6%	20.7%	100.0%
	Total	112	55	43	210
		53.3%	26.2%	20.5%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.972[a]	2	.615
Likelihood Ratio	1.021	2	.600
Linear-by-Linear Association	.675	1	.411
N of Valid Cases	210		

a. 3 cells (50.0%) have expected count less than 5. The minimum expected count is 1.43.

When was the last time you vaccinated your pet(s)?		Reasons For Keeping Pet										Total
		Companionship /part of the family	Security/Protec-tion	Hunting	Commercial purposes/Breeding	Health purposes	Security and Commercial purposes	Hunting & companionship	Security and Companionship	Others	No special reason	
Never	Count	30	14	11	0	0	0	2	4	4	6	71
	% within last time you vaccinated your pet(s)?	42.3%	19.7%	15.5%	0.0%	0.0%	0.0%	2.8%	5.6%	5.6%	8.5%	100.0%
< 3 months	Count	13	17	0	0	0	5	2	8	0	0	45
	% within the last time you vaccinated your pet(s)?	28.9%	37.8%	0.0%	0.0%	0.0%	11.1%	4.4%	17.8%	0.0%	0.0%	100.0%
<12 months	Count	15	13	0	3	3	4	0	19	4	0	61
	% within the last time you vaccinated your pet(s)?	24.6%	21.3%	0.0%	4.9%	4.9%	6.6%	0.0%	31.1%	6.6%	0.0%	100.0%
> 12 months	Count	8	7	1	3	0	0	0	3	0	0	22
	% within the last time you vaccinated your pet(s)?	36.4%	31.8%	4.5%	13.6%	0.0%	0.0%	0.0%	13.6%	0.0%	0.0%	100.0%
	Count	3	0	0	0	0	0	0	1	0	0	4

I don't know	% within the last time you vaccinated your pet(s)?	75.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	25.0%	0.0%	0.0%	100.0%
Total	Count	69	51	12	6	3	9	4	35	8	6	203
	% within the last time you vaccinated your pet(s)?	34.0%	25.1%	5.9%	3.0%	1.5%	4.4%	2.0%	17.2%	3.9%	3.0%	100.0%

Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	89.281[a]	36	.000
Likelihood Ratio	101.070	36	.000
Linear-by-Linear Association	.520	1	.471
N of Valid Cases	203		