Prevalence and control of brucellosis in Zimbabwe, risk factors, and challenges for control: A Review

T. A. Chari[1*], C. Gufe[2], P. Kayoka[3], R. Gabriel[2], S. Manatsa[4], B. Mbonjani[2], J. Marumure[5], Z. Makuvara[5], P. V. Makaya[2], C. Mupungani[6]

[1]Department of Biotechnology and Biochemistry, Faculty of Science, University of Zimbabwe, P.O. Box MP 167, Mount Pleasant, Harare, Zimbabwe.
[2] Department of Veterinary Technical Services, Central Veterinary Laboratories, Box CY55, 18A Borrowdale Road, Harare, Zimbabwe.
[3]Department of Agriculture and Animal Health, Unisa, Pretoria, South Africa
[4]Division of Veterinary Services, Epidemiology, P.O. Box 72, Gweru, Zimbabwe
[5]School of Natural Sciences, Great Zimbabwe University, Off Old Great Zimbabwe Road, P. Bag 1235, Masvingo, Zimbabwe.
[6]National Institute of Health Research, Ministry of Health and Child Care, Corner Josiah Tongogara and Mazowe Street, Harare, Zimbabwe.

[*]Corresponding author: tawandaachari@gmail.com

ORCID: https://orcid.org/0000-0002-7920-9258

Article history

Submitted: 19-09- 2023, Revised: 23-10-2023, Accepted: 09-01-2024, Published: 16-01-2024

Tanzania Veterinary Journal Vol. 38(1) 2023 ***https://dx.doi.org/10.4314/tvj.v38i1.2***

Prevalence and control of brucellosis in Zimbabwe, risk factors, and challenges for control: A Review

T. A. Chari[1*], C. Gufe[2], P. Kayoka[3], R. Gabriel[2], S. Manatsa[4], B. Mbonjani[2], J. Marumure[5], Z. Makuvara[5], P. V. Makaya[2], C. Mupungani[6]

[1]Department of Biotechnology and Biochemistry, Faculty of Science, University of Zimbabwe, P.O. Box MP 167, Mount Pleasant, Harare, Zimbabwe.
[2] Department of Veterinary Technical Services, Central Veterinary Laboratories, Box CY55, 18A Borrowdale Road, Harare, Zimbabwe.
[3]Department of Agriculture and Animal Health, Unisa, Pretoria, South Africa
[4]Division of Veterinary Services, Epidemiology, P.O. Box 72, Gweru, Zimbabwe
[5]School of Natural Sciences, Great Zimbabwe University, Off Old Great Zimbabwe Road, P. Bag 1235, Masvingo, Zimbabwe.
[6]National Institute of Health Research, Ministry of Health and Child Care, Corner Josiah Tongogara and Mazowe Street, Harare, Zimbabwe.

[*]Corresponding author: tawandaachari@gmail.com
ORCID link: https://orcid.org/0000-0002-7920-9258

SUMMARY
Brucellosis is an infectious zoonotic disease caused by *Brucella* species. The disease affects both animals and humans and if left unmonitored can be a major public health issue in Zimbabwe. The review was conducted using internet databases PubMed, Google Scholar, HINARI, and unpublished stored data at the Central Veterinary Laboratory of Zimbabwe. A total of 19 scientific publications were reviewed, with 18 being full-length journal papers and one PhD dissertation. Despite the lack of an adequate national-wide surveillance strategy, brucellosis is considered endemic in Zimbabwe, with an estimated prevalence of 11.44% in cattle and 4.04% in wildlife. In cattle, commercial herds accounted for the most prevalence and most tested samples, while small-holder or communal herds had low prevalence and fewer tested samples. *Brucella abortus*, *B. melitensis*, *B. ovis*, *B. canis*, and *B. suis* are some of the *Brucella* species circulating in Zimbabwe. Consumption of unpasteurized milk and dairy products, intimate contact with diseased animals, and insufficient veterinary services are all risk factors for brucellosis transmission in Zimbabwe. In Zimbabwe, brucellosis control faces challenges, namely insufficient resources, inadequate surveillance strategies, and a lack of public knowledge and education about the disease. Furthermore, insufficient diagnostic facilities and a scarcity of vaccinations for both animals impede disease control. Increased funds and resources are needed in Zimbabwe to expand surveillance, strengthen veterinary services, and promote public awareness and education about brucellosis. This review aimed at providing an overview of the prevalence and control of brucellosis in Zimbabwe, including its risk factors and the challenges associated with controlling brucellosis as well as identifying knowledge gaps and potential future research perspectives.

***Keywords*:** Brucellosis; Zimbabwe; Prevalence, Control, Risk Factors.

INTRODUCTION

Brucellosis is a highly contagious zoonotic infectious bacterial disease caused by facultative intracellular Gram-negative coccobacilli species of *Brucella* (Bergey and Holt , 1993). Brucellosis is a major problem in many low-income Sub-Saharan African countries, including Zimbabwe, where it affects both humans and animals (Gadaga *et al.* , 2016, Ducrotoy *et al.* , 2017).

The disease is frequently associated with stillbirth/abortions in animals, but in people, it is known as undulating fever, Mediterranean fever, or Malta fever named after the island of Malta, where it was initially detected (Corbel , 1997). Brucellosis is a significant problem in many low-income Sub-Saharan African countries mostly owing to a lack of distinct awareness to distinguish

it from other zoonotic infectious illnesses seen in Africa's wildlife-livestock interfaces/systems and due to a lack of active surveillance. Lack of active surveillance contributes to underreporting of brucellosis prevalence, and investment in innovative therapies such as vaccine production (McDermott and Arimi , 2002, McDermott *et al.* , 2013, Ducrotoy *et al.* , 2017). The above is aggravated by the lack of public understanding of brucellosis in Sub-Saharan African countries, particularly in the dairy industry (McDermott and Arimi , 2002, Ducrotoy *et al.* , 2017).

Additionally, animal migration across countries and conservation areas has significantly contributed to the spread of brucellosis in Zimbabwe (Muma *et al.* , 2007, Matope *et al.* , 2011, Gadaga *et al.* ,2016). Furthermore, Brucellosis has infected both commercial and communal farming systems in most sections of Zimbabwe where the ranching system is divided into commercial (dairy and beef) and small-scale/communal sectors with the later mainly comprising rural homesteads of less than 100 hectares. All farms under the commercial bracket include those ranches that have more than 100 hectares of grazing land for animals. Smallholder farmers use cattle for subsistence, trading, transportation, manure, drought power, and dairy production (Madsen and Anderson , 1995, Mohan *et al.* , 1996).

The risk and severity of the disease is much more higher in small scale production systems due to limited availability of grazing pastures, and veterinary practices and can lead to the reduction of the number of animals per homestead (Matope *et al.* , 2010). As a coping strategy, some farmers have switched to mixed farming and raise both large and small stock ruminants on the same farm. However, the practice increases the risk of brucellosis spreading from one host to another. For instance, cattle can serve as secondary hosts for *B. melitensis*, whereas small ruminants like goats can serve as primary hosts. In general, infected animals may not show any early symptoms of the disease, making control and prevention difficult (Mohan *et al.* , 1996, Corbel , 1997, Matope , 2008, Mosalagae *et al.* , 2011).

Further issues with brucellosis pervasiveness occurred as a result of the proximity of certain Trans-Frontier Conservation Areas to communal lands (Mohan *et al.* , 1996, Gadaga *et al.* , 2016), hence transferring brucellosis and other zoonotic diseases at wildlife/livestock/human interfaces. This can also be amplified through movement of unvaccinated livestock between farms, and the sharing of grazing lands and drinking water with wildlife (Matope *et al.* , 2010, 2011, Gomo *et al.* , 2012, Ndengu *et al.* , 2017). Efforts aimed at controlling the disease such as vaccinations, and contagious abortion certification programme are questionable in terms of efficience in controlling, and or eradicating brucellosis. Even though there is an epidemiological relationship between animals, cattle, and people, the processes and factors influencing brucellosis transmission in Zimbabwe have not been adequately investigated. This gap in knowledge has prompted the need to assess the present state of brucellosis in Zimbabwe, emphasizing accurate diagnosis, effective control techniques, and public awareness. Therefore, this review provides an overview of the epidemiology of brucellosis in Zimbabwe, the challenges associated with controlling brucellosis, and future research perspectives.

MATERIALS AND METHODS

This review included all the studies conducted in Zimbabwe on brucellosis in both domesticated and wildlife animals as well as humans. The goal of this analysis was to map the brucellosis environment in Zimbabwe. Thus, regardless of the publication year, research methodology, or environment (field or other), only papers that addressed members of the *Brucella* genus were included. There was both quantitative and qualitative research. Studies were also included without taking their calibre into account. The assessment did not include studies that used biological samples from Zimbabwe for diagnostic test evaluation or other scientific reasons carried out by researchers overseas. According to Zimbabwean guidelines, ethical approval was not needed for this animal-based review article.

Searching strategy

While searching the databases, keywords included combinations of terms such as "(brucellosis OR contagious abortion OR malta fever OR Brucella) AND (prevalence OR control OR diagnosis OR transmission OR vaccination OR treatment OR surveillance OR epidemiology OR one health) AND (humans OR public health OR animals OR livestock farming OR dairy products OR wildlife) AND Zimbabwe OR Rhodesia". Abstracts, full-length research articles, and review papers written in English were all considered. To find relevant articles, we searched PUBMED, Google Scholar, African Journals Online, and HINARI using the abovementioned keywords. To determine eligibility, full versions of articles that might apply were obtained, considered and analysed for inclusion. Data was collected from each publication separately and entered into a harmonised Table in MS Word. We extracted information about brucellosis prevalence and Brucella species isolated from the text, tables, and figures. Figure 1 depicts the article search, eligibility examination, and inclusion in this review.

Extracting and charting the results

The method of data extraction and charting involves reading the whole text of each article chosen for inclusion in the review and collecting pertinent information using a standardized data extraction/coding form. Basic information intended for narrative reporting was coded for this evaluation, and the targeted concepts were the focus of some analysis, data extraction, and graphing. Basic data extractions for each article include the study's location, author, publication year, goals, methodology, demographics, sample size, outcome measure, and key conclusions. The analytical data extraction and charting also allowed for enhanced mapping of the brucellosis disease burden, transmission risk factors, and management strategies, among others.

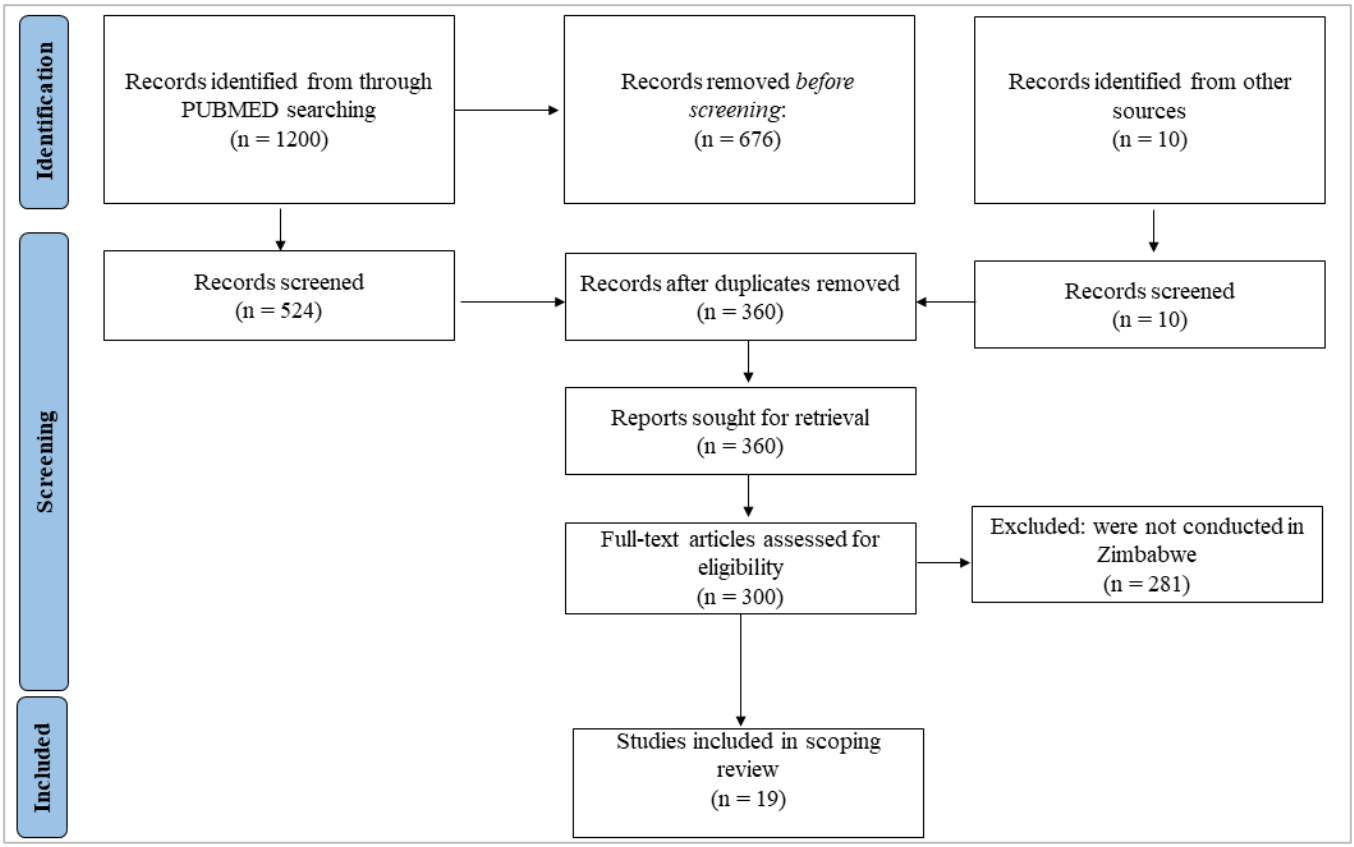

Figure 1. The flow diagram used for the literature search and review of articles related to cases of brucellosis in Zimbabwe (formerly Rhodesia).

RESULTS

From the original number of papers found on the databases, the review only aimed at those that were originally done in Zimbabwe and not extensions of data from another paper. A total of 19 scientific publications published from 1996 to date were reviewed (Mohan *et al.* , 1996, Matope , , 2019, , 2009, , 2010, Gomo , 2010, Matope *et al.* , 2011, Matope *et al.* , 2011, Matope, *et al.* , 2011, Mosalagae *et al.* , 2011, Gomo *et al.* , 2012, Gomo *et al.* , 2012, Motsi *et al.* , 2013, Gadaga *et al.* , 2014, , 2016, Ducrotoy *et al.* , 2017, Ndengu *et al.* , 2017, Vhoko *et al.* , 2018, Bhandi *et al.* , 2019). Of the 19 reviewed publications, 18 were full-length journal papers and one was a PhD dissertation. Of the studies published in Zimbabwe, most of them were done at the livestock/wildlife/human interfaces and there were 22 study sites (Figure 2). Most studies were done in the southeastern lowveld of Zimbabwe close to Gonarezhou National Park and other wildlife conservancies where some of the highest prevalence rates were recorded in the country.

The lack of more study sites around the country could be because of a lack of adequate funding for research in those areas or just general neglect of most researchers owing to the convenience of their location. This has affected the prevalence numbers that the Central Veterinary Laboratory of Zimbabwe has since it is now solely relying on those farmers who are financially capable of having their livestock tested and that data has also been incorporated in this review to give a general idea of brucellosis prevalence in the country (Table 1). Of the studies conducted in Zimbabwe on zoonotic diseases, none of them were state funded indicating that there has never been a surveillance team put in place to monitor brucellosis in the country.

Brucellosis Prevalence in Zimbabwe

Brucellosis has a broad prevalence pattern in Zimbabwe, with a higher prevalence in the communal/smallholder sector than in the commercial sector (Vhoko *et al.* , 2018). Annual fluctuations in brucellosis prevalence were more prevalent in cattle than in smaller ruminants (Table 1), according to routine serological testing. Variations in brucellosis may be due to ecological factors and management practices (Gadaga *et al.* , 2014, , 2016). Data for 2020, 2021, and 2022 were omitted due to COVID-19 lockdowns. Younger cows (aged 2 to 4 years) were noted to have a higher risk of seropositivity to the disease (Vhoko *et al.*, 2018, Bhandi *et al.* , 2019). There is a greater danger of zoonotic disease transmission among communally owned cattle due to wildlife proximity to grazing areas (Gomo *et al.* , 2012, Gadaga *et al.* , 2016). The closeness of some Trans-Frontier Conservation Areas with communal lands has further aided in the pervasive behaviour of brucellosis (Gadaga *et al.* , 2016), transmitting it among other zoonotic diseases that affect animals and eventually pass to humans. In studies using conventional serological testing by RBT and CFT, brucellosis was more frequent in individual cattle in communal areas close to conservation areas, with the frequency fluctuating yearly (Gadaga *et al.* , 2014, , 2016, Zengeya *et al.* , 2015, Ndengu *et al.* , 2017, Vhoko *et al.* , 2018, Bhandi *et al.* , 2019).

Over the years, the prevalence of bovine brucellosis has averaged in the range of 4.0–41.0% globally (Smits and Cutler , 2004), with the prevalence range values seemingly applicable for Zimbabwe (Gomo *et al.* , 2012, Gomo *et al.* , 2012, Ducrotoy *et al.* , 2017, Ndengu *et al.* , 2017, Vhoko *et al.* , 2018). However, previous studies in Zimbabwe (from 1996) indicated that commercial herds account for 10.0-53.0% of the total brucellosis prevalence, with small-holder or communal herds constituting 0.0-16.0% (Table 1). The high prevalence rates in the country can be attributed to farmers not vaccinating their cattle with the available vaccines due to a lack of finances. Subsequent research, however, revealed an 8.3% seroprevalence for the latter (Vhoko *et al.* , 2018). However, many recent studies into the zoonotic disease's prevalence ranged from 8 to 40% in communal dairy farms in select areas across the country (Matope *et al.* , 2010), with unpublished data from the country's Central Veterinary Laboratory (C.V.L) confirming some of the prevalence values published in the literature. However, data on the prevalence of brucellosis in livestock, wildlife, and humans are limited,

with most research focusing on cattle, limiting data on the nationwide incidence of brucellosis in small ruminants and other species.

The individual animal brucellosis prevalence in the country for the different production systems was found out to be (P = 8.7%; 95% C.I.: 7.6 - 9.8%) for communal and smallholder farms, (P = 16%; 95% C.I.: 14.5 - 17.5%) for samples from the country's CVL, (P = 2.3%; 95% C.I.: 1.3 - 3.3%) for wildlife areas and (P = 24.9%: 95% C.I.: 22.8 - 27.0%) for the commercial farms. This shows that commercial herds of cattle had a higher seropositivity than most of the samples included in the study, evidently indicating a higher risk of brucellosis seropositivity in commercial herds than in smallholder and communal herds. The overall brucellosis prevalence in the country can be pegged at 14% (95% C.I.: 13.5 – 14.5%), for all the cases that have been recorded in the country so far. This highlights the need for consistent surveillance and stakeholder education on zoonotic diseases and their risks in the country.

Brucella species detected and confirmed in Zimbabwe

Several members of the genus *Brucella* have been isolated and identified in Zimbabwe using cultural and molecular techniques. Some of the isolated strains were sequenced and identified down to their respective biovars, while most were only identified using culture and biochemical characterisation methods available in the country, with the main species being *B. abortus*, *B. melitensis,* and *B. suis* (Matope *et al.* , 2009, Ledwaba *et al.* , 2014, , 2019). *Brucella abortus* biovar1 was identified by culture, dye inhibition, phage typing, oxidative metabolic test, and agglutination with monospecific sera from stomach contents and cotyledons (Mohan *et al.*, 1996). In addition, *Brucella abortus* was isolated from blood and milk from seropositive cows in the Chiredzi communal areas (Gomo, Musari, *et al.* , 2012) and subsequently identified using the *Brucella*-specific 16-23S intergenic spacer (ITS) PCR and multiplex AMOS-PCR assays as shown in Table 2.

This isolation of *B. abortus* in cattle on community farms in Zimbabwe's Chiredzi area indicated a substantial public and animal health risk in wildlife/livestock/human interactions (Table 2). *Brucella* isolates have been biochemically characterized in Zimbabwe and assigned to different biovars. The isolates were identified as *B. abortus* biovar 1 (Condy and Vickers , 1972, Mohan *et al.* , 1996, Matope *et al.* , 2009), *B. abortus* biovar 2 (Matope *et al.* , 2009), *B. melitensis* biovar1 (Condy and Vickers , 1972, Matope *et al.* , 2009), and *B. suis* (Ledwaba *et al.* , 2014, , 2019).

Another study in Zimbabwe employed whole-genome sequencing to confirm the presence of *B. abortus* and *B. suis* in cattle (Ledwaba *et al.* , 2014), with *B. canis* and *B. ovis* being characterized through molecular methods (Ledwaba *et al.* , 2019). Although *B. abortus biovar1* was initially isolated from prematurely aborted fetuses (Madsen and Anderson , 1995, Mohan *et al.* , 1996), the same biovar later resurfaced in Hwange National Park from a premature birth of a waterbuck and eland hygroma liquid on a game ranch (Corbel *et al.* , 2006). *B. abortus* biovar2 was recovered from a premature birth in cattle (Matope *et al.* , 2009), while *B. melitensis* was obtained from a goat herd that originated in Mozambique. *B. abortus* has also been identified as the pathogen responsible for bovine brucellosis in Zimbabwe (Madsen and Anderson , 1995), with *B. abortus* biovar 1 the most likely common cause of brucellosis in smallholder cattle.

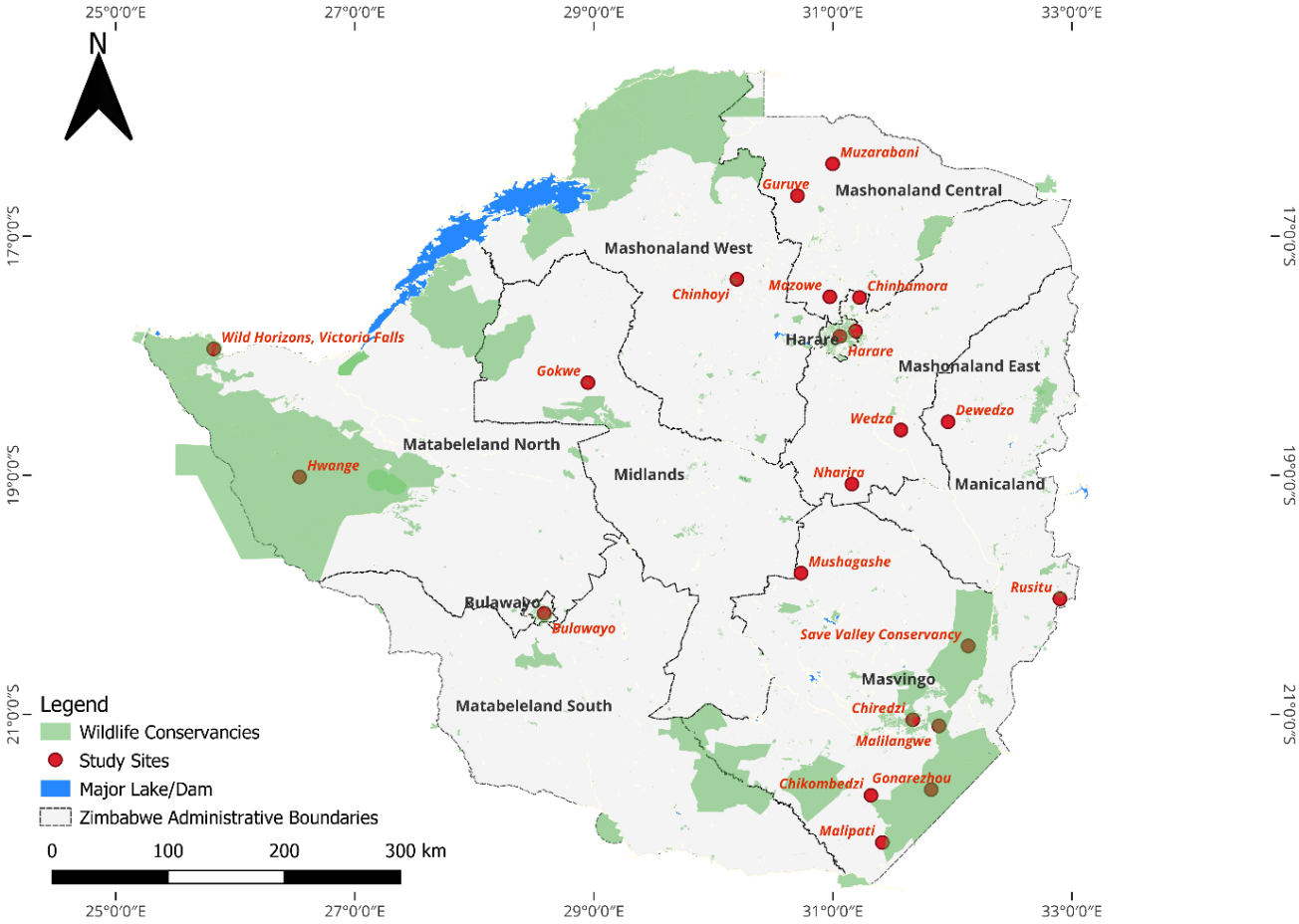

Figure 2. Based on the reviewed literature, a map of Zimbabwe was created that depicts the areas where Brucellosis has been researched.

Table 1. Individual *Brucella* seropositivity of animals in Zimbabwe.

Province	Production System	Sampling	DT (antigen/cut-off)	% Prevalence (n)	Host (source)	Reference
Masvingo	National reserve	Random sampling	RBPT, SAT (linear/≥1:80), CFT, 2-ME (NS)	6.5 (444)	African buffalo (*Syncerus caffer*)	(Madsen and Anderson, 1995)
Mashonaland East and Masvingo	National reserve	Random sampling	RBPT, SAT (linear/≥1:80), CFT, 2-ME (NS)	1.4 (555)	Eland antelope (*Tragelaphus oryx*)	(Madsen and Anderson, 1995)
Masvingo	National reserve	Random sampling	RBPT, SAT (linear/≥1:80), CFT, 2-ME (NS)	0.9 (222)	Giraffe (*Giraffa camelopardalis*)	(Madsen and Anderson, 1995)
Masvingo	National reserve	Random sampling	RBPT, SAT (linear/≥1:80), CFT, 2-ME (NS)	0.05 (2068)	Impala (*Aepyceros melampus*)	(Madsen and Anderson, 1995)

Table 1 continue….

Province	Production System	Sampling	DT (antigen/cut-off)	% Prevalence (n)	Host (source)	Reference
Midlands	Smallholder dairy	Stratified random sampling	RBPT, SAT (linear/>1:80)	4.11 (73)	Cattle (Friesian-Jersey and Red Dane Holstein,)	(Chivandi, 2006)
Masvingo	Communal farms	Systematic random sampling	RBPT (NS)	9.9 (1158)	Cattle (NS)	(Gomo, 2010, 2012)
vingo	National reserve	Systematic random sampling	RBPT (NS)	1.03 (97)	Giraffe (*Giraffa camelopardalis*)	(Gomo, 2010, 2012)
Gokwe	Communal farming sector	Stratified sampling	RBPT, c-ELISA (Svanovir)	12.6 (265)	Cattle (*Bos taurus and Bos indicus*)	(Matope *et al.*, 2011)
Malilangwe	Communal farming sector	Stratified sampling	RBPT, c-ELISA (Svanovir)	3.6 (305)	Cattle (*Bos taurus and Bos indicus*)	(Matope *et al.*, 2011)
Mushagashe	Communal farming sector	Stratified sampling	RBPT, c-ELISA (Svanovir)	5.7 (133)	Cattle (*Bos taurus and Bos indicus*)	(Matope *et al.*, 2011)
Nharira	Communal farming sector	Stratified sampling	RBPT, c-ELISA (Svanovir)	6.1 (272)	Cattle (*Bos taurus and Bos indicus*)	(Matope *et al.*, 2011)
Rusitu	Communal farming sector	Stratified sampling	RBPT, c-ELISA (Svanovir)	3.6 (354)	Cattle (*Bos taurus and Bos indicus* cross)	(Matope *et al.*, 2011)
Wedza	Communal farming sector	Stratified sampling	RBPT, c-ELISA (Svanovir)	2.3 (111)	Cattle (*Bos taurus and Bos indicus* cross)	(Matope *et al.*, 2011)
Masvingo	Rural communities	NS	RBPT, i-ELISA (NS)	8.3 (700)	Cattle (NS)	(Gomo *et al.*, 2012)
Zimbabwe	National reserve	NS	RBPT, CFT (NS)	17.0 (106)	African buffalo (*Syncerus caffer*)	(Motsi *et al.* , 2013)
Zimbabwe	National reserve	NS	RBPT, CFT (NS)	1.4 (**72**)	Impala (*Aepyceros melampus*)	(Motsi *et al.* , 2013)

Table 1 continue..

Province	Production System	Sampling	DT (antigen/cut-off)	% Prevalence (n)	Host (source)	Reference
Masvingo	Communal areas	Random sampling	RBPT, CFT (NS)	16.7 (1011)	Cattle (NS)	(Ndengu *et al.*, 2017)
Masvingo	National reserve	Aerial spotting	RBPT, CFT (NS)	20.7 (111)	African buffalo (*Syncerus caffer*)	(Ndengu *et al.*, 2017)
Zimbabwe	Various communities	Sample submission	RBPT, SAT, CFT	30.1 (12359)	NS	(Vhoko *et al.* , 2018)
Masvingo	Rural communities	NS	RBPT, CFT (NS)	0 (563)	Goats (NS)	(Bhandi *et al.*, 2019)
Zimbabwe	Various production systems	Sample submission	RBPT, SAT (linear/≥1:80), CFT	6.7 (16536)	NS	CVL unpublished data (2015-2019).

Abbreviations used in the Table: NS: not specified; RBPT: Rose Bengal Test; MRT: milk ring test; STT: standard tube test; SAT: standard agglutination test; c-ELISA: complement-enzyme linked immunosorbent assay; CFT: complement fixation test, n: sample size, DT: Diagnostic test.

Table 2. *Brucella* species isolated and confirmed in Zimbabwe.

Species	Identification method used	No of Strains	Period	Host (source)	Province	Reference
Brucella spp.	AMOS-PCR, MLVA, WGS-SNP	1	1990 – 2009	Sheep	Matebeleland South	(Ledwaba *et al.*, 2019)
	AMOS-PCR, MLVA, WGS-SNP	1	1990 - 2009	Cow	Mashonaland Central	(Ledwaba *et al.*, 2019)
B. melitensis	Culture, biochemical profiling	1	1987	Goats, Sheep	NS	(Madsen , 1989)
	Biochemical, AMOS-PCR profiling	1	NS	Goats (aborted fetuses)	Mashonaland Central	(Matope *et al.*, 2009)
B. abortus	Biochemical profiling	≥4	1921-1930	Human	NS	(Bevan , 1931)
	MRT, RBT, STT (NS)	2	1996	Cattle	Bulawayo	(Mohan *et al.*, 1996)
	Biochemical, AMOS-PCR profiling	1	NS	Cattle (aborted fetus)	Mashonaland Central	(Matope *et al.*, 2009)
	Biochemical, AMOS-PCR profiling	3	NS	Cattle (milk)	Midlands	(Matope *et al.*, 2009)
	Biochemical, AMOS-PCR profiling	2	NS	Cattle (hygroma)	Mashonaland East	(Matope *et al.*, 2009)

	Table 2 continue….					
	Biochemical, AMOS-PCR profiling	1	NS	Cattle (aborted fetus)	Matebeleland North	(Matope *et al.*, 2009)
	Biochemical, AMOS-PCR profiling	2	NS	Cattle (aborted fetus)	Mashonaland West	(Matope *et al.*, 2009)
	Biochemical, AMOS-PCR profiling	4	NS	Cattle (aborted fetus)	NS	(Matope *et al.*, 2009)
	Multiplex PCR, AMOS-PCR, NGS (Illumina)	1	NS	Cattle	NS	(Ledwaba *et al.*, 2014)
	AMOS-PCR, MLVA, WGS-SNP	2	1990 - 2009	Cattle	Matebeleland South	(Ledwaba *et al.*, 2019)
	AMOS-PCR, MLVA, WGS-SNP	1	1990 - 2009	Cattle	Harare	(Ledwaba *et al.*, 2019)
B. ovis	AMOS-PCR, MLVA, WGS-SNP	1	1990 - 2009	Sheep	Matebeleland North	(Ledwaba *et al.*, 2019)
B. suis	NGS (Illumina), AMOS-PCR, multiplex-PCR	1	NS	Pigs	NS	(Ledwaba *et al.*, 2014, , 2019)
	AMOS-PCR, MLVA, WGS-SNP	1	1990 - 2009	Pig	Mashonaland Central	(Ledwaba *et al.*, 2019)
	AMOS-PCR, MLVA, WGS-SNP	2	1990 – 2009	Cattle (testicles)	Mashonaland Central	(Ledwaba *et al.*, 2019)
	AMOS-PCR, MLVA, WGS-SNP	1	1990 – 2009	Cattle	Masvingo	(Ledwaba *et al.*, 2019)
	AMOS-PCR, MLVA, WGS-SNP	1	1990 – 2009	Cattle	Mashonaland West	(Ledwaba et al., 2019)
	AMOS-PCR, MLVA, WGS-SNP	1	1990 – 2009	Cattle (milk)	NS	(Ledwaba et al., 2019)
	AMOS-PCR, MLVA, WGS-SNP	1	1990 – 2009	unknown	NS	(Ledwaba *et al.*, 2019)
	AMOS-PCR, MLVA, WGS-SNP	1	1990 - 2009	Pig	Mashonaland West	(Ledwaba *et al.*, 2019)
B. canis	AMOS-PCR, MLVA, WGS-SNP	2	1990 - 2009	Dogs	Harare	(Ledwaba *et al.*, 2019)

Abbreviations used in the Table: NS: not specified; RBT: Rose Bengal Test; MRT: milk ring test; STT: standard tube test; MLVA: multiple-locus variable number tandem repeats analysis; WGS-SNP: whole genome sequencing-single nucleotide polymorphisms; NGS: next generation sequencing.

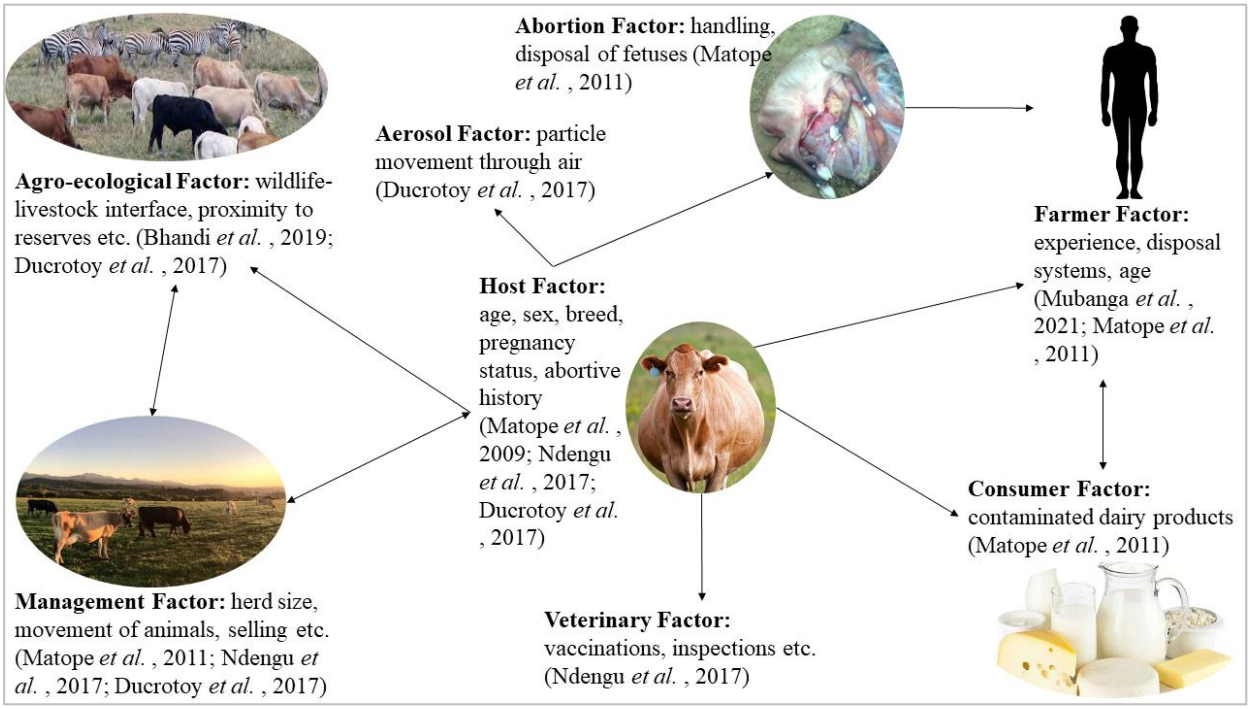

Figure 3. The drivers or risk factors influencing the spread of brucellosis in Zimbabwe. Some of the factors have been found to directly influence the spread of the disease, while others have a subtle indirect effect but eventually result in the disease upon contracting the bacterium Brucella.

Transmission modes and risk factors involved in Brucellosis dynamics

Brucellosis spreads from animals to humans via direct exposure when handling infected animals and animal by-products, the breathing of infectious aerosols (airborne transmission), and consumption of contaminated animal products (ingestion of unpasteurized dairy products, undercooked meat) (Gadaga *et al.* , 2016, Vhoko *et al.* , 2018). It is mostly an occupational infection, and transmission occurs chiefly in individuals working closely with animals, and animal products. Several brucellosis risk factors have been identified (Figure 3). Apart from animal to human, human-to-human brucellosis transmission is also feasible though uncommon (Khurana *et al.*, 2021) and can occur through blood transfusions, tissue/organ transplants, and sexual contact topping the list of potential transmission pathways. Other pathways for *Brucella abortus* transmission can be via direct contact with contaminated tissues, liquids (Figure 3), and aborted materials which contain substantial numbers of *Brucella* bacteria (Condy and Vickers , 1972, Mohan *et al.* , 1996, Mosalagae *et al.* , 2011, Tanner *et al.* , 2015, Vhoko *et al.* , 2018).

The improper disposal of infected carcasses, aborted foetuses and fluids have been the main routes of infection in Zimbabwe, with the infected body parts and secretions also contaminating the environment where they are disposed of (Gomo , 2010, , 2012, Blasco *et al.* , 2021). *Brucella* from animal waste can survive outside its preferred host for extended periods under harsh conditions (Moreno , 2021), lasting up to two months in water or soil and several months in dry substances (dust, roughage). These regions can become sites of infection if the animal carcasses or secretions come into contact with an individual (Figure 3) or when dust particles are inhaled or go into the conjunctiva of the eyes. Ingestion of infectious milk products, remains at the top (Mosalagae *et al.* , 2011, Blasco *et al.* , 2021), whether through calve feeding or as a human nutritional supplement (Munyeme *et al.* , 2010, Gomo *et al.* , 2012, Gadaga *et al.* , 2014, Vhoko *et al.* , 2018).

Brucellosis can be easily transmissible to people, and safety measures must be continuously taken when handling infected animals to prevent contamination (Motsi *et al.* ,2013). There is always an associated occupational risk for veterinarians and ranchers who continuously encounter infected animals, aborted foetuses, and placentas.

Age, geographical location, and contact with wildlife are all risk factors for animal brucellosis, with animals aged 5.5-7 years

being five times more likely to have aborted than those aged 2-4 years (Matope *et al.* , 2011). In addition, keeping mixed cattle breeds was linked to a higher risk of brucellosis. In another example, adult buffalo had a higher prevalence than juveniles and sub-adults under the age of six years. Again, seropositivity was marginally higher in animals from wildlife-livestock interface areas than in non-interface regions, even though there was no statistically significant difference (Gomo *et al.* , 2012).

Finally, contact with livestock was most likely in seropositive eland antelope, impala, and giraffe cases, indicating that the infection may be able to cycle independently in wildlife and, as a result, should be regarded as a potential source of reinfection for livestock (Motsi *et al.* , 2013). Religious and cultural perceptions also contribute to risk factors for animal brucellosis. In Zimbabwe, cattle are a significant source of income for local farmers, but lack of good grazing land, veterinary consultations, and vaccinations have significantly affected cattle production in communal areas and some commercial farms (Gadaga *et al.* , 2016, Ndengu *et al.* , 2017).

Brucellosis prevention and control strategy in Zimbabwe

Brucellosis is a major public health problem in Zimbabwe, particularly in rural regions where cattle are a major source of food and income for many people. In Zimbabwe, brucellosis control strategies include vaccination, testing and surveillance, animal movement control, education and awareness initiatives, treatment, and One Health strategy. Vaccination is the principal management method in Zimbabwe, with the *Brucella abortus* strain 19 vaccine being mainly available in commercial farms but rarely in communal farms (Gadaga *et al.* , 2016, Ndengu *et al.* , 2017, Bhandi *et al.* , 2019). However, the vaccine is not routinely available and accessible across the country, and immunisation coverage is insufficient. Testing and surveillance are critical for prompt identification or detection and response to brucellosis epidemics in both animals and humans. The Zimbabwean Brucellosis Control Scheme has not made much progress due to factors like economic state, under-funding, not fully functional, and policy grievances. To address this issue, the nation should prioritize and plan a robust and systematic brucellosis surveillance system to monitor case detection and disease prevalence estimation (Gadaga *et al.* , 2014, , 2016). Infected animals are commonly confined or slaughtered to reduce the spread of brucellosis, but this strategy is challenging in Zimbabwe due to the lack of money to compensate the farmers who lost animals due to culling or testing and killing.

Animal movement control is also crucial in controlling the spread of brucellosis. The Department of Veterinary Services regulates animal movement in Zimbabwe, and procedures such as quarantine and movement permits are employed to limit animal movement in and out of contaminated regions (Ndengu *et al.* , 2017, Bhandi *et al.* , 2019). The procedure involves premovement screening of brucellosis using serological tests such as rose Bengal and compliment tests. Education and awareness initiatives are critical for advocating good animal husbandry practices and avoiding brucellosis spreading. Increased awareness-raising and education initiatives on brucellosis and its prevention are needed in Zimbabwe. Education and awareness initiatives can be carried out in collaboration with multidisciplinary partners as part of one health plan to encourage positive behavioural changes in some risky practices, such as consuming raw milk (Ducrotoy *et al.* , 2017, Ndengu *et al.* , 2017).

National, provincial, and district zoonotic disease committees were set up to help with the One Health approach's zoonotic infection control. However, the current zoonotic disease committees still do not include enough essential parties, like farmers and wildlife experts (Gadaga *et al.* , 2016, Vhoko *et al.* , 2018). Working in an inter or transdisciplinary team would benefit the country by saving animal and human lives, reducing research and monitoring expenses, and improving ecosystem services. Poor anthropogenic environmental management practices, such as deforestation and haze, contribute to wildlife intrusions on farmed domestic areas, creating an unusually close-knit ecosystem that may harbour brucellosis between domestic animals, humans, and wildlife (Zengeya *et al.* , 2015).

However, the authors think that the success of One Health initiatives is solely dependent on how eager legislators and policymakers in office are to implement it. Integration has been crucial, and programs built on the One Health

idea should be prioritized, planned, and implemented to effectively control zoonotic diseases in the country (Godfroid , 2017). In Zimbabwe, the Department of Veterinary Services under the Ministry of Lands, Agriculture, Fisheries, Water, Climate, and Rural Development has not had enough funding to monitor most zoonotic diseases across the country (Gadaga *et al.* , 2016, Vhoko *et al.* , 2018). In some cases, Non-Governmental Organizations have been supporting government efforts, such as administering vaccinations in rural communities close to tourist destinations such as Victoria Falls (VF), where the Victoria Falls Wildlife Trust (VFWT) and Veterinarians for Animal Welfare Zimbabwe (VAWZ) have teamed up with members from the Ministry of Lands, Agriculture, Fisheries, Water, Climate and Rural Development (LaPenna *et al.* , 2020, Dixon *et al.* , 2021).

To improve the implementation of One Health strategies, experts and essential stakeholders should assess all plans, challenges, and possibilities to improve the approach's implementation in Zimbabwe (Kidia , 2018). Values and ethics are critical in guiding the development of One Health curricula and continuing professional education, as they describe the knowledge, skills, and attitudes required for effective brucellosis control. Transdisciplinary competencies should be further developed in addition to discipline-specific areas of expertise, and a thorough understanding of infectious diseases biology will always be required for any sound One Health approach to be implemented in the country (Kidia , 2018, LaPenna *et al.* , 2020). In conclusion, brucellosis control strategies in Zimbabwe require a combination of vaccination, testing, and education to effectively control the disease. Integrating these strategies with the One Health approach will help save lives, reduce research costs, and improve ecosystem services.

Challenges for Control of Brucellosis in Zimbabwe

Zimbabwe faces several barriers to implementing brucellosis control strategies, including scarcity of resources, inadequate surveillance systems, and inadequate animal health infrastructure (Ducrotoy *et al.* , 2017). The country's surveillance system is deficient, with limited diagnostic facilities, insufficient case reporting, and a lack of a coordinated national monitoring network (Gadaga *et al.* , 2016, Ndengu *et al.* , 2017). A test-and-kill strategy is used in low-incidence regions, with vaccination forbidden due to difficulty distinguishing between infected and vaccinated animals. However, test and kill would be impossible in areas where brucellosis is endemic, as the expenses of compensating farmers for losses would be prohibitively high and there would be insufficient brucellosis-free replacement stock available (Motsi *et al.* , 2013, Gadaga *et al.* , 2014, Zengeya *et al.* , 2015, Chigwenhese *et al.* , 2016, Ndengu *et al.* , 2017). Import permits should only be granted to farms or areas certified brucellosis-free. Infected cattle, particularly *B. abortus*-infected cows, are carriers for the rest of their lives, shedding *Brucella* in milk and other fluids. To minimize foodborne transmission, people are encouraged to consume pasteurized milk, dairy products, boiled milk, and thoroughly cooked meat (Ducrotoy *et al.* , 2017). In endemic regions, pasteurization of dairy products is recognized as a crucial safety technique. Raw or undercooked animal items should be avoided, and occupational *Brucella* exposure can be minimized by using protective clothes and equipment, following good hygiene, and taking safety precautions to avoid skin contamination, inhalation, or inadvertent ingesting of organisms while aiding a delivery, performing a necropsy, or slaughtering an animal.

Occupational *Brucella* infection is a major challenge in Zimbabwe since most farms are inadequately equipped with sufficient protective equipment for all their workers increasing the risk of exposure to the disease (Matope *et al.* , 2011, Gomo *et al.* , 2012). The country has a limited number of educated agricultural workers in the communal areas knowledgeable about zoonotic diseases (Gadaga *et al.* , 2014, , 2016), limited access to veterinary medications and vaccinations (Ducrotoy *et al.* , 2017), and insufficient diagnostic facilities, particularly in rural areas (Ducrotoy *et al.* , 2017, Godfroid , 2017, Ndengu *et al.* , 2017). Public knowledge about brucellosis is lacking, with many people unaware of the illness, its transmission, and treatment (Ndengu *et al.*, 2017). Commercially available animal vaccines are limited, and a protective and safe human vaccine is absent.

Limited access to vaccines is also a challenge, with the *B. abortus* strain 19 vaccine being scarce. Zimbabwe's current control methods are weak, with low vaccination coverage, insufficient testing and surveillance, and insufficient animal movement control. Traditional livestock husbandry systems, keeping vaccinated livestock for longer than the REV.1 vaccine's protection period, and constructing animal barns close to humans are all challenges in addressing this issue (Vhoko *et al.* , 2018). Prevention and control are most successful on a regional or national scale when backed by robust state veterinary infrastructure, laws, vaccination programs, surveillance, animal movement, and enforced slaughtering of sick animals and their contacts. Lastly, Zimbabwe lacks the political will to manage brucellosis, with minimal funding for disease control programs and insufficient legislative and regulatory frameworks. Addressing these challenges is crucial for Zimbabwe's success in reducing brucellosis (Ducrotoy *et al.* , 2017).

DISCUSSION

The majority of study sites on brucellosis in Zimbabwe are from Masvingo Province, resulting in a bias in the prevalence data of the country. This bias can lead to inaccurate data on the severity of the disease, which may result in the disease being overlooked by surveillance teams. This could reduce the efforts and resources needed to reduce the disease to less than 4% of the total national herd. The variation in brucellosis cases in the study sites can be attributed to ecological factors surrounding each province and differences in management practices (Gadaga *et al.* , 2014, , 2016). Studies have shown that most communal farmers are unaware of brucellosis (Mosalagae *et al.* , 2011), while many commercial farmers are aware of its frequency and incidence in their ranching areas (Gadaga *et al.* , 2016, Ndengu *et al.* , 2017). The social relevance of farm animal illness among locals varies, and owners' perceptions of wildlife presence have not been sufficiently recognized in Zimbabwe. Several studies have been done on the awareness of brucellosis among farmers (Gomo *et al.* , 2012, de Garine-Wichatitsky *et al.* , 2013, Gadaga *et al.* , 2014, , 2016, Zengeya *et al.* , 2015), and those studies indicated that most communal farmers were unaware of the disease, while many commercial farmers were aware of the frequency and incidence of brucellosis in the ranching areas where they operate (Madzima , 1987, Mohan *et al.* , 1996, Matope , 2008, Vhoko *et al.* , 2018).

The social relevance of farm animal illness among the locals has been shown to vary (Gomo *et al.* , 2012), and the owners' perceptions of the presence of wildlife in their locations have never been sufficiently recognized (Matope *et al.* , 2010, Gomo *et al.* , 2012). Therefore, it is possible to lower the risk of animal and human infection by educating farmers and locals in endemic areas. The results of repeated household surveys showed significant increases in farmers' knowledge of brucellosis and calf vaccination (from 0% to 32%) but poor milk habits with only 5% of households boiling milk before consumption (Ndengu *et al.* , 2017). The Ministry of Lands, Agriculture, Fisheries, Water, Climate and Rural Development and the Ministry of Health's cooperation with nurses and environmental health specialists has been enhancing the communication of knowledge, safe milking practices (57%), and calf vaccines (47%) (Vhoko *et al.* , 2018). Extensive intersectoral training has increased participation in community training and awareness programs of known diseases affection Zimbabwe. This highlighted the requirement for an efficient program for brucellosis awareness training from a One Health perspective.

The prevalence of zoonotic diseases among communally owned cattle in Zimbabwe, particularly in the South-Eastern Lowveld, has been increasing due to wildlife proximity to grazing areas (Gomo *et al.* , 2012, Chigwenhese *et al.* , 2016, Ndengu *et al.* , 2017). Bovine brucellosis prevalence in the global range is 4.0-41.0%, with Zimbabwe having the highest prevalence to date (Ducrotoy *et al.* , 2016, , 2017). This has been increased by the pervasive behaviour of brucellosis due to the closeness of homesteads to Tran-Frontier Conservation Areas, which offer free wildlife movement between neighbouring countries continuously

introducing zoonotic diseases into the communal herd. The brucellosis prevalence in Zimbabwe ranges from 8 to 40% in the communal dairy herd (Vhoko *et al.* , 2018), with the main identified species of concern being *B. abortus*, *B. melitensis*, and *B. suis* (Ledwaba *et al.* , 2019). These pathogens cause ailments to most infected animals nationwide. Brucellosis is primarily an occupational infection, with risk factors for brucellosis including human-to-human transmission, blood transfusions, transplants, and sexual contact. In Zimbabwe, improper disposal of infected carcasses, aborted foetuses, and fluids has been a major method of infection. Keeping mixed cattle breeds has been linked to a higher risk of brucellosis in Zimbabwe (Mosalagae *et al.* , 2011, de Garine-Wichatitsky *et al.* , 2013, Gadaga *et al.* , 2016). Seropositivity of animals was noted to be marginally higher in animals from wildlife-livestock interface areas than in non-interface regions, but no statistically significant difference was found from the data and results in recent studies done in Zimbabwe.

The absence of a coordinated effort between overseers of public health, the Department of Livestock Veterinary Services, the Department of Lands, Agriculture, Fisheries, Water, Climate and Rural Development, and the Ministry of Health and Child Care (MoHCC) in general health education regarding zoonotic diseases has resulted in most farmers being ignorant of zoonotic diseases (Vhoko *et al.* , 2018, Bhandi *et al.* , 2019). The only time farmers seem to care enough to be educated in terms of disease prevalence, control, and treatment methods is when there is an imminent potential outbreak that may occur. To address this issue, the Zimbabwean Brucellosis Control Scheme should prioritize and plan a brucellosis surveillance system to monitor case detection and disease prevalence estimation. National, provincial, and district zoonotic disease committees were set up to help with the One Health approach's zoonotic infection control, but the current committees still do not include enough essential parties, such as farmers and wildlife experts, to correctly inform various stakeholders on the dangers posed by the zoonotic diseases found in Sub-Saharan Africa (Welburn *et al.* , 2015, Ducrotoy *et al.* , 2017). Working in an inter- or transdisciplinary team would benefit the country by saving animal and human lives, reducing research and monitoring expenses, and improving ecosystem services. For instance, Wood and colleagues have recommended a holistic and interdisciplinary examination of zoonotic disease development and its determinants, highlighting the significance of collaboration across different disciplines (Wood *et al.* , 2012). Additionally, from the standpoint of One Health, a scoping review highlights the significance of interdisciplinary modelling for zoonotic diseases, emphasizing the necessity of reflexive, modest, and interactive approaches among modellers, policymakers, and affected communities for successful implementation (Grant *et al.* , 2016). The effective brucellosis management requires surveillance to identify infected animals, prevent the spread to non-infected animals, destroy reservoirs to remove infection sources, and stop the re-introduction of brucellosis, especially at the wildlife-livestock interfaces.

Based on the knowledge revealed by the review, Zimbabwe should focus on raising public awareness and reducing the spread of brucellosis by improving surveillance and reporting methods, particularly in communal farming systems. This will help identify new cases and track the spread of the disease. Sector-tailored comprehensive control schemes should be created to meet the specific demands of each sector. Stakeholders from each sectors should be involved in the development and implementation of the control programme, involving farmers, veterinary professionals, government officials, and health professionals. Strengthening veterinary services, particularly in communal areas, can help improve animal health and limit the spread of brucellosis. This can involve veterinary team training, capacity building, and distribution of vaccinations and diagnostic testing. Working with vaccine manufacturers and providing subsidies or incentives can make immunizations and diagnostic tests more affordable for community farmers. Raise public knowledge on brucellosis through public education initiatives, community outreach programs, and social media outlets. Emphasize the need for immunization, responsible animal husbandry, and the dangers of ingesting unpasteurized dairy products. Increase the availability of diagnostic tests and antibiotics for brucellosis diagnosis and

treatment, and provide training and capacity development for farmers and veterinary professionals in both sectors. Additionally, Zimbabwe should conduct more research to better understand the epidemiology of brucellosis in Zimbabwe and develop disease-control methods. These studies should focus on the processes and factors influencing brucellosis transmission and the possibility of cross-species transmission between animals and humans.

In conclusion, brucellosis, which affects both humans and animals, is a major public health problem in Zimbabwe. The disease is caused by *Brucella* species and can be transferred by direct contact with diseased animals or ingestion of contaminated animal products. The most frequent *Brucella* species found in Zimbabwe are *B. abortus* and *B. melitensis*.

In Zimbabwe, the incidence of brucellosis varies depending on the location and population investigated. This review has shown that Brucellosis is common in both cattle and wildlife, particularly in rural regions where there is high interaction between wildlife, livestock and human. Due to a lack of resources and infrastructure, efforts to manage and prevent brucellosis in Zimbabwe have been restricted. However, managing the proliferation of brucellosis in Zimbabwe requires a holistic strategy which involves sufficient government funds to enhance surveillance, establish a comprehensive control programme, reinforce veterinary services, increase awareness among the public, optimise diagnosis and treatment in humans, and research to further comprehend the disease and develop more effective vaccines.

ACKNOWLEDGEMENT

The authors received no specific funding for the research, authorship, and/or publication of this article.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

REFERENCES

Bergey, D.H. and Holt, J. *Bergey's manual of deterinative bacteriology*. 9th Editio. Baltimore: Willians & Wilkins, 1993.

Bevan, L.E.W. Notes on a case of Rhodesian undulant fever. *Trans. R. Soc. Trop. Med. Hyg.*, 24, 93–95, 1931.

Bhandi, S., Pfukenyi, D.M., Matope, G., Murondoti, A., Tivapasi, M., Ndengu, M., Scacchia, M., Bonfini, B., *et al.* Brucellosis and chlamydiosis seroprevalence in goats at livestock–wildlife interface areas of Zimbabwe. *Onderstepoort J. Vet. Res.*, 86 (1), 2019.

Blasco, J.M., Moreno, E., and Moriyón, I. Brucellosis. *Vet. Vaccines*, 295–316, 2021.

Chigwenhese, L., Murwira, A., Zengeya, F.M., Masocha, M., de Garine-Wichatitsky, M., and Caron, A. Monitoring African buffalo (Syncerus caffer) and cattle (Bos taurus) movement across a damaged veterinary control fence at a Southern African wildlife/livestock interface. *Afr. J. Ecol.*, 54 (4), 415–423, 2016.

Chivandi, E. Sero-prevalence of bovine brucellosis in the Gokwe Smallholder Dairy Project Herd of Zimbabwe. *South. Africa J. Educ. Sci. Technol.*, 1 (2), 2006.

Condy, J.B. and Vickers, D.B. Brucellosis in Rhodesian Wildlife. *J. S. Afr. Vet. Assoc.*, 43 (2), 175–9, 1972.

Corbel, M.J. Brucellosis: An Overview. *Emerg. Infect. Dis.*, 3 (2), 213–21, 1997.

Corbel, M.J., Food, of the United Nations, A.O., Organization, W.H., and for Animal Health, W.O. Brucellosis in humans and animals, 2006.

Dixon, J., Manyau, S., Kandiye, F., Kranzer, K., and Chandler, C.I.R. Antibiotics, rational drug use and the architecture of global health in Zimbabwe. *Soc. Sci. Med.*, 272, 113594, 2021.

Ducrotoy, M., Bertu, W.J., Matope, G., Cadmus, S., Conde-Álvarez, R., Gusi, A.M., Welburn, S., Ocholi, R., *et al.* Brucellosis in Sub-Saharan Africa: Current challenges for management, diagnosis and control. *Acta Trop.*, 165, 179–193, 2017.

Ducrotoy, M.J., Conde-Álvarez, R., Blasco,

J.M., and Moriyón, I. A review of the basis of the immunological diagnosis of ruminant brucellosis. *Vet. Immunol. Immunopathol.*, 171, 81–102, 2016.
Gadaga, B.M., Etter, E., Mukamuri, B., Makwangudze, K.J., Pfukenyi, D.M., and Matope, G. Brucellosis and bovine tuberculosis at an animal-human interface in Zimbabwe. *Int. J. Infect. Dis.*, 21, 237, 2014.
Gadaga, B.M., Etter, E.M.C., Mukamuri, B., Makwangudze, K.J., Pfukenyi, D.M., and Matope, G. Living at the edge of an interface area in Zimbabwe: cattle owners, commodity chain and health workers' awareness, perceptions and practices on zoonoses. *BMC Public Health*, 16 (1), 84, 2016.
de Garine-Wichatitsky, M., Miguel, E., Mukamuri, B., Garine-Wichatitsky, E., Wencelius, J., Pfukenyi, D.M., and Caron, A. Coexisting with wildlife in transfrontier conservation areas in Zimbabwe: cattle owners' awareness of disease risks and perceptions of the role played by wildlife. *Comp. Immunol. Microbiol. Infect. Dis.*, 36 (3), 321–32, 2013.
Godfroid, J. Brucellosis in livestock and wildlife: Zoonotic diseases without pandemic potential in need of innovative one health approaches. *Arch. Public Heal.*, 2017.
Gomo, C. A survey of Tuberculosis and Brucellosis in wildlife and cattle in the South-East Lowveld of Zimbabwe, 2010.
Gomo, C., de Garine-Wichatitsky, M., Caron, A., and Pfukenyi, D.M. Survey of brucellosis at the wildlife–livestock interface on the Zimbabwean side of the Great Limpopo Transfrontier Conservation Area. *Trop. Anim. Health Prod.*, 44 (1), 77–85, 2012.
Gomo, C., Musari, S., De Garine-Wichatitsky, M., Caron, A., Pfukenyi, D.M., and Van Heerden, H. Detection of Brucella abortus in Chiredzi district in Zimbabwe. *Onderstepoort J. Vet. Res.*, 79 (1), E1-5, 2012.
Grant, C., Lo Iacono, G., Dzingirai, V., Bett, B., Winnebah, T.R.A., and Atkinson, P.M. Moving interdisciplinary science forward: Integrating participatory modelling with mathematical modelling of zoonotic disease in Africa. *Infect. Dis. Poverty*, 5 (1), 1–12, 2016.
Khurana, S.K., Sehrawat, A., Tiwari, R., Prasad, M., Gulati, B., Shabbir, M.Z., Chhabra, R., Karthik, K., *et al.* Bovine brucellosis–a comprehensive review. *Vet. Q.*, 41 (1), 61–88, 2021.
Kidia, K.K. The future of health in Zimbabwe. *Glob. Health Action*, 11 (1), 2018.
LaPenna, R., Moyo, I., Dawson, J., Foggin, C., and Olea-Popelka, F. Using a One Health Approach to Address the Challenges Posed by Rabies to Animals and People in Rural Areas in Victoria Falls, Zimbabwe, 2020.
Ledwaba, B., Mafofo, J., and van Heerden, H. Genome Sequences of Brucella abortus and Brucella suis Strains Isolated from Bovine in Zimbabwe. *Genome Announc.*, 2 (5), 2014.
Ledwaba, M.B., Gomo, C., Lekota, K.E., Le Flèche, P., Hassim, A., Vergnaud, G., and van Heerden, H. Molecular characterization of Brucella species from Zimbabwe. *PLoS Negl. Trop. Dis.*, 13 (5), e0007311, 2019.
Madsen, M. The current status of brucellosis in Zimbabwe. *Zimbabwe Vet. J.*, 20, 133–145, 1989.
Madsen, M. and Anderson, E.C. Serologic Survey of Zimbabwean Wildlife for Brucellosis. *J. Zoo Wildl. Med.*, 26 (2), 240–245, 1995.
Madzima, W.M. Zimbabwe: Bovine brucellosis and brucellosis of small ruminants: Diagnosis, control and vaccination. *Tech. Ser.*, 1987.
Matope, G. The impact of restocking communal cattle on the spread of brucellosis in Zimbabwe. *Unpubl. DPhil thesis, Univ. Zimbabwe, Harare, Zimbabwe*, 2008.
Matope, G., Bhebhe, E., Muma, J., Skjerve, E., and Djønne, B. Characterization of some Brucella species from Zimbabwe by biochemical profiling and AMOS-PCR. *BMC Res. Notes*, 2 (1), 261, 2009.
Matope, G., Bhebhe, E., Muma, J.B., Lund, A., and Skjerve, E. Herd-level factors for Brucella seropositivity in cattle reared in smallholder dairy farms of Zimbabwe. *Prev. Vet. Med.*, 94 (3–4), 213–221, 2010.
Matope, G., Bhebhe, E., Muma, J.B., Lund, A., and Skjerve, E. Risk factors for

Brucella spp. infection in smallholder household herds. *Epidemiol. Infect.*, 139 (1), 157–64, 2011.
Matope, G., Bhebhe, E., Muma, J.B., Oloya, J., Madekurozwa, R.L., Lund, A., and Skjerve, E. Seroprevalence of brucellosis and its associated risk factors in cattle from smallholder dairy farms in Zimbabwe. *Trop. Anim. Health Prod.*, 43 (5), 975–82, 2011.
Matope, G., Muma, J.B., Toft, N., Gori, E., Lund, A., Nielsen, K., and Skjerve, E. Evaluation of sensitivity and specificity of RBT, c-ELISA and fluorescence polarisation assay for diagnosis of brucellosis in cattle using latent class analysis. *Vet. Immunol. Immunopathol.*, 141 (1–2), 58–63, 2011.
Matope, G., Tivapasi, M., Ndengu, M., Pfukenyi, D.M., De Garine-Wichatitsky, M., Bhandi, S., Bonfini, B., Murondoti, A., *et al.* Brucellosis and chlamydiosis seroprevalence in goats at livestock-wildlife interface areas of Zimbabwe. *Onderstepoort J. Vet. Res.*, 86 (1), e1–e9, 2019.
McDermott, J., Grace, D., and Zinsstag, J. Economics of brucellosis impact and control in low-income countries. *Rev. Sci. Tech.*, 32 (1), 249–61, 2013.
McDermott, J.J. and Arimi, S.. Brucellosis in sub-Saharan Africa: epidemiology, control and impact. *Vet. Microbiol.*, 90 (1–4), 111–134, 2002.
Mohan, K., Makaya, P. V, Muvavarirwa, P., Matope, G., Mahembe, E., and Pawandiwa, A. Brucellosis surveillance and control in Zimbabwe: bacteriological and serological investigation in dairy herds. *Onderstepoort J. Vet. Res.*, 63 (1), 47–51, 1996.
Moreno, E. The one hundred year journey of the genus Brucella (Meyer and Shaw 1920). *FEMS Microbiol. Rev.*, 45 (1), 2021.
Mosalagae, D., Pfukenyi, D.M., and Matope, G. Milk producers' awareness of milk-borne zoonoses in selected smallholder and commercial dairy farms of Zimbabwe. *Trop. Anim. Health Prod.*, 43 (3), 733–739, 2011.
Motsi, T.R., Tichiwangana, S.C., Matope, G., and Mukarati, N.L. A serological survey of brucellosis in wild ungulate species from five game parks in Zimbabwe: research communication. *Onderstepoort J. Vet. Res.*, 80 (1), 1–4, 2013.
Muma, J.B., Samui, K.L., Oloya, J., Munyeme, M., and Skjerve, E. Risk factors for brucellosis in indigenous cattle reared in livestock-wildlife interface areas of Zambia. *Prev. Vet. Med.*, 80 (4), 306–317, 2007.
Munyeme, M., Muma, J.B., Munang'andu, H.M., Kankya, C., Skjerve, E., and Tryland, M. Cattle owners' awareness of bovine tuberculosis in high and low prevalence settings of the wildlife-livestock interface areas in Zambia. *BMC Vet. Res.*, 6 (1), 21, 2010.
Ndengu, M., Matope, G., de Garine-Wichatitsky, M., Tivapasi, M., Scacchia, M., Bonfini, B., and Pfukenyi, D.M. Seroprevalence of brucellosis in cattle and selected wildlife species at selected livestock/wildlife interface areas of the Gonarezhou National Park, Zimbabwe. *Prev. Vet. Med.*, 146, 158–165, 2017.
Smits, H.L. and Cutler, S.J. Contributions of biotechnology to the control and prevention of brucellosis in Africa. *African J. Biotechnol.*, 3 (12), 631–636, 2004.
Tanner, M., Inlameia, O., Michel, A., Maxlhuza, G., Pondja, A., Fafetine, J., Macucule, B., Zacarias, M., *et al.* Bovine Tuberculosis and Brucellosis in Cattle and African Buffalo in the Limpopo National Park, Mozambique. *Transbound. Emerg. Dis.*, 62 (6), 632–638, 2015.
Vhoko, K., Iannetti, S., Burumu, J., Ippoliti, C., Bhebhe, B., and De Massis, F. Estimating the prevalence of Brucellosis in cattle in Zimbabwe from samples submitted to the Central Veterinary Laboratory between 2010 and 2014. *Vet. Ital.*, 54 (1), 21–27, 2018.
Welburn, S.C., Beange, I., Ducrotoy, M.J., and Okello, A.L. The neglected zoonoses—the case for integrated control and advocacy. *Clin. Microbiol. Infect.*, 21 (5), 433–443, 2015.
Wood, J.L.N., Leach, M., Waldman, L., MacGregor, H., Fooks, A.R., Jones, K.E., Restif, O., Dechmann, D., *et al.* A framework for the study of zoonotic disease emergence and its drivers: spillover of bat pathogens as a case study. *Philos. Trans. R. Soc. B Biol. Sci.*,

367 (1604), 2881–2892, 2012.
Zengeya, F.M., Murwira, A., Caron, A., Cornélis, D., Gandiwa, P., and de Garine-Wichatitsky, M. Spatial overlap between sympatric wild and domestic herbivores links to resource gradients. *Remote Sens. Appl. Soc. Environ.*, 2, 56–65, 2015.