University of Veterinary Medicine Budapest
Department of Parasitology and Zoology

Parasitic species and zoonotic diseases affecting companion animals in resource-limited and rural communities in South Africa

Lise Anne van der Elst

Supervisor: Dr Szekeres Sándor, Assistant Professor

Department of Parasitology and Zoology

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A háziállatokat és a vadon élő állatokat érintő parazita fajok és zoonózisos betegségek a korlátozott erőforrásokkal rendelkező és vidéki közösségekben Dél-Afrikában

Abstract

Companion animals in resource-limited and rural communities in South Africa are negatively impacted by the socioeconomic, cultural, and environmental challenges that their owners face, resulting in increased parasitic and disease burden. The research notes the exacerbating impact of climate change and urbanisation on zoonotic disease risk, linked to alterations in vector ecology and wildlife-domestic animal interactions. Cultural practices, including informal livestock slaughter and the unrestricted keeping of pet animals, are contributing factors to the persistence, and spread of zoonoses. The lack of accessible veterinary services, largely provided by overstretched welfare organizations, poses the most substantial barrier to disease management. This is compounded by infrastructural deficiencies such as inadequate sanitation and water supply systems, which facilitate disease transmission.

This review focuses on identifying the main parasitic and pathogenic species associated with companion animals in impoverished communities and explores their role in the emergence and spread of parasitic and zoonotic diseases. Data taken from parasitic surveys conducted across South Africa spanning four decades were collated and analysed. The most prevalent species and vector-borne pathogens found were *Rhipicephalus sanguineus*, the primary vector of *Ehrlichia canis*, *Haemaphysalis elliptica*, the primary vector of *Babesia rossi* and *Rhipicephalus simus*, a vector of the zoonotic spotted fever Rickettsia group. *Ancylostoma* species causing cutaneous larval migrans in humans were found to be widely occurring in most communities, while tapeworms of less zoonotic importance were also prevalent. The most widespread parasites are those that have adapted to exploiting overlapping habitats between humans, domestic animals, and wildlife. These parasites are not only markers of poor animal health but are also indicative of the heightened risk faced by human populations, particularly those with compromised immune systems. The predominant occurrence of mixed infections and the emergence of new pathogenic and potentially zoonotic species, highlight the importance of widening future research and the urgent need for improved access to veterinary treatment and methods of prevention in resource-limited communities. This review lays the groundwork for future research directions, emphasising the importance of a One Health approach, targeted

interventions, education, and global cooperation to alleviate the burden of parasitic diseases in marginalised populations.

A szocioökonómiai, kulturális és környezeti tényezők mellett a megemelkedett parazita és kórokozó előfordulás súlyos terhet jelent a korlátozott erőforrásokkal rendelkező és vidéki közösségekben élő társállatok és gazdáik számára. Kutatások felhívják a figyelmet a klímaváltozás, a fokozott városiasodás súlyosbító hatására a zoonotikus betegségekkel való fertőződés kockázatára, a vektorok ökológiájára és a vad és háziállatok közötti kapcsolatokra is. A különböző népi szokások, mint a bejelentés nélküli haszonállat vágás és kóbor állatokhoz való viszony is súlyosbító tényezőkként jelennek meg a zoonózisok terjedése esetében. Az állatorvosi szolgáltatásokhoz, amelyeket a jóléti vagy segély szervezetek kiterjesztett munkaként végeznek gyakran nehezen hozzáférhető, amely számottevő nehezítő tényezője a betegségek elleni küzdelemben. Ezen felül, az infrastruktúrális hiányosságok, a rossz fertőtlenítési lehetőségek és a hiányos hozzáférés a fertőtlenített, biztonságos vezetékes vízhez képes gyorsítani, elősegíteni egyes betegségek terjedését.

Ebben a munkában a szegény körülmények között élő közösségek társállatait érintő főbb paraziták meghatározására és a vektorok által közvetített megbetegedések esetszámnövekedésére és terjedésére összpontosítok a parazitás megbetegedéseket vizsgáló, több évtizedre visszamenő, dél-afrikai kutatásokban közölt adatokat felhasználva.

A leggyakoribb paraziták/vektorok és kórokozók a következőek: a *Rhipicephalus sanguineus,* amely az *Ehrlichia canis* kórokozó legfőbb hordozója; a *Haemaphysalis elliptica*, a *Babesia rossi* parazita legfőbb terjesztője és a *Rhipicephalus simus*, a zoonotikus „spotted fever” *Rickettsia*-csoport vektora; az *Ancylostoma* fajok, a bőrben vándorló féreglárva kórképet okozó és mind gyakrabban előforduló parazita az ilyen közösségekben. Ezzel ellentétben a kisebb zoonotikus potenciállal rendelkező galandférgek is gyakoriak. A leggyakoribb paraziták azok, amelyek képesek voltak alkalmazkodni az egymással kapcsolatban lévő különböző életterekhez, amelyeken az emberek osztoznak a haszonállataikkal és a körülöttük élő vadvilággal. Ezek a paraziták nem csak a rossz állattartási gyakorlat jelei, hanem potenciális veszélyforrás az immunhiányos betegségekben küzdők számára.

A paraziták kevert előfordulása és a zoonotikus potenciállal rendelkező kórokozók növekvő száma felhívja a figyelmet a téma további kutatásának, az állatorvosi szolgáltatáshoz való hozzáférhetőségének javítására és a preventív kezelések fontosságára ezekben a közösségekben. Ebben a munkában megalapozhatom a jövőbeli kutatások irányát, az „Egy

Egészség” megközelítés, célzott közbelépések, oktatási programok és globális összefogás fontosságát hangsúlyozva ezeknek a kiszolgáltatott közösségek parazitás megbetegedéseinek a csökkentése érdekében.

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Background and challenges faced by resource-limited communities

The interactions between humans, domestic animals and wildlife in rural and impoverished communities are pivotal factors in the emergence and spread of parasitic and zoonotic diseases. While such diseases are a concern worldwide, developing nations bear a heavier burden. Several factors contribute to this, including widespread immunocompromised conditions like HIV/AIDS, daily dependence on animals, and limited resources for disease control and prevention. Additionally, the resurgence of many diseases can be traced back to the deterioration of essential public health practices such as sanitation, vaccination, and measures against vector-borne illnesses. Embracing a One Health approach, which emphasises the interconnectedness of human, animal, and environmental health, is crucial for effective health promotion in these vulnerable settings.

60% of all known human pathogens are zoonotic[1] and around 73% of emerging and re-emerging infectious human diseases are also zoonotic[2]. Poverty has been found to increase the risk of zoonotic diseases in communities that live in close contact with their livestock or with wildlife. In fact, it is estimated that one quarter of the disease burden in low income countries can be attributed to zoonoses[2].

Infectious diseases predominantly impact impoverished and marginalised communities, trapping them in a cycle of sickness and economic hardship. Successful public health strategies must acknowledge the vital connection between human and animal interactions. While there's growing emphasis on managing neglected tropical diseases (NTDs) to combat poverty, endemic diseases transmitted between animals and humans often remain overlooked, even though they potentially pose a significant health challenge.

South Africa's political history, marked by the long era of apartheid and segregation, has bequeathed deep-seated inequalities that pervade its society. These historical divisions have manifested in stark disparities in wealth, education, and living conditions. As of the last known statistics, the country faced significant challenges with high unemployment rates, particularly among the youth, and widespread poverty. Many South Africans reside in informal settlements known as townships, often in corrugated iron shacks that lack running water and proper sanitation. This environment not only exacerbates socio-economic hardships but also creates a fertile ground for the emergence and spread of zoonotic diseases, as close quarters and inadequate infrastructure make it difficult to maintain hygiene and control disease vectors. The lingering effects of an education system grappling with resource limitations and disparities continue to entrench a cycle of poverty, as insufficient educational outcomes limit economic opportunities. Consequently, these communities are disproportionately affected by zoonotic diseases, which place an additional burden on individuals and the healthcare system, further complicating efforts to break out of poverty.

The first democratically held elections in South Africa in 1994 saw the end of the Apartheid system and an increase in literature documenting the living conditions and veterinary requirements of resource-limited communities.

Veterinary Needs Assessments (hereafter referred to as VNA's) were frequently used in South Africa when quantifying the needs of a specific community and their animals. VNA's (Developed by MEDUNSA) provide a relatively quick method of assessing the health of animals in a community, while also categorising the socio-economic requirements of the community itself[3].

Based on studies of specific communities (urban, peri-urban and rural) the most widely reported need was access to affordable veterinary treatment for animals[4]. Prophylactic treatments, for example vaccination, regular antiparasitic treatment were also requested, as well as sterilisation to prevent breeding. Preventing cruelty by rescue or inspection and the collection of stray animals were also mentioned[4].

Minnaar and Krecek (2001) reported that owners indicated that they would consider standard veterinary procedures if a veterinarian were affordable and accessible. There was also a desire for better education regarding caring for livestock and pets[4].

These studies also found that the general health of the animals was poor, there was a massive infection rate of both internal and external parasites including a 90-93% infection of zoonotic *Ancylostoma* and this corresponded to an outbreak of cutaneous *larval migrans* in children in the same community[5].

The needs identified from communities in South African studies aligns with themes outlined in an international literature review conducted by LaVallee et al. (2017) on veterinary care for underserved communities. Their study indicated that the most common barriers to veterinary care included cost and accessibility to veterinary support, veterinarian-client communication, cultural and language barriers, and a lack of client education[6].

It is accepted that the increasing globalisation in trade and human movement plays a key role in the increased risk of zoonotic disease and also in emerging and re-emerging parasitic diseases[7]. Increased population density is also identified as a significant factor in the spread of zoonotic parasitic diseases. As urbanization and human settlements expand, there is a greater overlap between human habitats and those of wildlife. This proximity facilitates the transmission of parasites from animals to humans.

Populations at higher risk of zoonotic parasitic diseases include young children and the elderly, pregnant women, and immunocompromised people. In research conducted in South Africa focusing on patients living in resource-limited communities, there was documented evidence of current or past zoonotic infections[2].

South Africa has the highest proportion of HIV positive people in Southern Africa. It was found that approximately 70% of the population live with HIV/AIDS and the rate of new infection and mortality was calculated to be 31% and 34% respectively[8].

Notably, in populations with a significant prevalence of HIV infections, the proportion of zoonotic infections can be considerably higher[9]. Furthermore, the presence of HIV can exacerbate the clinical severity of numerous zoonoses, often leading to prolonged and chronic illness[8].

In the rural localities of South Africa, a greater fraction of the population may be deemed at high risk since individuals of working age often relocate to urban centres and cities seeking employment. Consequently, this results in children being left behind under the guardianship of older family members.

Gastrointestinal helminth infections or protozoal parasite infections are highly common in developing countries and can result in significant illness and even death. Sadly, children in economically challenged communities are disproportionately impacted by these diseases[10].

In many developing nations, the primary impediments to public health stem from the pervasive issues of unsafe water, deficient sanitation infrastructure, and suboptimal personal hygiene practices[11].

In rural and resource-constrained communities in South Africa, inadequate waste disposal infrastructure leads to poor waste disposal practices and significantly contributes to the spread of diseases among both humans and animals. Govender et al. (2016) discovered that residents in Cape Town's urban townships resorted to unsafe and unsanitary means for disposing of human waste, both within and outside their homes[6]. Similarly, Berrian et al. (2016) shed light on the disposal of single-use diapers in the Mnisi community, where the predominant method was incineration, although the practice of discarding diapers in the environment or near rivers was also prevalent[7]. Additionally, as noted by Ngcamphalala (2018), developing countries with inadequate sanitation practices, such as open defecation and subpar household sanitation, experience a higher prevalence of hookworm infections[8].

Multiple studies have concluded that household wastewater management is not considered a priority in many resource-limited urban communities and disposal methods are often inappropriate leading to environmental contamination[12].

The attitude towards pet ownership in different South African cultures is influenced by various factors including the country's political history, socio-economic disparities, traditional beliefs about animals, and the level of urbanization. South Africa, known for its significant socio-economic inequality, reflects these disparities in terms of animal health. Research has shown that pets from resource-limited communities (RLC) often suffer from preventable diseases, requiring longer hospital stays and being presented for treatment at advanced stages of illness[4, 9, 13].

A study conducted by Eckersly (1992) revealed that almost half of the hospitalised pets in RLC were diagnosed with infectious diseases, with tick-borne diseases such as *Ehrlichia* and *Babesia* being the most prevalent. This suggests a higher risk of exposure to tick-borne illnesses in these communities. Additionally, the study found a notable difference in hospitalisation rates for parasitic diseases, particularly helminths[13]. These findings indicate a greater prevalence of parasitic infections in pets from RLC.

The socio-economic factors that contribute to this disparity in pet health are intertwined with the political history of South Africa. The country's history of racial segregation and economic inequality has resulted in marginalised communities lacking access to basic healthcare services for both humans and animals. This limited access to veterinary care, combined with a lack of education and awareness about preventive measures, contributes to the higher incidence of preventable diseases and delays in seeking treatment for pets in RLC.

Furthermore, traditional ideologies towards animals play a significant role in shaping attitudes towards pet ownership in different South African cultures. For instance, in some cultures, pets may be valued more for their utilitarian purposes, such as guarding or hunting, rather than as companions or family members. This can impact the level of care and consideration given to the animals' health and well-being.

Another identified factor in the spread of zoonotic disease is the cultural practice of informal livestock slaughter for personal consumption without proper meat inspection[14] or hygiene[3]. Free-roaming dogs then feed on discarded offal and meat, further increasing the risk of disease transmission and spread[15]. This combined with livestock keeping increases the risk for zoonotic parasites like *Echinococcus granulosus*, as its complicated life cycle requires a so-called domestic dog-ruminant-dog cycle[16].

In South Africa, the nexus between human health, animal welfare, and societal economics is strikingly illustrated by the widespread presence of apparently stray and free-roaming dogs in urban and rural communities. The World Health Organization categorises dog populations based on their dependency on humans and their level of movement restriction, ranging from restricted and supervised dogs to family dogs (fully dependent, unrestricted) to neighbourhood dogs(semi/unrestricted, semi-dependent) and feral dogs (independent, unrestricted)[17]. Most dogs in South Africa fall in to the second and third category of family or neighbourhood dogs[17]. Conan et al. (2015) argue that despite the common notion that there are large populations of unowned dogs in African communities, multiple studies have shown that this is not the case. They maintain that these dogs are owned and largely unconfined and with variable levels of human dependency[18].

The movement of free-roaming dogs across urban and rural landscapes provides a conduit for the dissemination of a myriad of parasitic zoonoses. These dogs often scavenge for food, which may include consuming wildlife and household pests that harbour zoonotic parasites[19]. For instance, Amidou et al. (2013) found that where domestic animals commonly roamed in search of sustenance the risk of contracting *Cryptosporidium* from contaminated sources was notably heightened. This increased exposure risk is corroborated by the higher infection rates observed in stray animals compared to their home-based counterparts[20].

Moreover, the interaction between free-roaming dogs and wild mammalian predators can be a salient factor in the spread of zoonotic pathogens[19]. These canids are known to feed on small mammals, insects, reptiles, and fish, all of which can serve as vectors or paratenic/intermediate hosts for zoonotic helminths such as *Echinococcus* spp., *Taenia* spp., *Trichinella* spp., and *Toxocara* spp.[19]. Such dietary habits are conducive to the transmission of parasites, particularly when dogs venture into wildlife habitats, leading to a higher likelihood of encounters with infected wild prey or contaminated environments.

The diet of dogs in socioeconomically disadvantaged communities often consists of maize porridge, occasionally supplemented with commercial dog food, milk, leftovers, or scavenged items[4]. This feeding pattern, reliant on "when available" resources, may inadvertently lead to the consumption of parasitised food, thus perpetuating the cycle of infection[4].

These dynamics underline the criticality of understanding dog demography for planning effective population management and disease control measures[21]. Mass sterilization programs, commonly employed to reduce the number of stray and free-roaming dogs, may be ineffective, if the population is being maintained and supported by humans[18]. These movements, often driven by the persistent demand for dogs, can facilitate the incursion of new diseases into communities.

Consequently, the control of parasitic diseases, particularly zoonoses, within these populations requires a multifaceted approach. This includes addressing the socioeconomic factors that contribute to the prevalence of free-roaming dogs and implementing comprehensive disease surveillance and control programs that extend beyond the community to regional levels. Vaccination programs, for example, need to be widespread and sustained to curb the spread of diseases like rabies, taking into account the pivotal role of human factors in the success of these interventions[21].

In summary, the role of stray and free-roaming dogs as vectors in the spread of parasitic zoonoses in socioeconomically disadvantaged communities in South Africa is multifactorial and complex. The interaction between these dogs, wildlife, and household pests creates a significant public health concern that necessitates integrated One Health strategies tailored to the unique environmental, social, and economic contexts of these communities.

In most of South Africa, veterinary services provided to resource-limited communities for companion animals are provided entirely by privately funded individual welfare organisations. Some are satellites of larger international organisations such as the SPCA, PDSA etc; while others are smaller and run by a few volunteers or individuals who have taken an interest in a particular community. The communities are unofficially divided into territories and shared out between the larger welfare organisations who are often able to provide hospitals and mobile clinics on the borders of the communities they serve.

The clients must provide proof that they cannot afford private veterinary care before they can use the services of the welfare, and usually only basic veterinary care is provided focusing on primary health care. While owners are expected to pay significantly reduced fees based on a sliding scale dependent on their monthly salary, the reality is that very few actually do. Most of the organisation's funding comes from individual and corporate doners who make either one-off contributions or sign up for regular monthly donations. These donations play a pivotal role in sustaining the day-to-day operations of these organizations, especially as they receive no financial help from the government.

Corporate sponsorships contribute to the financial backbone of these welfare bodies. Several businesses and corporations, recognising the value of corporate social responsibility, either offer financial support directly or provide in-kind donations. On a similar note, some animal welfare organizations in South Africa receive grants from international animal welfare bodies, trusts, and foundations. These grants are often tied to specific projects and might come with certain stipulations that organizations need to adhere to.

What this means for clients is that usually they must travel very far for their animals to receive veterinary attention or wait until a mobile service can attend to them. As a result, there is an overwhelming volume of animals and owners requiring care and an inadequate capacity for these organisations to provide it.

In recent decades, the effects of climate change on the world's ecologies have become increasingly evident and the subject is at the forefront of global media and politics. Global warming, altered precipitation patterns and the increasing frequency of extreme weather events, has profound implications for the distribution and prevalence of parasitic species and consequently, the diseases they spread.

As highlighted by Berrian et al. (2016), changes in the environment can affect the interface between wildlife and domestic animals[22]. Climate change can modify natural habitats, leading to shifts in wildlife distributions. This can result in increased contact between wildlife, domestic animals, and humans, thereby facilitating the spill-over of zoonotic parasites.

Many zoonotic parasites are transmitted through vectors like mosquitoes, ticks, and fleas. Warmer temperatures can expand the geographical range of these vectors, leading to the spread of diseases to previously unaffected regions. For instance, Froeschke and Matthee[23] discussed the influence of landscape characteristics on helminth infestations, which can be exacerbated by climate-induced changes in vector habitats.

Warmer temperatures and altered rainfall patterns can prolong the transmission seasons of certain zoonotic parasites. For instance, prolonged wet seasons can provide ideal breeding grounds for mosquito vectors, increasing the risk of diseases like malaria.

Climate change can induce stress in both wildlife and domestic animals, potentially compromising their immune systems. Weakened immunity can make these animals more susceptible to parasitic infections, which can then be transmitted to humans.

As noted by Collyer et al. (2023), human mobility plays a role in the spread of infections. Climate-induced events, such as droughts or floods, can lead to human migrations, increasing the risk of exposure to new zoonotic parasites. Water shortages in periods of drought may force humans to access water used by wildlife or vice versa. Flooding could exacerbate contamination of water sources or aid in the transmission of water borne zoonotic parasites[24].

Daszak, Cunningham, and Hyatt (2000) emphasised the role of wildlife as reservoirs for many pathogens. Climate change can alter the abundance and distribution of these reservoir hosts, influencing the dynamics of disease transmission[25].

Viljoen et al. (2020) found that caracals living in peri urban, human modified landscapes in the Cape Peninsula had a higher rate of infection of tick borne pathogens usually found in domestic cats and dogs[26].

Unlike diseases that affect and are transmitted by humans alone, most zoonotic parasitic diseases require the consideration of animal reservoirs and, when combined with a complex parasitic life cycle, make interventions more challenging[27].

Crossover of parasites and the pathogens they carry between companion animals and wild South African species has received a lot of attention in the literature in the last decade, especially with the discovery of multiple potentially zoonotic new species.

The unprecedented scale of human-induced landscape modification has precipitated a multitude of ecological disruptions, from heightened environmental pollution and significant biodiversity loss to the emergence of infectious diseases. The relentless fragmentation of natural habitats has notably augmented the interface among wildlife, domestic animals, and humans, potentially intensifying pathogen loads and facilitating their spillover[19]. This trend positions wildlife parasitic diseases as an ascending concern within the One Health framework, which underscores the interconnectedness of human, animal, and environmental health. Increasing urbanization, in particular, has been identified as a cardinal catalyst of emerging infectious diseases among wildlife populations[26]. Research spanning various human-altered landscapes is increasingly documenting the adverse consequences of urban encroachment on wildlife health, revealing that disease prevalence can fluctuate markedly in conjunction with environmental transformation.

In the backdrop of these multifaceted challenges, it becomes imperative to understand the full spectrum of parasitic species and zoonotic diseases affecting both domestic animals and wildlife, especially in resource-limited and rural communities.

This review aims to:

1. Identify and document the main zoonotic parasitic species affecting companion animals in rural and underprivileged communities in South Africa.

2. Investigate the zoonotic potential of these species, the diseases and risk they pose to both human and animal health.

3. Explore the challenges faced by resource-limited and rural communities in South Africa when it comes to managing and preventing parasitic diseases. Identify how socio-economic, environmental, and cultural factors impact the prevalence and risk of disease transmission.

4. Provide a comprehensive summary of the current state of research in this area, to identify gaps in the existing literature and provide suggestions of areas for future research.

Method

An extensive literature search was conducted using online databases (Google scholar, PubMed etc). Only full text journal articles in English were included in this review (published or unpublished).

Peer-reviewed scientific articles dating from 1979 onward were selected for review, with the primary focus on parasitic samples derived from cats and/or dogs in resource-limited and rural communities South Africa. These criteria included owned and stray animals in communities or at animal welfare organisations.

While the initial screenings included studies on various species, only those that discussed species also found in dogs and cats were retained. Studies were also excluded if the parasitological surveys were not conducted within South Africa, if they did not encompass the pertinent animal species, or if their content was pharmacological in nature. In cases where a single study included samples from diverse species, only data relevant to cats and dogs were integrated into the results. Such studies underwent a comprehensive review to extract information specifically concerning companion animals.

Before categorization, all abstracts underwent careful scrutiny. Emergent themes from these abstracts were identified and earmarked as categories. Based on these themes, specific search strings were crafted to refine the research focus. Articles cited within the reviewed literature were further assessed for their relevance and incorporated into the review when deemed necessary.

From the preliminary search results, identified parasite species were organised within a Zotero Library into three primary categories: Arthropods, Helminths, and Vector-borne pathogens. Each category was further subdivided based on the genus. Broad thematic areas, in alignment with the literature review objectives, were discerned, and relevant research articles were collated under these thematic areas.

Survey data was meticulously transferred to Excel spreadsheets where it was categorised as either Arthropods, Helminths, or Vector-borne parasites. Each pertinent study was then sorted based on various criteria such as the date of the study, geographic locality, sample size, host species, identified parasite species, percentage prevalence in the sample, and the method of sample collection. The prevalence of each species in each sample (separated according to location or method of sample collection) was calculated. The total average prevalence for each species was then calculated and a count of how many times a species was identified over all studies. Care was taken to ensure that data was not duplicated, especially since there were instances where multiple articles might have utilised a singular dataset.

Parasites and vector-borne pathogens of companion animals in resource-limited communities.

Vector-borne pathogens

Vector-borne pathogens, which are transmitted through blood-feeding arthropods and other invertebrate vectors, play a significant role in the epidemiology of emerging infectious diseases. Within the spectrum of these pathogens, members of the orders Rickettsiales, Eucoccidia, and Piroplasmida are of notable concern. Pathogens from the Anaplasmataceae family, such as *Anaplasma* and *Ehrlichia* species, have been identified in a wide range of hosts, including various wild carnivores. Despite their recognised impact, comprehensive molecular baseline data regarding the distribution of these pathogens remains deficient in several global regions, rendering the evaluation of their emerging or receding nature challenging. Among these vector-borne diseases, infections caused by *Babesia* species are especially significant in South Africa from both a veterinary and human medical standpoint.

Babesia

Canine babesiosis, a tick-borne parasitic disease, has a significant impact on the health of dogs in South Africa. The causative agents of canine babesiosis are protozoan intraerythrocytic parasites belonging to the genus *Babesia*. In the pathogen's life cycle, ticks serve as the final hosts, where zygote formation occurs in a tick's intestine, while dogs act as intermediate hosts, with asexual division of the parasite occurring inside red blood cells.

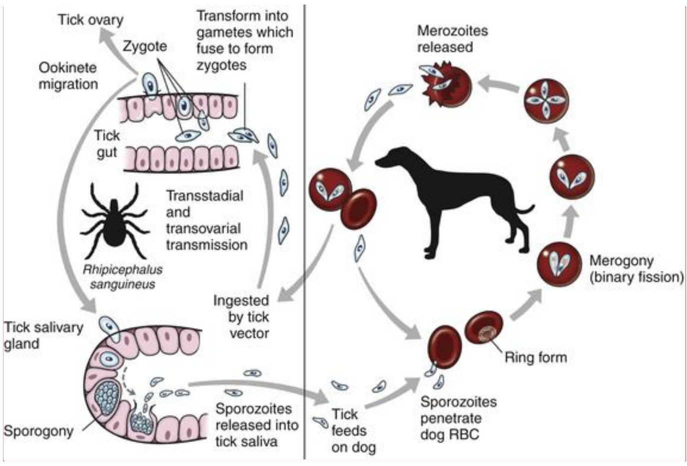

Figure 1

The life cycle of *Babesia canis*[28]

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Severity of disease is different according to babesia species and immune status of the infected dog. Less pathogenic species such as *Babesia vogeli* induce mild disease in adult dogs but can cause severe anaemia in young puppies. The prevalence of *B. vogeli* recorded from all literature by province is shown in Table 1. Severe and complicated babesiosis on the other hand has been likened to sepsis or malaria in humans, causing immune mediated inflammatory responses and tissue hypoxia in various organs[29].

Table 1

Prevalence of *Babesia vogeli* in South Africa from literature published from 2000-2006[29]

South Africa	South Africa: various provinces	4.4% (13 out of 297)	Before 2004 [3]
	Northern South Africa: Northern Gauteng province and North West province	2.7% (14 out of 527)	2000–2006
	Central South Africa: Free State province	10.1% (13 out of 129)	2000–2006

Notably, there are eight distinct *Babesia* species responsible for infecting dogs. Among these, *Babesia canis*, *B. vogeli*, *Babesia rossi*, and *Babesia coco* (unofficial name) are categorised as large piroplasms due to the larger size of their developmental stages, including trophozoites and merozoites. In contrast, the second group of *Babesia* species, referred to as small *Babesia*, includes *Babesia gibsoni*, *Babesia conradae*, and *Babesia vulpes*, with their developmental stages being comparatively smaller[29]. *Babesia negrevi* is a recently described species, detected in Israel, that does not fall directly into the large and small categories, but is somewhere in between[30]. *B. rossi* and *B. vogeli* are endemic to South Africa. *Babesia vogeli* is transmitted by the host tick species *Rhipicephalus sanguineus*, which also transmits *Ehrlichia canis*[31]. The species of the host tick differs according to geographic location and *Babesia* species worldwide but are always in the Ixodidae family.

Babesia rossi is a particularly virulent *Babesia* species and poses a significant challenge in South Africa. Infection induces acute illness in susceptible individuals. Severe complications may manifest following infection, including immune-mediated haemolytic anaemia, acute renal failure, pulmonary oedema, and pancreatitis[32]. Severe metabolic derangements, neurological damage, systemic inflammatory response syndrome, multi-organ dysfunction syndrome, and septic shock can also occur[29]. A mortality rate of 10% within 24 hours of hospitalisation due to *B. rossi* infection was observed at a university hospital between 2006 and 2016[33].

Between 1988 and 1993, an annual average of approximately 11,000 dogs sought treatment at the Onderstepoort Veterinary Academic Hospital (OVAH), and a substantial 11% of these cases were diagnosed with canine babesiosis. A further 34% of these diagnosed cases required hospitalisation. These data highlight the rapid progression and severe consequences of *B. rossi* in domestic dogs. Table 2 shows the most recent prevalence data for dogs infected with *B. rossi* across South Africa.

Table 2

Prevalence of dogs infected with *Babesia rossi* from literature published from 2000-2021*[29]*

Country/Region		Prevalence of Infected Dogs (No. of Infections)	Time of Blood Collection
South Africa	South Africa (7 out of 9 provinces)	36.9% (420 out of 1138)	2000–2006
	Cape Town region	12.7% (16 out of 126)	Before 2014 [1]
	Eastern South Africa: KwaZulu-Natal province	0% (0 out of 49)	Before 2020 [1]
	South Africa (Onderstepoort Veterinary Academic Hospital, University of Pretoria)	9.6% (1222 out of 12,706) [2]	2004–2010
	Zenzele (settlement near Johannesburg)	31.2% (34 out of 109 dogs) [3]	2008–2014
	North-central part of South Africa (Mogale's Gate Biodiversity Centre and S.A. Lombard Nature Reserve)	30.8% (33 out of 107) [4]	Between 2011 and 2017 [1]
	Northern South Africa (provinces: North West and Limpopo)	5.3% (16 out of 301) [5]	Before 2008 [1]
	Northern South Africa (Kruger National Park)	9.6% (5 out of 52) [5]	Before 2021 [1]
	Northeast and Southwest	4.9% (7 out of 143) [6]	2007–2011

Haemaphysalis elliptica is the known vector for *B. rossi.* It has been found in wild canids such as Black-backed jackal (*Canis mesomelas*) and African wild dogs (*Lycaon pictus*) where it is typically subclinical. The evolutionary perspective suggests that domesticated dogs in this region have not had adequate time to adapt to the presence of this parasite[34] and that wild canid species' may act as a reservoir for *B. rossi*.

Feline babesia

The occurrence of feline babesiosis in South Africa is notable as despite the disease occurring sporadically in other countries, in South Africa it is characterised by significant clinical symptoms and regular occurrence.

In South Africa, four *Babesia* species, including *Babesia felis*, *Babesia leo*, *Babesia lengau*, and *Babesia microti*, have been identified in domestic cats. Previously all cases had been assumed to be caused by *Babesia felis*, however not all patients had the same symptoms or the same response to treatment.

With the development of molecular technology, taxonomic classifications have become clearer, and a new *Babesia* species was discovered in 2019, temporarily named *Babesia* sp. cat Western Cape[35].

Rickettsiae

Rickettsial diseases are attributable to infections by obligate intracellular bacteria belonging to the order Rickettsiales, encompassing the genera *Rickettsia, Orientia, Anaplasma*, and *Ehrlichia*. The *Rickettsia* genus is taxonomically classified based on phenotypic and phylogenetic characteristics. Predominantly, pathogenic *Rickettsia* species are categorised under the spotted fever group (SFG), apart from *Rickettsia prowazekii* and *Rickettsia typhi*, which are classified within the typhus group (TG) *Rickettsia*.

The SFG includes notable human pathogens like *Rickettsia rickettsii* and *Rickettsia africae*, among others. There exists a subset of SFG Rickettsia, including species closely related to the human pathogen *Rickettsia felis*, forming what is considered a transitional group, though its delineation from other SFG Rickettsia remains a topic of scientific discourse. Furthermore, there is an ancestral group comprised of non-pathogenic species such as *Rickettsia bellii*. While the principal vectors of SFG Rickettsia are hard ticks (Ixodidae), other arthropods also serve as vectors for specific species, such as fleas for *R. felis* and mites for *Rickettsia akari*. With over 30 species identified globally, SFG Rickettsia pathogens are widespread, causing a spectrum of diseases that are either globally dispersed or region-specific[36].

Rickettsial infections are a significant public health concern in South Africa, with domestic animals often serving as sentinels for these diseases[37]. The primary vectors for Rickettsiales are arthropods, including ticks, fleas, mites, and lice, which facilitate the transmission of these obligate intracellular bacteria to a variety of hosts[37, 38]. Transmission occurs through the bite, or contact with the faeces, of infected arthropod vectors. Among the Rickettsiales, the spotted fever group Rickettsiae (SFGR) like *Rickettsia conorii, Rickettsia africae,* and potentially *R. felis*, are of particular concern in South Africa due to their impact on human and animal health.

Rickettsia africae, the causative agent of African tick-bite fever (ATBF), and *R. conorii*, responsible for Mediterranean spotted fever (MSF), are well-documented pathogens in South Africa[39]. While indigenous human populations often do not display overt clinical signs, these pathogens can cause severe disease in tourists, making rickettsioses a concern for the country's tourism industry[39]. The ecology of these diseases is closely linked to tick exposure, particularly in game hunting and nature reserve areas, where contact with tick-infested cattle and wildlife is common[37].

In the context of companion animals, *R. conorii* and *R. africae* have been detected in dog ticks, with significantly high infection rates found in certain provinces[38]. Kolo et al. (2016) reported the first detection of *R. felis* in South Africa, an emerging pathogen that causes flea-borne spotted fever in humans[37].

The brown dog tick, *Rhipicephalus sanguineus*, and the yellow dog tick, *Haemaphysalis elliptica*, have been identified as potential vectors for *R. conorii* in South Africa[38]. These findings suggest that dogs could act as hosts in the life cycle of these rickettsial organisms, although the clinical presentation in canines is not as well characterised as in humans.

The risk factors for infection with rickettsial pathogens include tick and flea exposure in environments where these vectors are endemic. In humans, rickettsial diseases can present with fever, headache, and rash, and in severe cases, may lead to hospitalisation[37, 39] or even death[36]. As the symptoms can resemble other febrile disorders, there is a danger of delayed or missed diagnosis, which highlights the need for increased research and improved molecular detection methods[36].

Effective prevention strategies for rickettsioses include the control of arthropod vectors through the use of acaricides and insect repellents, as well as environmental management practices that reduce the contact between vectors, humans, and domestic animal[38]. Awareness campaigns aimed at people travelling to endemic areas, particularly during peak transmission seasons, are also critical for reducing the incidence of rickettsial diseases.

Anaplasma

Anaplasma species are tick-borne pathogens of significant veterinary and public health importance. In South Africa, *Anaplasma phagocytophilum* and *Anaplasma platys* are the principal species identified in companion animals, with evidence suggesting the presence of a novel *Anaplasma* species[31, 37, 39, 40]. *Anaplasma* species are classified within the order Rickettsiales and are known to exploit both vertebrate and invertebrate hosts in their life cycles[41].

Anaplasma phagocytophilum, the causative agent of human granulocytic anaplasmosis (HGA) and canine granulocytic anaplasmosis (CGA), is transmitted by ticks of the *Ixodes* genus in various regions, with a complex host range including various wild and domestic animals[41]. In South Africa, the vector ecology is yet to be fully delineated, but evidence of *Anaplasma* DNA has been found in domestic dogs and various tick species, indicating a potential for diverse vector relationships[39]. The clinical presentation in animals infected with *A. phagocytophilum* can range from acute to subclinical, including anorexia, fever, lethargy, and in some cases, musculoskeletal and central nervous system involvement[2].

Anaplasma platys is known to cause infectious cyclic thrombocytopenia in dogs, with *R. sanguineus* sensu lato, implicated as the vector. Clinically, *A. platys* can cause a range of symptoms from mild subclinical infection to more severe presentations, including cyclical fever and bleeding disorders due to the pathogen's affinity for infecting host platelets[31]. *Anaplasma* *platys* has been suggested to have zoonotic potential, although this is less clearly defined compared to *A. phagocytophilum*[41].

Recent molecular studies have identified *Anaplasma* sp. SA dog, a novel *Anaplasma* strain closely related to *A. phagocytophilum*, in domestic dogs within South Africa[40]. This emerging species has been detected in both canine blood samples and *R. sanguineus* ticks, suggesting the latter may serve as the vector within the region[41]. While the full clinical implications of *Anaplasma* sp. SA dog are not yet fully understood, its detection in a human patient with acute febrile illness suggests a potential for human infection[37].

Diagnosis of *Anaplasma* infections typically relies on molecular techniques, such as PCR and sequencing of the 16S rRNA gene, to detect the presence of pathogen DNA within host blood or vector samples[39]. These methods have been instrumental in characterising the genetic diversity of *Anaplasma* species in South Africa and have provided insights into their molecular epidemiology[41].

The management of *Anaplasma* infections includes the use of tetracycline antibiotics, with doxycycline being a primary choice for the treatment of HGA in humans. Similar treatment protocols are employed in veterinary medicine for infected animals[41]. Control measures focus on tick prevention strategies, including the use of acaricides and the management of tick habitats to reduce exposure risks.

The detection of *Anaplasma* species in companion animals highlights the need for continued surveillance and research to better understand the ecology, pathogenicity, and zoonotic potential of these organisms. With the increasing recognition of these pathogens in South Africa, both veterinary and human health communities must remain vigilant and responsive to the challenges posed by these tick-borne diseases[41].

Ehrlichia

The *Ehrlichia* genus encompasses a group of obligate intracellular gram-negative bacteria transmitted by ticks, with *Ehrlichia canis*, *Ehrlichia chaffeensis,* and *Ehrlichia ruminantium* being the primary species of concern in South African companion animals[42]. The taxonomy of *Ehrlichia* has been refined based on 16S rRNA gene sequences, dividing the genus into distinct genogroups that also include the agents of human granulocytic ehrlichiosis[31]. This taxonomic reclassification aligns *Ehrlichia* within the broader spectrum of vector-borne pathogens that affect both animal and human health.

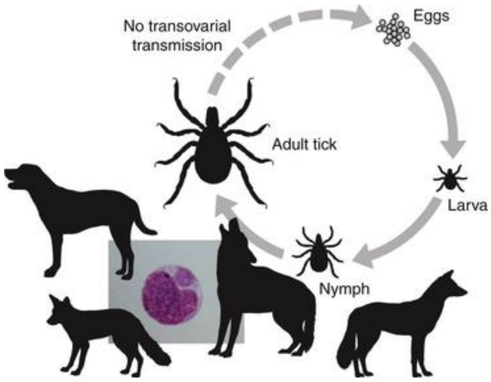

Figure 2.

Life-cycle of *Ehrlichia* spp.[43]

Vectors for these bacteria are primarily ticks, which play a crucial role in their lifecycle. Dogs act as definitive hosts for *E. canis*, which is known to infect monocytes, while *E. chaffeensis*, an agent also of human monocytic ehrlichiosis, can be found in both human and canine monocytes. *Ehrlichia ruminantium*, traditionally associated with ruminants, has been commonly identified in the blood of dogs in South Africa[42]. The lifecycle of these pathogens involves acquisition by the tick vector during blood feeding and subsequent transmission to a new host when the tick feeds again.

Clinically, ehrlichiosis in dogs presents in acute, subclinical, and chronic phases, with a typical incubation period of approximately three weeks[31]. During the acute phase, hallmark signs such as thrombocytopenia and normocytic, normochromic, non-regenerative anaemia are observed, alongside symptoms such as high fever, haemorrhages, depression, lethargy, and anorexia[31]. The subclinical phase can be deceptive, as infected dogs may appear outwardly healthy while harbouring underlying haematological abnormalities. If the infection progresses to the chronic stage, dogs may develop pancytopenia and, in severe cases, bone marrow suppression leading to death, often due to secondary infections[31].

Figure 3.

A dog showing epistaxis because of Ehrlichia infection (photograph taken by author)

Ehrlichia species carry a zoonotic potential, with *E. chaffeensis* being a notable pathogen in human ehrlichiosis cases. In South Africa, serological studies have revealed a significant exposure of dogs to both *E. canis* and *E. chaffeensis*, indicating a potential risk to human health, especially for individuals in close contact with infected ticks or companion animals[42, 44]. The rising seroprevalence of *E. chaffeensis* suggests an increasing incidence of this pathogen, corroborating the public health significance of these bacteria[42].

Theileria

Theileria has been detected as a subclinical infection in dogs and it has been proposed that this is because of less virulent or more commensal host-pathogen relationship compared to the disease in other species[45]. The most common symptoms in clinical cases are pale mucous membranes, and increased bleeding tendencies, oral bleeding, petechiae, ecchymoses, haematuria, haematochezia etc, coupled with inappetence and lethargy.

Anaemia and or thrombocytopaenia have been identified as "hall mark symptoms" for the three major tick-borne haemoparasites (Babesia, Ehrlichia and Theileria)[45]. The pathophysiology of Theileria remains unknown in dogs, however an immune-mediated process, possibly involving bone marrow, has been proposed for the subsequent anaemia and thrombocytopaenia.

Treatment is imidocarb dipropionate and if treated early, there is a good prognosis.

In summary, vector-borne pathogens in companion animals in South Africa represent a complex interplay between ticks, animals, and humans, with a range of clinical manifestations and significant implications for public health. The implications of these vector-borne pathogens occurring in resource-poor areas of South Africa are even more profound. Without access to veterinary intervention, the inevitability of morbidity and mortality due to infection looms large, underscoring the pressing need for comprehensive preventive strategies and further research into the epidemiology of these parasites in the region[31]. Monitoring the prevalence and distribution of these pathogens remains a critical component of veterinary public health in South Africa[39].

Helminths

Toxocara species are parasitic nematodes of global distribution, with *Toxocara canis, Toxocara cati* and *Toxascaris leonina* being the main species of concern in companion animals. In South Africa, these parasites are endemic and pose significant risks to animal and human health.

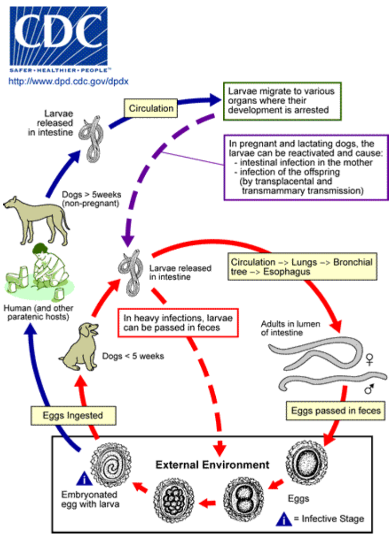

Figure 4

Life cycle of *Toxocara canis[46]*

Toxocara canis, a parasitic nematode, completes its life cycle within canine hosts, with humans serving as accidental hosts. The lifecycle of *Toxocara* spp. involves the shedding of un-embryonated eggs in the faeces of the definitive host, which, upon maturation in the environment after 1-2 weeks, become infectious to other hosts (Figure 4).

In adult dogs, larvae resulting from egg hatching may encyst in various tissues, while in puppies, larvae migrate through the respiratory and gastrointestinal tracts, eventually developing into adult worms in the small intestine. The encysted stages in adult dogs can be reactivated during pregnancy, leading to transplacental and transmammary transmission to puppies. Lactating bitches and infected puppies then excrete infective eggs. Humans, inadvertently acting as hosts, acquire the infection by ingesting these infective eggs from contaminated soil. Once ingested, the eggs hatch, and the larvae traverse the intestinal wall, disseminating to diverse tissues such as the liver, heart, lungs, brain, muscle, and eyes. While these larvae do not undergo further development in human tissues, their presence can incite severe local reactions, giving rise to the clinical manifestations of toxocariasis, notably visceral larva migrans (VLM) and ocular larva migrans (OLM) [46].

These eggs can be directly ingested by the definitive hosts or by humans, particularly children, leading to a range of clinical manifestations. Humans with symptoms of toxocariasis are technically paratenic hosts, as *T. canis* cannot complete its life cycle in humans[35].

Appleton (2017) delineates the widespread prevalence of *T. canis* in South Africa, with infection rates varying significantly across urban areas. Eggs can remain viable in the environment for months or even years once they mature to the infective stage.

Human infection with *T. canis*, resulting in conditions such as visceral larva migrans (VLM) and ocular larva migrans (OLM), underscores the zoonotic danger posed by these parasites. Although no comprehensive data on the prevalence of human toxocariasis in South Africa exist, serological surveys imply that the condition may be underdiagnosed[35]. The clinical presentation of VLM and OLM in humans can be severe, with the potential for organ damage and vision loss, particularly in children who are the most frequently infected demographic.

Pal et al. (2023) reiterate the significance of Toxocara and hookworm species as public health concerns, with dog faeces identified as a primary vector for environmental contamination[36]. This is especially pertinent in socioeconomically disadvantaged communities where sanitation infrastructure may be inadequate, increasing the risk of human exposure to infective parasitic forms.

Hookworms

Hookworms are soil transmitted nematodes which have a filarial third larval phase that can actively penetrate skin. Hookworm species are found worldwide but have the highest documented presence in sub-Saharan Africa[47]. Their distribution is influenced by geographical and climatic conditions and they are widely distributed in tropical and subtropical regions, where warmer temperatures and higher rainfall facilitate their transmission. Hookworms of South African veterinary and zoonotic importance include those from the Ancylostomatoidae superfamily, in particular Ancylostoma genus.

Ancylostoma

Ancylostoma species, commonly known as hookworms, are a genus of parasitic nematodes that hold significant medical and veterinary importance due to their zoonotic potential and the morbidities they cause in their hosts. These helminths share a general lifecycle which commences with the excretion of eggs in the faeces of an infected host. Upon reaching a suitable environment, the eggs hatch into larvae, which then undergo a series of moults to become infective third-stage larvae. The infective larvae actively penetrate the skin of a new host, migrate through the circulatory system to the lungs, ascend the bronchial tree to the throat, and are subsequently swallowed. Once in the small intestine, they attach to the intestinal wall to feed on blood, where they mature into adult worms, thus completing their lifecycle.

While the L_3 larva are the infectious stage, transmission is possible through transplacental and trans mammary routes (the latter has been recorded with only *A. caninum* in dogs). Canids can also be infected by ingesting paratenic hosts like rodents or insects containing larvae. This is significant with regards to resource-limited communities as some studies highlighted common issues with household pests, especially rodents[48]. Hossain and Bhuiyan (2016) have reported transmission of infective larvae through fomites such as clothing dried on the ground, leading to human infestations when the clothes are worn again[49].

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In South Africa, there are four main species of concern: *A. caninum, A. braziliense, A. ceylanicum,* and *A. tubaeforme.*

Ancylostoma caninum primarily parasitises dogs, its most common host. It is widely distributed in areas where canine populations are dense, often correlating with socio-economic factors influencing pet care and sanitation. Clinically, infected animals may exhibit signs ranging from mild gastrointestinal discomfort to severe anaemia and hypoproteinaemia, depending on the intensity of the infection. Adult *A. caninum* worms ingest a higher volume of blood than the other mentioned species combined, causing mortality in severely infested puppies and kittens[50]. Infected puppies have been found to be more susceptible to acute or chronic haemorrhagic anaemia, especially if infected through the trans mammary route. *Ancylostoma caninum* larvae are also able to remain dormant in tissues for months to years, resuming migration and causing reinfection when the host is triggered by stress, illness or high doses of corticosteroids[47]

The zoonotic risk posed by *A. caninum* is associated with cutaneous *larva migrans* (CLM), where the larvae migrate within the human epidermis, causing serpiginous tracks. It has also been found to occasionally cause eosinophilic enteritis if it reaches the adult stage in humans and some reports suggest that it might cause diffuse unilateral subacute neuroretinitis[51]. Less commonly it can be associated with folliculitis, localised myositis, erythema multiforme and ocular disturbances[47]. Hookworm infection in children can lead to mental impairment[52], growth deficiencies, protein deficiency malnutrition and anaemia[47]. In both companion animals and humans, severe infestation can lead to neonatal or maternal mortality, prematurity and a decreased birthweight[47].

Ancylostoma braziliense is another species with a notable distribution in the warmer regions of South Africa, predominantly infecting cats and dogs. Like *A. caninum*, this species can cause cutaneous *larva migrans* in humans, characterised by so called 'creeping eruptions' on the skin which can persist for over 100 days[47].

Ancylostoma ceylanicum is of particular concern due to its ability to mature and reproduce in the human intestine, not merely causing a transient infection as the aforementioned species do[53]. Its distribution is somewhat less understood in South Africa but is believed to overlap regions with other *Ancylostoma* species. In both its animal hosts and humans, it can cause iron deficiency anaemia and protein-losing enteropathy, presenting a more severe zoonotic risk than the other species.

Lastly, *Ancylostoma tubaeforme* primarily infects felines and has a similar geographic distribution to *A. braziliense* in South Africa. While it does not typically infect humans, there is a potential for zoonotic transmission, albeit at a significantly lower risk compared to the other species.

In summary, while the lifecycle of *Ancylostoma* species involves a direct life cycle that can be completed outside the host, their ability to cause significant morbidity in both animal and human populations cannot be understated. The clinical manifestations in animals can range from subclinical to severe, whereas the primary concern in humans remains the cutaneous *larva migrans*, except for *A. ceylanicum*, which can cause more severe systemic disease.

Dipylidium caninum

Dipylidium caninum, colloquially known as the "flea tapeworm," persists as a parasitic cestode of considerable veterinary significance and poses a zoonotic threat to public health. The lifecycle of *D. caninum* is indirect, necessitating both a definitive host, where the parasite achieves sexual maturity, and intermediate hosts, which harbour the larval stages. The definitive hosts are predominantly domestic dogs and cats, although a range of other carnivorous mammals can harbour the adult tapeworm. In the lifecycle, after the mature segments of the tapeworm are excreted with the faeces of the definitive host, the eggs contained within are released into the environment and subsequently ingested by the intermediate hosts, which are typically flea larvae. Within these flea larvae, the tapeworm eggs develop into infective cysticercoids. When the definitive host ingests these parasitised fleas, often during grooming, the cycle is completed as the cysticercoids develop into adult tapeworms within the intestine.

In South Africa, *D. caninum* exhibits a pervasive geographical distribution, paralleling the presence of its definitive hosts and intermediate flea hosts. This ubiquity reflects the widespread infestation of fleas in domestic and stray animal populations and the close association these animals have with human settlements.

Clinically, the infestation in definitive animal hosts may present as an asymptomatic carriage or include signs such as perianal irritation, manifested by scooting or excessive licking, vague gastrointestinal disturbances, and in heavy infestations, intestinal blockage. While typically not life-threatening, these clinical signs can impact the quality of life and welfare of the affected animals.

The zoonotic risk of *D. caninum*, while relatively low, is most significant in young children who may inadvertently ingest infected fleas. In humans, the infection, known as dipylidiasis, is usually mild, presenting as abdominal discomfort, diarrhoea, and sometimes pruritus ani. The disease is often discovered when the proglottids, which are motile segments of the tapeworm containing eggs, are excreted in the faeces, causing alarm and prompting medical consultation.

The intermediate hosts, often fleas belonging to the genera *Ctenocephalides felis* and *Ctenocephalides canis*, play a pivotal role in the transmission dynamics of *D. caninum*. The environment, particularly where flea populations are left uncontrolled, acts as a reservoir for the parasite's eggs, perpetuating the lifecycle.

Risk factors for infection with *D. caninum* include poor pet hygiene, infestation with fleas, and close contact between pets and young children. Inadequate control of flea populations in the domestic setting further heightens the risk of tapeworm transmission.

Preventative measures against *D. caninum* infestation involve an integrated approach. Effective flea control programs using insecticides and growth regulators, regular deworming of domestic animals with praziquantel or other suitable anthelmintics. Environmental treatment to reduce flea populations is essential as human infection occurs only with accidental flea ingestion.

Taenia species

The *Taenia* genus encompasses a group of cestode parasites that follow a complex lifecycle, typically involving an adult stage in the intestinal tract of carnivorous definitive hosts and larval stages in various intermediate or paratenic hosts. This lifecycle begins with the release of gravid proglottids or eggs into the environment through the faeces of the definitive host. Intermediate hosts ingest these infectious agents, and upon entry, the larvae encyst within the host's tissues, forming cysticerci. When a definitive host consumes tissue from an infected intermediate host, it ingests the cysticerci, which then develop into adult tapeworms in the intestine, completing the lifecycle.

In South Africa, several *Taenia* species are of particular interest due to their impact on livestock, wildlife, and potential zoonotic transmission to humans.

Taenia hydatigena commonly parasitises domestic and wild canids as definitive hosts. Ruminants, including sheep and cattle, act as the primary intermediate hosts. The distribution of *T. hydatigena* is closely tied to pastoral and wildlife areas where these host species interact. In intermediate hosts, the larvae typically encyst in the omentum and mesentery, causing little clinical disease unless the burden is high. In humans, *T. hydatigena* is considered to have a low zoonotic potential, with rare cases of cysticercosis involving the accidental ingestion of eggs leading to cyst formation in various organs.

Taenia multiceps has a definitive host range that includes dogs and other canids, while the intermediate hosts are usually sheep, goats, and sometimes cattle. Geographic distribution is widespread where sheep farming is prevalent. This parasite can cause "gid" or "sturdy," a severe neurological condition in intermediate hosts resulting from the larval stage, known as *coenurus cerebralis*, encysting in the brain. Although human cases are exceedingly rare, they can occur when humans inadvertently ingest eggs, leading to *coenurosis,* a severe condition characterised by cyst formation in the central nervous system.

Taenia pisiformis typically infects domestic dogs and wild carnivores as definitive hosts, with lagomorphs serving as the intermediate hosts. This species is distributed wherever these two host groups overlap, often in rural and wildlife-urban interface areas. In intermediate hosts, cysticerci form in the liver and peritoneal cavity, usually with minimal clinical signs. *T. pisiformis* has minimal zoonotic potential, as humans are not typically in the cycle of transmission.

Taenia taeniaeformis finds its definitive hosts in felines, including domestic cats and wild felids, while the intermediate hosts are primarily rodents. This tapeworm is common in urban and suburban areas where its intermediate hosts are plentiful. Larvae form cystic structures, typically in the liver of the intermediate host, called strobilocerci, which can cause significant pathology and impairment of liver function. The zoonotic risk to humans is considered very low for *T. taeniaeformis*, with few documented cases of accidental infection.

For all *Taenia* species, the zoonotic risk primarily exists where humans can encounter infective eggs through faecal contamination or ingestion of undercooked, infected meat. However, direct zoonotic transmission is relatively rare, with most concerns centring on the economic and health impacts on animal hosts.

Prevention strategies are critical and include proper cooking of meat, control of definitive host populations, routine antiparasitic treatment of domestic animals, and improved sanitation to reduce environmental contamination with tapeworm eggs. Public health education also plays a vital role in reducing the risk of human exposure and infection.

Spirocerca lupi

Spirocerca lupi is a parasitic nematode that induces significant clinical pathology in canine hosts and is characterised by a complex lifecycle involving both intermediate and paratenic hosts. The lifecycle initiates when eggs containing first-stage larvae are excreted in the faeces of an infected dog. These eggs are then ingested by coprophagous beetles, which serve as the intermediate hosts. Within these beetles, the larvae develop to a stage infectious to the definitive canine host. Dogs become infected upon ingesting these beetles directly or indirectly through paratenic hosts such as birds, reptiles, or small mammals that have predated upon infected beetles. Once inside the definitive host, the larvae migrate through the gastric wall, establishing in the oesophageal wall where they develop into adult worms.

In South Africa, the distribution of *S. lupi* is notably prevalent in warmer regions where intermediate and paratenic hosts are abundant. The parasitic infection is most reported in domestic dogs, which are the principal definitive hosts, although wild canids may also serve as reservoirs of infection.

Clinically*,* *S. lupi* infection in canines can lead to a condition known as spirocercosis, presenting with a range of signs from asymptomatic to severe. Early infection may go unnoticed; however, as the parasite develops, clinical signs may include vomiting, regurgitation, weight loss, and dysphagia. Severe complications such as oesophageal nodules, spondylitis, and even oesophageal sarcomas can arise from chronic infection, significantly impacting the health and wellbeing of the animal.

The zoonotic potential of *Spirocerca lupi* is considered to be low, with few reported cases of human infection. In the rare instances of human infestation, the parasite typically does not develop to maturity, and clinical manifestations may mimic other gastrointestinal ailments, making the diagnosis complex without a high index of suspicion.

Diagnosis of spirocercosis primarily involves the detection of the characteristic *S. lupi* eggs in the faeces or, more definitively, through endoscopic examination revealing the presence of adult worms or nodules in the oesophagus. Additional diagnostic modalities include radiography and ultrasonography to identify oesophageal thickening or associated spondylitis.

Treatment of spirocercosis can be challenging and is centred around anthelmintic administration, with drugs such as ivermectin and milbemycin oxime being commonly used. In cases with severe oesophageal damage or nodular formation, surgical intervention may be necessary. Moreover, the administration of anti-inflammatory medications can be supportive in managing the inflammatory responses induced by the parasite.

Preventative measures against *S. lupi* infection involve control of the insect intermediate host population, avoidance of feeding dogs' raw prey or offal which could harbour the parasite, and regular anthelmintic prophylaxis in endemic areas. Education of dog owners about the risks and signs of spirocercosis is essential for early detection and intervention, thereby reducing the parasite's impact on canine health.

Arthropods

Rhipicephalus sanguineus (Brown dog tick, kennel tick)

Rhipicephalus sanguineus, commonly referred to as the brown dog tick or kennel tick[54] is an endophilic, three-host tick species, primarily adapted for all growth stages to domestic dogs.

As the most widely distributed tick species in the world, *R. sanguineus* demonstrates a remarkable adaptive capacity to survive in many different habitats, but is most accommodated to thrive within urban environments, including human dwellings and dog kennels[54, 55]. Studies by Rautenbach et al. (1991) have reported higher abundances of *R. sanguineus* in locales where stray dogs are common or where dogs are densely housed in shelters, a situation often exacerbated by inadequate tick control measures[56]. The evolutionary journey of *R. sanguineus* may have been closely aligned with burrowing carnivores, which likely brought these ticks into increased contact with humans as dogs became domesticated[38]. Despite their widespread distribution, *R. sanguineus* tick populations are reliant on the availability of domestic dogs to maintain large population sizes, and in cases of high dog population density or movement restriction, infestation can be severe[54, 55].

Rhipicephalus sanguineus is implicated as the primary vector for significant canine zoonotic pathogens, namely *E. canis* and *Hepatozoon canis*, which are responsible for canine monocytic *ehrlichiosis* and *canine hepatozoonosis*, respectively[38]. It is also a well-documented carrier of *B. vogeli* and perhaps *B. gibsoni,* but not of the other *Babesia* species found in carnivores[57]. In humans, it transmits *R. conorii conorii* and *Rickettsia rickettsii,* but in contrast to Mediterranean countries, there are other tick species in Southern Africa which are more commonly implicated for zoonotic rickettsia transmission[54].

Under specific environmental conditions, such as high tick infestations and low availability of preferred hosts*, R. sanguineus* shows an opportunistic host selection, resorting to parasitising rodents, small mammals, and in some cases, humans.

Rhipicephalus simus (The glossy tick)

Rhipicephalus simus is a three-host telotropic tick found in the savannah biome regions of southern Africa. The adults primarily feed on ruminants but also dogs, horses, zebra, large wild carnivores, and warthogs. The immature stages prefer murid rodents.

It is one of the most common tick species on farm dogs or dogs that are in contact with livestock in the North West province[58] and the adults transmit *Anaplasma marginale* and *A. centrale* to cattle and *R. africae* to humans. The species is toxin producing and is a cause of paralysis in young ruminants[54].

Rhipicephalus appendiculatus (Brown ear tick)

Rhipicephalus appendiculatus is a fast developing three host tick that is adapted to feeding on cattle and wild ruminants. It also infests domestic dogs and sheep. The immature stages can feed on smaller ruminants and hares, if necessary, but all life stages can be maintained feeding only on cattle. It is so named because of its colour and because the adults prefer to attach in and around the ear pinna, sometimes around the head. In South Africa its distribution is seasonal, and it is limited to the savannah biomes preferring temperate climatic conditions[54].

This species is well known as a vector for *Theileria parva*, which causes East Coast fever or Corridor disease in cattle. It also transmits *T. taurotragi*, *Anaplasma bovis*, *R. conorii* and Nairobi sheep fever[54].

Amblyomma hebraeum (South African bont tick)

Amblyomma hebraeum is a three-host tick, found along the east coast of South Africa and in the northeast regions of the country. The adults' hosts are large and small domestic ruminants and large wild ruminants (notably giraffe, buffalo, and rhinoceroses). The immature stages parasitise the same hosts as the adults, but also smaller antelope, hares and birds and reptiles[54]. The name 'bont' refers to the variegated appearance and the coloured stripes on its' legs.

Amblyomma hebraeum is a vector of *E. ruminantium* which is the cause of heartwater in ruminants. To date, of the 8 known genotypes of *E. ruminantium*, only one has been found in South African dogs. These dogs presented with typical signs of *Ehrlichia* but tested negative on North American specific PCR, however, were positive when tested with primers amplifying *E. ruminantium* specific genes[59].

Allan (2017) noted that the presence of *E. ruminantium* is increasing in dogs, especially in free-roaming dogs that have contact with livestock[31]. Allsopp and Allsop (2001) recorded that seemingly healthy dogs can be carriers of *E. ruminantium*[59] and its presence in multiple studies in this review may be cause for concern.

A. hebraeum also transmits the zoonotic pathogens, *R. africae* and *R. conorii,* and the species has also been found on dogs infected with *Anaplasma* species[41].

Haemaphysalis elliptica (Yellow dog tick)

A note on taxonomy: *Haemaphysalis elliptica* is morphologically similar to *Haemaphysalis leachi*, which is the tick species recorded as being prevalent in domestic dogs in South Africa in studies conducted before 2007. It was later determined that *H. leachi* has the same hosts as *H. elliptica*, however only occurs in Africa from Egypt to Zimbabwe, while *H. elliptica* occurs in the south and the east of Africa. Therefore, all previously described *H. leachi* specimens described in South African studies are assumed to be *H. elliptica*[60].

Haemaphysalis elliptica is a three-host tick species distributed widely across South Africa occurring wherever there are canids and murid rodents to sustain it. The adults prefer domestic dogs and wild carnivores such as black backed jackals, larger felids, and foxes. The immature stages prefer murid rodents but can also be maintained on the adult's hosts. Older studies suggest that *H. elliptica* is associated with pet dogs from more affluent areas[58], however this may no longer be the case (personal observation in Western Cape Province).

Haemaphysalis elliptica is an important species in the veterinary field as it is the only known vector capable of transmitting *B. rossi* to domestic dogs[61]. It is also the most prevalent tick species found on cats in the Western Cape region[62].

Rhipicentor nuttalli

The genus *Rhipicentor* consists of only two species globally: *Rhipicentor bicornis* and *Rhipicentor nuttalli*. Both these species are exclusively found in Africa. *Rhipicentor nuttalli* is notably widespread in South Africa, with documented occurrences in several provinces. While adult *R. nuttalli* ticks primarily target domestic dogs, wild canids and felids like leopards, and the South African Hedgehog, the preferred hosts of the tick's larval and nymphal stages are less well-documented. However, there are records indicating that these juvenile forms infest various rock elephant shrew species throughout South Africa[63]. Notably, *R. nuttalli* adults release a toxin that can induce paralysis in dogs.

Results

A total of 407 articles were collected into a Zotero library. 218 studies were selected for further analysis and data capture. Of these, only 8 studies had relevant arthropod data, 11 papers researched helminth sampling and 8 studies collected sampling data on vector-borne pathogens, totalling a review of 27 articles.

The studies recorded sampling of 6976 dogs and more than 1537 cats, with 131 parasitic species or pathogen combinations reported over 44 years (Table 3).

Table 3:

Data collated from the 27 journal articles on parasites and VBP samples from companion animals in resource-limited and rural communities in South Africa.

Parasite	n (dogs)	n (cats)	Parasite species/infection combinations total	Ref
Helminths	3116	1504	32	[4, 5, 56, 64–69]
Arthropoda	1639	Not available	53	[31, 37–39, 56, 58, 70, 71]
VBP	2221	33	46	[21, 31, 37–39, 45, 56, 72–75]
Total	6976	1537	131	

Table 4 shows the helminth species sampled from dogs and cats in resource-limited communities across South Africa and the frequency with which each species was recorded.

Table 4.

Total number of helminth species recorded for cats and dogs. The count for the dog species indicates how frequently a species occurred in the total studies (made by author).

Genus	Species found on dogs	Count	Genus	Species found on cats
Nematode	*Ancylostoma species*	16	**Acanthocephala**	*Centrorhynchus species*
Nematode	*Toxocara canis*	15	**Nematode**	*Pterygodermatites species*
Cestode	*Dipylidium caninum*	14	**Cestode**	*Taenia taeniaeformis*
Cestode	*Taenia species*	14	**Cestode**	*Joyeuxiella fuhrmanni*
Nematode	*Toxascaris leonina*	12	**Cestode**	*Taenia solium*
Nematode	*Spirocerca lupi*	7	**Cestode**	*Dipylidium caninum*
Nematode	*Ancylostoma caninum*	6	**Nematode**	*Ancylostoma tubaeforme*
Cestode	*Taenia hydatigena*	6	**Nematode**	*Ancylostoma braziliense*
Nematode	*Ancylostoma braziliense*	5	**Nematode**	*Toxocara cati*
Cestode	*Echinococcus granulosus*	4	**Nematode**	*Ancylostoma caninum*
Nematode	*Ancylostoma ceylanicum*	2	**Nematode**	*Ancylostoma ceylanicum*
Cestode	*Joyeuxiella species*	2	**Nematode**	*Physaloptera praeputialis*
Cestode	*Taenia multiceps*	2	**Nematode**	*Toxocara canis*
Nematode	*Trichuris vulpis*	2	**Nematode**	*Aleurostrongylus abstrusus*
Cestode	*Dipetalonema reconditum*	1	**Nematode**	*Vogeloides species*
Cestode	*Mesocestoides lineatus*	1	**Nematode**	*Dirofilaria repens*
Nematode	*Physaloptera canis*	1		
Cestode	*Taenia pisiformes*	1		
Cestode	*Taenia serialis*	1		

Commented [SS3]: its a nematod not an acanthocephalan species

19 helminth species were recorded in dogs and the most prevalent across the studies were *Ancylostoma* species, *Toxocara canis*, *D. caninum* and *Taenia* species (Table 4). *Toxascaris leonina* and *S. lupi* were also commonly reported. In cats 16 different species were mentioned, including one Acanthocephala species. Interestingly *Taenia solium* was found in one sample but this was reported as an incidental finding. Counts of frequency were not calculated for the cat helminth species as there was a very small proportion of studies that included cats. Out of the biggest study of 1502 cats conducted in Gauteng, the highest prevalence was *A. tubaeforme* (42%), *A. braziliense* (25%) and *D. caninum* (23%)[65].

Ancylostoma caninum is the most prevalent hook worm species found in dogs in South Africa, followed by *A. braziliense* and *A. ceylanicum*. The latter is of great zoonotic importance as it is the only one able to cause patent infection in humans. It must also be noted that *A. braziliense* and *A. ceylanicum* cannot be differentiated microscopically and only one study employed molecular detection methods to confirm identification to species level[47].

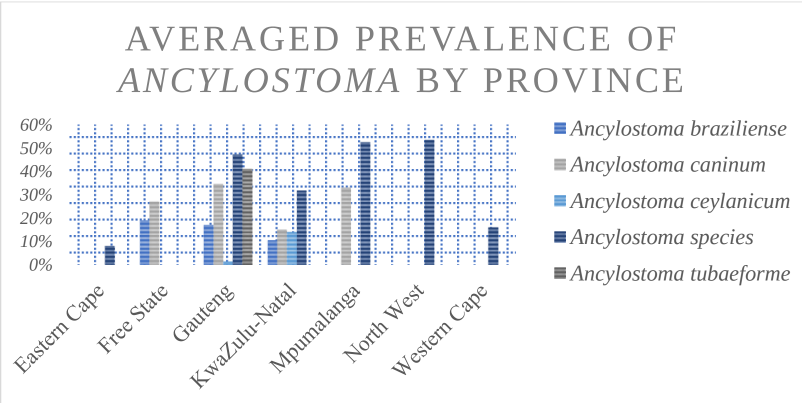

Figure 5

Averaged prevalence of *Ancylostoma* species by province in samples taken from dogs and cats in RLC across South Africa, compiled from literature published between 1979 and 2018 (made by author)

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The results show that *Ancylostoma* species were found mostly in the northwestern part of the country (Figure 5). The highest prevalence was from studies conducted in the North West province. The Western and Eastern Cape provinces had a lower prevalence, most likely due to climatic conditions. The Western Cape experiences hot, dry summers and cold, wet winters. The eggs and larvae would succumb to desiccation in summer and if they would survive, the cold winter would supress the egg development and kill any free living larvae[47].

Dipylidium caninum was widely found across the provinces in both dogs and cats. The highest recorded infection rates tended to be animals from that were sampled with necropsy[5, 65, 67, 76]. The data are presented in Figure 6, and while the averaged proportion of the study samples were calculated for each province, in some provinces such as the Western Cape, the data was limited to a single study.

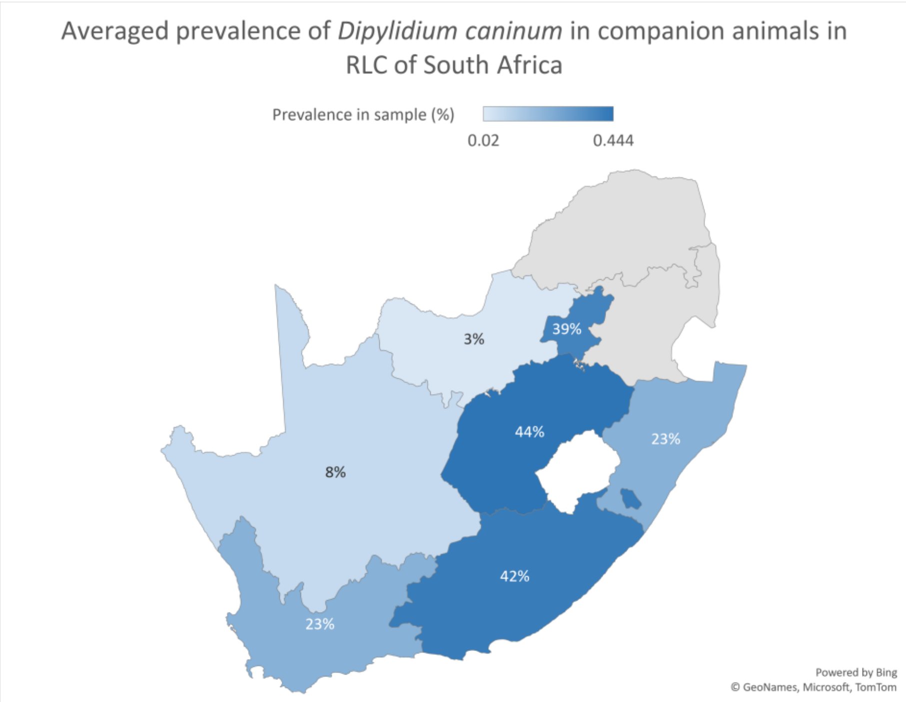

Figure 6

A map of South Africa showing the averaged prevalence per province of *D. caninum* in companion animals sampled from RLC, compiled from literature published between 1979 and 2002 (made by author)

All the tick genera recorded were hard ticks of the Ixodidae family, as shown in Table 5. The most abundant tick species affecting dogs were *R. sanguineus, H. elliptica* and *R. simus*. As most of the studies sampled dogs in either hospital settings or urban areas, the infection rate of *R. sanguineus* was generally quite high. *R. simus* is a vector of *A. marginale* and *A. centrale.*

Table 5

Tick species found on cats and dogs in resource-limited and rural communities in South Africa. Bold indicates the most sampled species (made by author).

Dog species	Cat species
Amblyomma hebraeum	*Amblyomma hebraeum*
Amblyomma marmoreum	*Amblyomma marmoreum*
Amblyomma species	*Haemaphysalis colesbergensis*
Haemaphysalis colesbergensis	*Haemaphysalis elliptica*
Haemaphysalis elliptica	*Haemaphysalis spinulosa*
Haemaphysalis species	*Haemaphysalis zumpti*
Haemaphysalis spinulosa	*Ixodes cavipalpus*
Haemaphysalis zumpti	*Ixodes corwini*
Hyalomma glabrum	*Ixodes neitzi*
Hyalomma truncatum	*Ixodes pilosus*
Ixodes corwini	*Ixodes pilosus*
Ixodes neitzi	*Ixodes rubicundus*
Ixodes pilosus	*Rhipicentor nuttalli*
Ixodes rubicundus	
Ixodes species	
Rhipicentor nuttalli	
Rhipicephalus evertsi evertsi	
Rhipicephalus appendiculatus	
Rhipicephalus capensis	
Rhipicephalus follis	
Rhipicephalus gertrudae	
Rhipicephalus lunulatus	
Rhipicephalus microplus	
Rhipicephalus neumanni	
Rhipicephalus nitens	
Rhipicephalus sanguineus	
Rhipicephalus simpsoni	
Rhipicephalus simus	
Rhipicephalus tricuspis	
Rhipicephalus turanicus	
Rhipicephalus warburtoni	

The information regarding tick species on domestic cats came from a large review of all tick species recorded in SA and had no information regarding geographic distribution or prevalence[70].

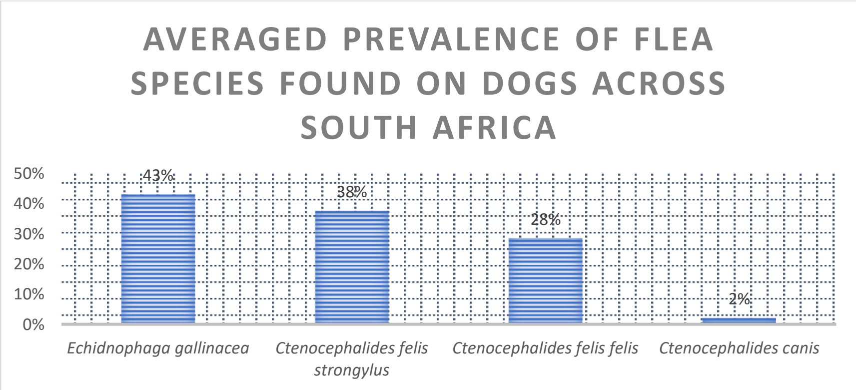

Figure 7

Combined prevalence of flea species found on dogs in RLC across South Africa (made by author)

Only 3 studies reported flea species and the overall prevalence of each is shown in Figure 7. Interestingly, Bryson et al. (2000) found that in the Maboloka community in the North West province, *Echidnophaga gallinacea* was the most prevalent species found on dogs. This was attributed to the close association between the dogs and free-ranging chickens as well as a sampling bias since *E. gallinacea* tends to clump together and is therefore easier to collect[58]. Kolo et al. (2016) found that all fleas collected from dogs living in Mnisi community tested positive for *R. felis*[37]. The species in their study were *E. gallinacea* and *Ctenocephalides felis strongylus*.

Only two studies (both conducted in Maboloka, North West province) recorded sampling lice species. Both reported finding *Heterodoxus spiniger*[56, 58] and one also reported *Trichodectes canis*[56]. The proportion of the dogs sampled that had lice infestation was always less than 1%.

Heterodoxus spiniger is an ectoparasitic louse belonging to the family *Boopidae*, found mainly in tropical and subtropical regions. Its primary host is dogs, but it can infest other animals, such as wild canids and some marsupials. Clinical signs in dogs include pruritis, dermatitis and focal alopecia. Heavy infestations in puppies or compromised animals can also cause anaemia.

The same two studies also recorded evidence of myiasis caused by the larva of *Cordylobia anthropophaga* in 0,5 to 5% of the dogs sampled[56, 58]. Evidence of wounds created by the larva of *Stomoxys calcitrans* was also reported.

In total, 46 vector-borne pathogens and infection combinations were reported. A detailed list can be found in Appendix A. *Ehrlichia* and *Babesia* species were the most often reported genera (Figure 8) and of these, *E. canis* and *B. rossi* were the most common pathogen species overall in dogs (Figure 9). These figures included the samples of dogs that were infected with more than one pathogen at the same time.

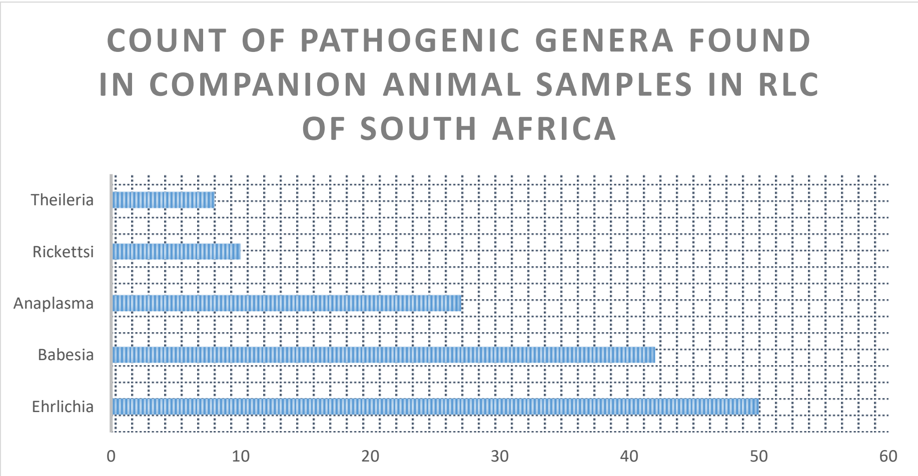

Figure 8:

The most reported pathogen genera found in samples from dogs and cats in RLC of South Africa, compiled from literature published between 1991 and 2022 (made by author).

From samples taken from 33 cats, the vector-borne species listed in Table 6 were found, however none of the sampling sites were definitively in rural or resource-limited communities, so these data are included only for interest.

Table 6

Pathogens species found in domestic cats in South Africa

Cat species
Anaplasma phagocytophilum
Babesia species
Babesia felis
Babesia lengau
Babesia leo

Of the species found in dogs, *E. canis R. africae, R. felis, Coxiella burnetii* and *A. phagocytophilum* are potentially zoonotic (Figure 8).

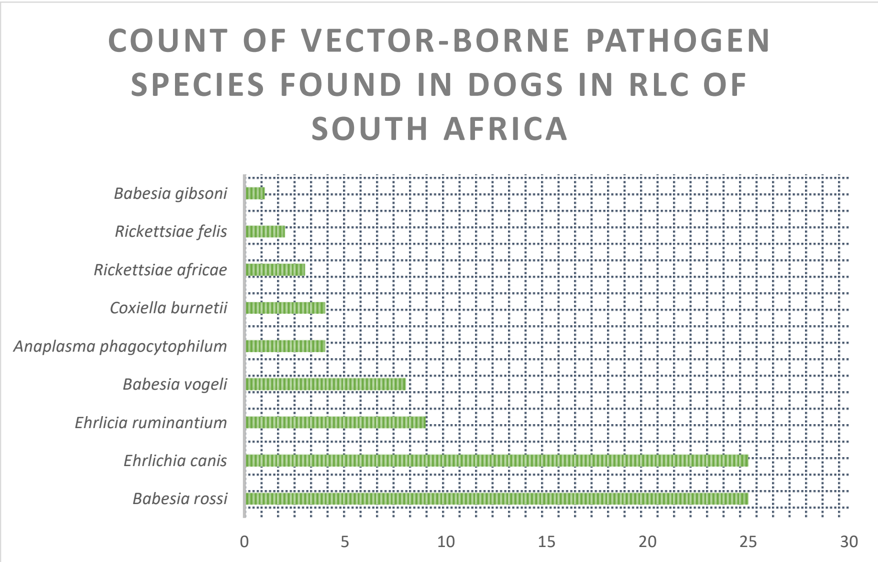

Figure 9

The most commonly occurring vector-borne pathogens in samples taken from dogs RLC across South Africa from 1991-2022 (made by author).

The presence of *Ehrlichia* species was found in approximately 70% of the dogs sampled with more than one pathogenic species. Coinfections of *Anaplasma* and *Ehrlichia* species was found to be very high in the Mnisi community in the Mpumalanga Province[37]. *Babesia rossi* was also commonly combined with *Ehrlichia* infection.

Almost all the data regarding the vector-borne pathogens in the included studies came from molecular identification methods. Reverse line blotting method (RLB) or polymerase chain reaction (PCR) techniques were used, apart from one study conducted in 1991 which identified *Babesia* species and *Ehrlichia* species from blood smears. The presence of *Ehrlichia* can be identified by the morulae that are formed during the first week of infection. These morulae are vacuoles of densely packed bacteria usually located in monocytes, however they are not present in cases with low parasite numbers and identifying them by light microscopy is time consuming[31].

The highest incidence of *Babesia rossi* infection was found in the Gauteng province (65%). These data include the samples where *B. rossi* was one of multiple pathogens found in a single host. The averaged prevalence of *B. rossi* across the provinces of South Africa are shown in Figure 10.

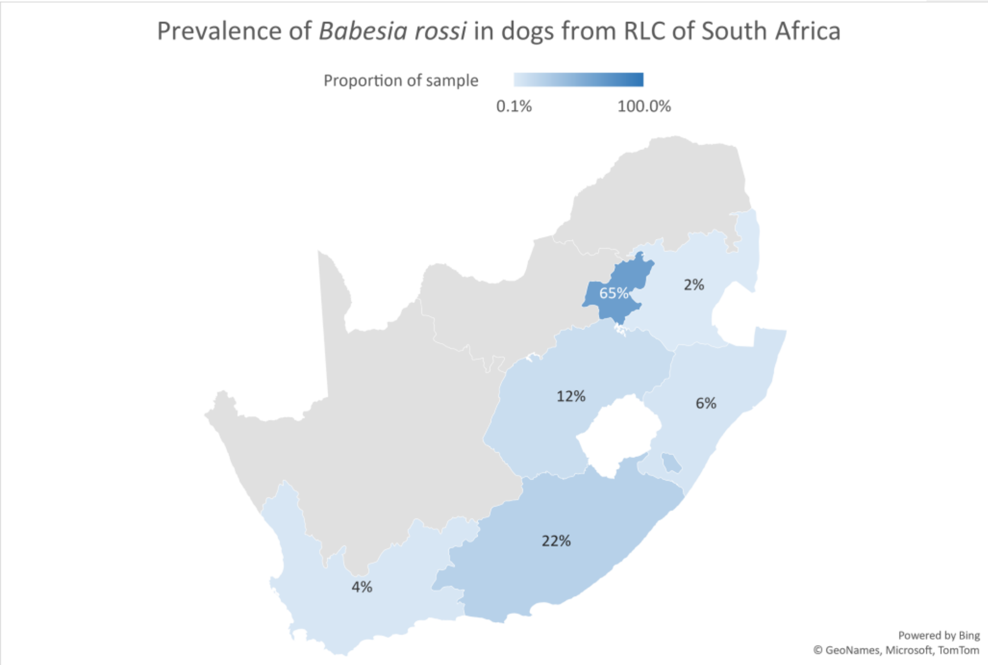

Figure 10:

Averaged prevalence of *Babesia rossi* infection reported in dogs in RLC of South Africa in literature published between 1979-2022~~A map showing the prevalence of sampled dogs testing positive for B. rossi infection~~ (made by author)

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Discussion

In 2010, 28 tick species had been found on domestic dogs in South Africa[77]. In this review, those 28 species were documented, and no new species have been added.

The high prevalence of *R. sanguineus* ticks was unsurprising, given that most of the studies were samples taken from dogs in kennel environments, either at welfare organisations or densely populated urban townships. Many of the most commonly recorded tick species are also associated with cattle or ruminant hosts in their lifecycle which is to be expected in rural settings.

Despite the fact that the prevalence of intestinal helminths is decreasing in the developed world[7], in many rural and developing communities the risk posed to human health by these parasites can still be significant. This is evidenced by this review, where multifaceted issues lend themselves to zoonotic infection which may well be present but is not being reported.

Preventative measures must focus on breaking the lifecycle of these parasites through improved sanitation, public education, and veterinary interventions such as regular deworming programs for pets. Effective management of animal waste, coupled with measures to prevent environmental contamination, can reduce the incidence of both *T. canis* and *T. leonina* infections. Environmental management rather than limiting direct contact with dogs is especially relevant for *T. canis* prevention as the infective larval stage takes 1-2 weeks to develop and the eggs are not infective[78]. Public health strategies should also promote awareness regarding the risks of exposure to contaminated soil, especially in areas where children play, and the importance of maintaining good hygiene practices to prevent the ingestion of infective eggs.

The most common vector-borne pathogens in resource-limited and rural communities is consistent with the general literature of all dog populations across South Africa. In general, the highest prevalence of *B. rossi* was found in regions around Johannesburg in Gauteng. It is important to highlight that in RLC the incidence of acute and severe disease such as *B. rossi* infection may be even higher than what is reported because many animals are not brought in for treatment in time. This again highlights the importance of improving companion animal health care for these communities.

Mixed infection of tick-borne pathogens was commonly recorded, with dogs being infected with two or more pathogenic species. Reasons for this could include a crossover of tick vector habitat and hosts. For example, Matjila (2008) found coinfections of *B. vogeli* and *E. canis* since both pathogens are transmitted by *R. sanguineus* ticks. They also found coinfections of *B. rossi* and *E. canis* which is easily explained by *R. sanguineus* and *H. elliptica* sharing overlapping geographical distribution and the fact that both species have been collected from the same host[72]. Another mechanism for the increased occurrence of multiple infections that has been suggested is the co-housing of domestic animal species[38]. Allan (2017) found that infections with *E. canis* were always combined with infections of *E. ruminantium* in a study conducted in the Western Cape. The article points out that these findings could just be incidental or perhaps due to dogs coming into contact with livestock[31]. Whatever the mechanism, multiple infections should always be viewed as concerning as the pathogens may affect the host or even the coinfecting pathogens in some ways[38].

Gray (2013) indicates that *R. conorii* can cause subclinical infection in dogs which can then be taken up by ticks, in which case, dogs could act as a reservoir for this zoonotic *Rickettsia* species[55].

The 'One Health' approach emphasises a holistic collaboration among professionals in human and animal health, as well as those in environmental and agricultural fields. Although the principle is widely accepted, its practical application struggles, especially when trying to bridge the gap between academic studies and policy implementation.

A primary advantage of the One Health strategy is its cost-effectiveness. By addressing issues in animal populations, it can achieve broader societal and public health benefits more efficiently than by focusing only on human interventions. For instance, while human rabies can be countered with timely treatments after exposure, the extensive costs of human vaccination strain health finances. In contrast, vaccinating domestic dog populations is a more economical alternative.

Efforts to address these challenges require a multifaceted approach. Community-based education programs can raise awareness about zoonotic risks and proper animal care. Veterinarians, wildlife experts, and public health officials must collaborate to develop integrated surveillance systems. Moreover, interventions should consider the ecological interactions between domestic animals, wildlife, and humans.

Awareness of parasites, the diseases they cause and how to break the cycle of transmission is fundamental to the control and prevention of zoonotic disease. The main strategy in addressing this issue must focus on education. Berrian et al. (2016) found a correlation between increased animal-ownership and decreased formal education. Their study in the Mnisi community also found that 96% of animal owners desired education regarding animal diseases[48].

Education programs regarding effective antiparasitic products are sorely needed in many township communities. Products used to control ectoparasites range from carbolic acid based outdoor cleaning solutions (Jeyes fluid) to livestock dips (Diazinon, Amitraz) to carbamate and organophosphate based insecticides to used car oil[4]. Similarly, owners reported using a product called Bob-Martin tablets (containing pyrantal pamoate and niclosamide) for deworming, however no difference in parasite load between treated and non-treated dogs was found[4]. Education regarding basic companion animal keeping is taught by many Animal Welfare organisations who have school outreach programs in the communities they serve. Patients are often brought into welfare hospitals by young children or teenagers, who are solely responsible for their care in the household (personal observation). Education regarding better nutrition and antiparasitic treatments is greatly appreciated by these clients and adherence to treatment plans and return visits are often higher than with adult clients (personal observation).

Focused and practical education programmes can be set up for specific communities based on the relevant parasitic species in that region[7]. Heukelbach et al. (2002) for example, reports that providing education regarding appropriate footwear combined with instructions on how to use anthelmintics is the most effective way to prevent CLM[79]. Bugg et al. (1999) proposes that targeted and strategic treatment and prevention measures tailored to specific parasites species affecting communities and the subsequent disease consequences, will be more effective in prevention while also avoiding the increase of antimicrobial resistance[80].

The role of veterinarians and support staff is also extremely important when it comes to education. Hohn et al. (1992) found that making clients aware of their role in maintaining their pet's health led to increased visits for preventative services, better nutrition choices for dogs and generally an increase in pet body condition and a decrease in parasite burden[81].

Environmental management strategies must also be prioritised for the same reason. An example of this is removing faeces from the yard on a regular basis to decrease the number of viable helminth eggs being maintained in the environment[80]. Another is keeping dogs contained to their owner's property to reduce shedding. Even simple awareness of hand washing, supervision of toddlers when they are interacting with animals, use of antimicrobial hand sanitisers, can help to decrease the risk of zoonotic pathogens.

Financial resources are unquestionably the limiting factor in the ability for animal welfare organisations to instigate real change in the communities they serve. Government funding should be regularly provided; however, this is complicated by a large degree of variation in policies regarding treatment protocol, euthanasia, and adoption for example. Government funding would require standardization and regulation of agencies and their governance, which is a current issue noted by Murray and Thomas (2019)[82].

Conclusion:

The knowledge of parasitic lifecycle patterns, host species and transmission plays a crucial role when developing effective control measures[7].

This review had many limitations, but it highlights the critical need for wider studies in South Africa. There is a geographical research bias as the current literature is mostly focused on studies conducted in the Northeast part of the country, specifically and unsurprisingly, around the South Africa's only veterinary university. The paucity of research in the other provinces is reflected in the results of this study. Given the magnitude of resource-limited and rural communities in South Africa and the comparatively sparse number of parasitic surveys that have been conducted over the last 40 years, it can be concluded that there is a significant gap in this research. The importance of conducting ongoing and current research is highlighted by the ever-increasing discovery of new species and variants of pathogens that have been 'known' for decades. The use of molecular methods is invaluable when establishing taxonomies especially for quickly developing and adapting organisms such as vector-borne pathogens.

Research, collaboration, and education should be the focus of human doctors and veterinarians, as there is an obvious lack of information regarding the epidemiology of widely occurring and preventable zoonotic conditions facing people living in resource-limited environments. It must also be noted that since most of the studies assessing the needs of these communities were conducted over 20 years ago, there should be a renewed focus on this research.

Resource-limited and rural communities in South Africa face unique challenges due to the coexistence of domestic animals, wildlife, and humans. Parasitic species and zoonotic diseases traverse these interconnected networks, underscoring the need for integrated interventions. By adopting a One Health approach, we can address the complexities of disease transmission, foster sustainable coexistence, and improve the health and well-being of animals and people.

Appendix

Table 7

~~A count of V~~Vector borne single and multiple pathogen infections ~~species and combinations of infections~~ found in dogs living in RLC in South Africa

Species	Count
Ehrlichia canis	12
Babesia rossi	12
Anaplasma/Ehrlichia genus-specific	6
Babesia vogeli	5
Rickettsiae species	5
Anaplasma/Ehrlichia genus	4
Ehrlichia ruminantium	4
Anaplasma phagocytophilum	4
Coxiella burnetii	4
Babesia rossi, Ehrlichia canis	3
Rickettsiae africae	3
Theileria species dog	2
Babesia rossi	2
Rickettsiae felis	2
Ehrlichia ruminantium, Ehrlichia canis	2
Babesia species	1
Ehrlichia species	1
Babesia rossi, Ehrlichia canis	1
Babesia rossi, Babesia vogeli	1
Babesia rossi, Babesia vogeli, Ehrlichia canis	1
Babesia gibsoni	1
Babesia rossi, Ehrlichia canis	1
Theileria species dog, Ehrlichia canis	1
Trypanosoma congolense	1
Anaplasma/Ehrlichia species	1
Theileria taurotragi	1
Anaplasma/Ehrlichia genus specific, *Babesia rossi*	1
Theileria/Babesia genus	1
Theileria/Babesia genus, *Ehrlichia canis*	1
Ehrlichia ruminantium, Ehrlichia canis, Babesia vogeli	1
Multiple infection	1
Anaplasma omatjenne	1
Anaplasma/Ehrlichia genus specific, *Ehrlichia ruminantium*	1
Ehrlichia ruminantium, Ehrlichia canis, Babesia rossi	1
Anaplasma/Ehrlichia genus specific, *Ehrlichia canis*	1
Anaplasma/Ehrlichia genus-specific, B1 genus-specific, B2 genus-specific	1
Anaplasma/Ehrlichia genus-specific, B1 genus-specific	1
Anaplasma/Ehrlichia genus specific, *Babesia felis*	1
Anaplasma/Ehrlichia genus-specific, B1 genus-specific, *Ehrlichia canis*	1
Anaplasma/Ehrlichia genus specific, *Ehrlichia canis,* T/B genus specific	1
Anaplasma/Ehrlichia genus specific	1
Anaplasma/Ehrlichia genus-specific, B1 genus-specific, *Babesia rossi*	1

Anaplasma/Ehrlichia genus-specific, Babesia rossi, T/B genus-specific, B1 genus-specific	1
Theileria genus	1

References

1. Molyneux DH (2006) Control of Human Parasitic Diseases: Context and Overview. In: Molyneux DH (ed) Advances in Parasitology. Academic Press, pp 1–45

2. J.G S, Quan Vanessa, Frean John, L K, Rossouw Jennifer, Weyer Jacqueline, Marcotty Tanguy, Godfroid Jacques, H B (2018) Prevalence of Selected Zoonotic Diseases and Risk Factors at a Human-Wildlife-Livestock Interface in Mpumalanga Province, South Africa. Vector-Borne and Zoonotic Diseases. https://doi.org/10.1089/vbz.2017.2158

4. Minnaar WN, Krecek RC (2001) Veterinary needs of dogs in two resource-limited communities in the Gauteng and North West provinces of South Africa. J S Afr Vet Assoc 72:209–213. https://doi.org/10.4102/jsava.v72i4.654

5. Minnaar WN, Krecek RC (2001) Helminths in dogs belonging to people in a resource-limited urban community in Gauteng, South Africa. Onderstepoort Journal of Veterinary Research 111–117

6. LaVallee E, Mueller MK, McCobb E (2017) A Systematic Review of the Literature Addressing Veterinary Care for Underserved Communities. Journal of Applied Animal Welfare Science 20:381–394. https://doi.org/10.1080/10888705.2017.1337515

7. Robertson ID, Irwin PJ, Lymbery AJ, Thompson RCA (2000) The role of companion animals in the emergence of parasitic zoonoses. International Journal for Parasitology 30:1369–1377. https://doi.org/10.1016/S0020-7519(00)00134-X

8. Froberg MK, Dannen D, Bakken JS (2004) Babesiosis and HIV. The Lancet 363:704. https://doi.org/10.1016/S0140-6736(04)15645-6

9. Fung HL, Calzada J, Saldaña A, Santamaria AM, Pineda V, Gonzalez K, Chaves LF, Garner B, Gottdenker N (2014) Domestic dog health worsens with socio-economic deprivation of their home communities. Acta Tropica 135:67–74. https://doi.org/10.1016/j.actatropica.2014.03.010

10. Benitez-Bolivar P, Rondón S, Ortiz M, Díaz-Díaz J, León C, Riveros J, Molina H, González C (2022) Morphological and molecular characterization of the parasite Dipylidium caninum infecting an infant in Colombia: a case report. Parasites Vectors 15:463. https://doi.org/10.1186/s13071-022-05573-4

11. Ojuromi O, Ashafa T (2016) Cryptosporidiosis in southern Africa: review of prevalence and molecular epidemiology. South African Journal of Botany 103:341. https://doi.org/10.1016/j.sajb.2016.02.143

12. Govender T, Barnes JM, Pieper CH (2011) Contribution of Water Pollution From Inadequate Sanitation and Housing Quality to Diarrheal Disease in Low-Cost Housing Settlements of Cape Town, South Africa. Am J Public Health 101:e4–e9. https://doi.org/10.2105/AJPH.2010.300107

13. Eckersley GN, Hohn E, Reyers F, Turner GV, Wolmarans L (1992) A comparison between the disease status of hospitalized dogs from developed and those from developing communities. J S Afr Vet Assoc 63:2–6

14. McCrindle CME Hay IT, Kirkpatrick RD, Odendaal JSJ & Calitz EM (1996) An investigation of the relative morbidity of zoonoses in paediatric patients admitted to Ga-Rankuwa Hospital. Journal of the South African Veterinary Association 67:151–154. https://doi.org/10.10520/AJA00382809_1670

15. Wahlers K, Menezes CN, Wong M, Mogoye B, Frean J, Romig T, Kern P, Grobusch MP (2011) Human cystic echinococcosis in South Africa. Acta Tropica 120:179–184. https://doi.org/10.1016/j.actatropica.2011.08.006

16. Karshima SN, Ahmed MI, Adamu NB, Magaji AA, Zakariah M, Mohammed K (2022) Africa-wide meta-analysis on the prevalence and distribution of human cystic echinococcosis and canine Echinococcus granulosus infections. Parasites Vectors 15:357. https://doi.org/10.1186/s13071-022-05474-6

17. Conan A, Geerdes JAC, Akerele OA, Reininghaus B, Simpson GJG, Knobel D (2017) Census and vaccination coverage of owned dog populations in four resource-limited rural communities, Mpumalanga province, South Africa. J S Afr Vet Assoc 88:. https://doi.org/10.4102/jsava.v88i0.1529

18. Conan A, Akerele O, Simpson G, Reininghaus B, Rooyen J van, Knobel D (2015) Population Dynamics of Owned, Free-Roaming Dogs: Implications for Rabies Control. PLOS Neglected Tropical Diseases 9:e0004177. https://doi.org/10.1371/journal.pntd.0004177

19. Tull A, Valdmann H, Tammeleht E, Kaasiku T, Rannap R, Saarma U (2022) High overlap of zoonotic helminths between wild mammalian predators and rural dogs – an

emerging One Health concern? Parasitology 149:1565–1574. https://doi.org/10.1017/S0031182022001032

20. Amidou S, Machuene AT, Pascal B (2013) The epidemiology of cryptosporidium in cats and dogs in the Thohoyandou region, South Africa. Afr J Microbiol Res 7:2510–2518. https://doi.org/10.5897/AJMR12.1391

21. Morters MK, Archer J, Ma D, Matthee O, Goddard A, Leisewitz AL, Matjila PT, Wood JLN, Schoeman JP (2020) Long-term follow-up of owned, free-roaming dogs in South Africa naturally exposed to Babesia rossi. International Journal for Parasitology 50:103–110. https://doi.org/10.1016/j.ijpara.2019.11.006

22. Berrian AM, Smith MH, van Rooyen J, Martínez-López B, Plank MN, Smith WA, Conrad PA (2018) A community-based One Health education program for disease risk mitigation at the human-animal interface. One Health 5:9–20. https://doi.org/10.1016/j.onehlt.2017.11.002

23. Froeschke G, Matthee S (2014) Landscape characteristics influence helminth infestations in a peri-domestic rodent - implications for possible zoonotic disease. Parasit Vectors 7:393. https://doi.org/10.1186/1756-3305-7-393

24. Collyer BS, Truscott JE, Mwandawiro CS, Njenga SM, Anderson RM (2023) How important is the spatial movement of people in attempts to eliminate the transmission of human helminth infections by mass drug administration? Phil Trans R Soc B 378:20220273. https://doi.org/10.1098/rstb.2022.0273

25. Daszak P, Cunningham AA, Hyatt AD (2000) Emerging Infectious Diseases of Wildlife-- Threats to Biodiversity and Human Health. Science 287:443–449. https://doi.org/10.1126/science.287.5452.443

26. Viljoen S, O'Riain MJ, Penzhorn BL, Drouilly M, Serieys LEK, Cristescu B, Teichman KJ, Bishop JM (2020) Molecular detection of tick-borne pathogens in caracals (*Caracal caracal*) living in human-modified landscapes of South Africa. Parasites Vectors 13:220. https://doi.org/10.1186/s13071-020-04075-5

27. Kolo AO, Collins NE, Brayton KA, Chaisi M, Blumberg L, Frean J, Gall CA, M. Wentzel J, Wills-Berriman S, Boni LD, Weyer J, Rossouw J, Oosthuizen MC (2020) Anaplasma phagocytophilum and Other Anaplasma spp. in Various Hosts in the Mnisi

Community, Mpumalanga Province, South Africa. Microorganisms 8:1812. https://doi.org/10.3390/microorganisms8111812

28. Sykes JE (2013) Canine and Feline Infectious Diseases. Elsevier Health Sciences

29. Zygner W, Gójska-Zygner O, Bartosik J, Górski P, Karabowicz J, Kotomski G, Norbury LJ (2023) Canine Babesiosis Caused by Large Babesia Species: Global Prevalence and Risk Factors—A Review. Animals 13:2612. https://doi.org/10.3390/ani13162612

30. Baneth G, Nachum-Biala Y, Birkenheuer AJ, Schreeg ME, Prince H, Florin-Christensen M, Schnittger L, Aroch I (2020) A new piroplasmid species infecting dogs: morphological and molecular characterization and pathogeny of Babesia negevi n. sp. Parasites & Vectors 13:130. https://doi.org/10.1186/s13071-020-3995-5

31. Allan RE (2017) The occurrence of tick-borne pathogens, in dogs in welfare organisations and townships of Cape Town

32. Jacobson LS (2006) The South African form of severe and complicated canine babesiosis: Clinical advances 1994–2004. Veterinary Parasitology 138:126–139. https://doi.org/10.1016/j.vetpar.2006.01.047

33. Penzhorn BL (2020) Don't let sleeping dogs lie: unravelling the identity and taxonomy of Babesia canis, Babesia rossi and Babesia vogeli. Parasites Vectors 13:184. https://doi.org/10.1186/s13071-020-04062-w

34. Penzhorn BL (2011) Why is Southern African canine babesiosis so virulent? An evolutionary perspective. Parasites & Vectors 4:51. https://doi.org/10.1186/1756-3305-4-51

35. Bosman A-M, Penzhorn BL, Brayton KA, Schoeman T, Oosthuizen MC (2019) A novel Babesia sp. associated with clinical signs of babesiosis in domestic cats in South Africa. Parasites Vectors 12:138. https://doi.org/10.1186/s13071-019-3395-x

36. Husin NA, AbuBakar S, Khoo JJ (2021) Current tools for the diagnosis and detection of spotted fever group Rickettsia. Acta Tropica 218:105887. https://doi.org/10.1016/j.actatropica.2021.105887

37. Kolo AO, Sibeko-Matjila KP, Maina AN, Richards AL, Knobel DL, Matjila PT (2016) Molecular Detection of Zoonotic Rickettsiae and *Anaplasma* spp. in Domestic Dogs and Their Ectoparasites in Bushbuckridge, South Africa. Vector-Borne and Zoonotic Diseases 16:245–252. https://doi.org/10.1089/vbz.2015.1849

38. Wyk C-LV, Mtshali K, Taioe MO, Terera S, Bakkes D, Ramatla T, Xuan X, Thekisoe O (2022) Detection of Ticks and Tick-Borne Pathogens of Urban Stray Dogs in South Africa. Pathogens 11:862. https://doi.org/10.3390/pathogens11080862

39. Mtshali K, Nakao R, Sugimoto C, Thekisoe O (2017) Occurrence of Coxiella burnetii, Ehrlichia canis, Rickettsia species and Anaplasma phagocytophilum-like bacterium in ticks collected from dogs and cats in South Africa. Journal of the South African Veterinary Association 88:1–6. https://doi.org/10.4102/jsava.v88i0.1390

40. Inokuma H, Oyamada M, Kelly PJ, Jacobson LA, Fournier P-E, Itamoto K, Okuda M, Brouqui P (2005) Molecular Detection of a New Anaplasma Species Closely Related to Anaplasma phagocytophilum in Canine Blood from South Africa. Journal of Clinical Microbiology 43:2934–2937. https://doi.org/10.1128/jcm.43.6.2934-2937.2005

41. Kolo A (2023) Anaplasma Species in Africa—A Century of Discovery: A Review on Molecular Epidemiology, Genetic Diversity, and Control. Pathogens 12:702. https://doi.org/10.3390/pathogens12050702

42. Esemu SN, Ndip LM, Ndip RN (2011) Ehrlichia species, probable emerging human pathogens in sub-Saharan Africa: environmental exacerbation. Reviews on Environmental Health 26:. https://doi.org/10.1515/REVEH.2011.034

43. Themes UFO (2016) Babesiosis. In: Veterian Key. https://veteriankey.com/babesiosis/. Accessed 13 Nov 2023

44. Pretorius A-M, Kelly PJ (1998) Serological survey for antibodies reactive with Ehrlichia canis and E. chaffeensis in dogs from the Bloemfontein area, South Africa. J S Afr Vet Assoc 69:126–128. https://doi.org/10.4102/jsava.v69i4.840

45. Rosa CT, Pazzi P, Nagel S, McClure V, Christie J, Troskie M, Dvir E (2014) Theileriosis in six dogs in South Africa and its potential clinical significance. J S Afr Vet Assoc 85:7 pages. https://doi.org/10.4102/jsava.v85i1.1114

46. Life Cycle. http://www.antimicrobe.org/Lifecycle/b68lc.asp. Accessed 4 Nov 2023

47. Ngcamphalala PI, Lamb J, Mukaratirwa S (2020) Molecular identification of hookworm isolates from stray dogs, humans and selected wildlife from South Africa. Journal of Helminthology 94:e39. https://doi.org/10.1017/S0022149X19000130

48. Berrian AM, Van Rooyen J, Martínez-López B, Knobel D, Simpson GJG, Wilkes MS, Conrad PA (2016) One Health profile of a community at the wildlife-domestic animal interface, Mpumalanga, South Africa. Preventive Veterinary Medicine 130:119–128. https://doi.org/10.1016/j.prevetmed.2016.06.007

49. Hossain M, Bhuiyan MdJU (2016) Hookworm Infection: A Neglected Tropical Disease of Mankind. J Inf Mol Biol 4:24–43. https://doi.org/10.14737/journal.jimb/2016/4.2.24.43

50. Chidumayo NN (2018) Epidemiology of canine gastrointestinal helminths in sub-Saharan Africa. Parasites Vectors 11:100. https://doi.org/10.1186/s13071-018-2688-9

51. Bowman DD, Montgomery SP, Zajac AM, Eberhard ML, Kazacos KR (2010) Hookworms of dogs and cats as agents of cutaneous larva migrans. Trends in Parasitology 26:162–167. https://doi.org/10.1016/j.pt.2010.01.005

52. Daba M, Naramo M, Haile G (2021) Current Status of Ancylostoma Species in Domestic and Wild Animals and Their Zoonotic Implication: Review. AVS 9:107. https://doi.org/10.11648/j.avs.20210904.14

53. Ng-Nguyen D, Hii SF, Nguyen V-AT, Van Nguyen T, Van Nguyen D, Traub RJ (2015) Re-evaluation of the species of hookworms infecting dogs in Central Vietnam. Parasites & Vectors 8:401. https://doi.org/10.1186/s13071-015-1015-y

54. Estrada-Peña A, Bouattour A, Camicas J, Walker A (2004) Tiques d’importance médicale et vétérinaire: le bassin méditerranéen. ICTTD CD-ROM, Mediterraneans ticks. 3-12, 12.

55. Gray J, Dantas-Torres F, Estrada-Peña A, Levin M (2013) Systematics and ecology of the brown dog tick, Rhipicephalus sanguineus. Ticks and Tick-borne Diseases 4:171–180. https://doi.org/10.1016/j.ttbdis.2012.12.003

56. Rautenbach GH Boomker, J & De Villiers IL (1991) A descriptive study of the canine population in a rural town in southern Africa. Journal of the South African Veterinary Association 62:158–162. https://doi.org/10.10520/AJA00382809_1416

57. Ackermann R (2019) Bacterial microbiome of *Rhipicephalus sanguineus* ticks collected from dogs in the Mnisi community, South Africa

58. Bryson NR, Horak IG, Höhn EW, Louw JP (2000) Ectoparasites of dogs belonging to people in resource-poor communities in North West Province, South Africa. J S Afr Vet Assoc 71:175–179. https://doi.org/10.4102/jsava.v71i3.709

59. Allsopp MTEP, Allsopp BA (2001) Novel Ehrlichia Genotype Detected in Dogs in South Africa. J Clin Microbiol 39:4204–4207. https://doi.org/10.1128/JCM.39.11.4204-4207.2001

60. Apanaskevich DA, Horak IG, Camicas J-L (2007) Redescription of *Haemaphysalis* (*Rhipistoma) elliptica* (Koch, 1844), an old taxon of the *Haemaphysalis (Rhipistoma) leachi* group from East and southern Africa, and of *Haemaphysalis (Rhipistoma) leachi* (Audouin, 1826) (Ixodida, Ixodidae). Onderstepoort Journal of Veterinary Research 74:181–208. https://doi.org/10.10520/EJC86301

61. Penzhorn BL, Harrison-White RF, Stoltsz WH (2020) Completing the cycle: *Haemaphysalis elliptica*, the vector of Babesia rossi, is the most prevalent tick infesting black-backed jackals (*Canis mesomelas*), an indigenous reservoir host of B. rossi in South Africa. Ticks and Tick-borne Diseases 11:101325. https://doi.org/10.1016/j.ttbdis.2019.101325

64. Minnaar N, Krecek R, Schwan V (1998) Helminth parasites of dogs from two resource - limited communities in South Africa. Parasitology International 47:191. https://doi.org/10.1016/S1383-5769(98)80488-1

65. Baker' MK, Lange L, Verster A (1989) A SURVEY OF HELMINTHS IN DOMESTIC CATS IN THE PRETORIA AREA OF TRANS- VAAL, REPUBLIC OF SOUTH AFRICA, PART 1: THE PREVALENCE AND COMPARISON OF BURDENS OF HELMINTHS IN ADULT AND JUVENILE CATS. Journal of the South African veterinary Association 60:139–142

66. Schwan EV, Miller DB, De KD (2000) *Dirofilaria repens* in a cat with acute liver failure. Journal of the South African Veterinary Association 71:197–200. https://doi.org/10.10520/EJC99351

67. Verster A GASTRO-INTESTINAL HELMINTHS OF DOMESTIC DOGS IN THE REPUBLIC OF SOUTH AFRICA. Onderstepoort J vet Res, 46, 79-82 (1979)

68. Mukaratirwa S, Singh VP (2010) Prevalence of gastrointestinal parasites of stray dogs impounded by the Society for the Prevention of Cruelty to Animals (SPCA), Durban and Coast, South Africa. Journal of the South African Veterinary Association 81:123–125

69. Rothmann W, De Waal PJ (2017) Diversity of Spirocerca lupi in domestic dogs and black-backed jackals (*Canis mesomelas*) from South Africa. Veterinary Parasitology 244:59–63. https://doi.org/10.1016/j.vetpar.2017.07.026

70. Espinaze MPA, Hellard E, Horak IG, Cumming GS (2016) Analysis of large new South African dataset using two host-specificity indices shows generalism in both adult and larval ticks of mammals. Parasitology 143:366–373. https://doi.org/10.1017/S0031182015001730

72. Matjila PT, Leisewitz AL, Jongejan F, Penzhorn BL (2008) Molecular detection of tick-borne protozoal and ehrlichial infections in domestic dogs in South Africa. Veterinary Parasitology 155:152–157. https://doi.org/10.1016/j.vetpar.2008.04.012

73. Mofokeng LS, Taioe OM, Smit NJ, Thekisoe OMM (2020) Parasites of veterinary importance from domestic animals in uMkhanyakude district of KwaZulu-Natal province. J S Afr Vet Assoc 91:. https://doi.org/10.4102/jsava.v91i0.2023

74. Bosman A-M, Venter EH, Penzhorn BL (2007) Occurrence of *Babesia felis* and *Babesia leo* in various wild felid species and domestic cats in Southern Africa, based on reverse line blot analysis. Veterinary Parasitology 144:33–38. https://doi.org/10.1016/j.vetpar.2006.09.025

75. Bosman A-M, Oosthuizen MC, Venter EH, Steyl JC, Gous TA, Penzhorn BL (2013) *Babesia lengau* associated with cerebral and haemolytic babesiosis in two domestic cats. Parasites Vectors 6:128. https://doi.org/10.1186/1756-3305-6-128

76. Minnaar WN, Krecek RC, Fourie LJ (2002) Helminths in dogs from a peri-urban resource-limited community in Free State Province, South Africa. Veterinary Parasitology 107:343–349. https://doi.org/10.1016/S0304-4017(02)00155-3

77. Matthee S, Lovely C, Gaugler A, Beeker R, Venter HR, Horak IG (2010) Ixodid ticks on domestic dogs in the Northern Cape Province of South Africa and in Namibia. Journal of the South African Veterinary Association 81:126–128

78. Appleton CC (2017) Nematode Parasites of Humans in South Africa. In: Fourie H, Spaull VW, Jones RK, Daneel MS, De Waele D (eds) Nematology in South Africa: A View from the 21st Century. Springer International Publishing, Cham, pp 521–558

79. Heukelbach J, Mencke N, Feldmeier H (2002) Editorial: Cutaneous larva migrans and tungiasis: the challenge to control zoonotic ectoparasitoses associated with poverty. Trop Med Int Health 7:907–910. https://doi.org/10.1046/j.1365-3156.2002.00961.x

80. Bugg RJ, Robertson ID, Elliot AD, Thompson RCA (1999) Gastrointestinal Parasites of Urban Dogs in Perth, Western Australia. The Veterinary Journal 157:295–301. https://doi.org/10.1053/tvjl.1998.0327

81. Hohn E.W.; Williams J.H.; Kirkpatrick R.D (1992) A qualitative study of the attitudes of members of a developing community towards their dogs and veterinary services. Journal of the South African veterinary Association1992 63:121–124

82. Murray C, Thomas A (2019) Perceptions of governance in the animal welfare sector. AJOBE 13:. https://doi.org/10.15249/13-2-222

83. Fourie LJ, Kok DJ, Van Zyl W, Horak IG (2002) Hosts, seasonal occurrence and life cycle of *Rhipicentor nuttalli* (Acari: Ixodidae). Onderstepoort Journal of Veterinary Research 69:177–187

84. Penzhorn BL, Oosthuizen MC (2020) *Babesia* Species of Domestic Cats: Molecular Characterization Has Opened Pandora's Box. Front Vet Sci 7:134. https://doi.org/10.3389/fvets.2020.00134

85. Matthee S, Van Der Mescht L, Wilson B, Lamberski N (2011) Flea diversity on small carnivores in the Northern Cape Province, South Africa. African Zoology 46:27–31. https://doi.org/10.1080/15627020.2011.11407475

86. McCrindle CM, Tice G, Mogajane ME, Stewart CG, Mosupi H (1994) An investigation into the potential veterinary needs of a semi-rural low-income community. J S Afr Vet Assoc 65:90–96

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Statements

UNIVERSITY OF VETERINARY MEDICINE, BUDAPEST
founded in 1787, EU-accredited since 1995

INTERNATIONAL STUDY PROGRAMS
secretary, student@univet.hu

Thesis progress report for veterinary students

Name of student: LISE ANNE VAN DER ELST

Neptun code of the student: RAV30K

Name and title of the supervisor: SANDOR SZEKERES PHD

Department: PARASITOLOGY AND ZOOLOGY

Thesis title: PARASITE SPECIES AFFECTING COMPANION ANIMALS IN CAPE TOWN

Consultation – 1st semester

	Timing			Topic / Remarks of the supervisor	Signature of the supervisor
	year	month	day		
1.	2023	01	11	THESIS TOPIC MEETING	
2.	2023	02	01	OUTLINE OF THE THESIS	
3.	2023	02.	22	LITERATURE PROGRESS	
4.	2023	03.	29	– II –	
5.	2023	05.	02	– II –	

Grade achieved at the end of the first semester: 5

Consultation – 2nd semester

	Timing			Topic / Remarks of the supervisor	Signature of the supervisor
	year	month	day		
1.	2023	08	22	EMAIL CONSULTATION	
2.					
3.					
4.					

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