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Cost-Effectiveness of Acaricide Application Methods against Heartwater Disease in South Africa

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Abstract: In an economic sense, heartwater disease is the most important tick-borne disease faced by South African livestock farmers. Methods to control the disease vary among farmers, and the preferred method depends on the prevalence of the disease in a specific area. The cost-effectiveness of different acaricide prevention methods against heartwater disease has not yet been determined amongst South African livestock producers. The study's objective was to determine the cost-effectiveness of acaricide prevention methods used against heartwater disease in South Africa. Data used for this study were collected through a survey and structured questionnaires from 272 commercial livestock farmers in South Africa. Cost-effectiveness analyses were done on the spray, plunge, and pour-on acaricide application methods. For sheep and cattle, the plunge method proved to be the most cost-effective in all provinces of South Africa. In goats, pour-on acaricide application was the most cost-effective. The study recommends that extension activities provide farmers with information with which to choose the most appropriate acaricide application for the effective and sustainable control of heartwater disease.

Keywords: acaricide; prevention methods; spray; plunge; pour-on; sustainable strategies

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1. Introduction

Animal products contributed roughly 45.2% of the total value of South Africa's agricultural produce during the 2019/2020 financial year, with cattle-, sheep-, and goat-related products representing roughly 35% of this value [1]. The estimated 2.1 million livelihoods depending on these livestock industries emphasize the importance thereof [2]. With the need for livestock products increasing in South Africa, it is crucial for the sector to be efficient and sustainable by reducing inefficiencies in the value chain, for example, infectious diseases such as heartwater [3–5].

Heartwater disease is caused by the ricketsial organism *Ehrlichia ruminantium*, and is a tick-borne disease. The tick species *Amblyomma hebraeum* (bont-tick), a three-host and ixodid tick, was identified as the principal vector of this organism in southern Africa [6]. *Amblyomma* ticks are confined to south-eastern Africa and occur mainly in frost-free, wooded savannah regions and dry bushveld areas. The preferred hosts for adult ticks are cattle, sheep, and goats, and they are found throughout the year but are more abundant in warmer seasons. Although heartwater is not present in all of South Africa's provinces, it is the most economically important tick-borne disease and it has major financial implications for livestock farmers [4,7,8]. The impact of heartwater is validated by the number of livestock mortalities the disease causes and is worsened by livestock farmers' high expenditure that has to be incurred to control the ticks and treat the disease. Furthermore, the disease leads to sub-optimal production in livestock herds where lower fertility, weight loss, damaged hides, and decreased milk production has been recorded [9].

Traditionally, heartwater disease is controlled by dipping; immunization through infection (block method), creating an endemic state; and preventing the disease with prophylactic antibiotic application and treatment [10]. Methods to control the disease vary among farmers, and the preferred method depends on the prevalence of the disease in a specific area [11]. Tick control refers to the reduction of threats created by ticks by treating the environment and animals [12]. The *Amblyomma*-tick requires an intensive tick control strategy [13].

An economic analysis evaluates the impact of an animal disease and related control measures to support industry role players. Prevention and control methods are assessed to determine the best method benefitting the overall society and the additional investments of that method [14]. The absence of an animal disease contributes to the increased productivity of livestock, which in turn increases the profitability of livestock farmers and results in lower prices for customers [15].

International and national studies focus on estimating the economic losses as a result of the production losses, the coverage of ticks, implications for animal health, and the challenges of achieving effective measures of control; the costs of handling and control associated with tick-borne diseases; and assessing the direct cost and economic impact of livestock diseases [15–18]. The lack of information on the cost-effectiveness of acaricide prevention methods for heartwater disease makes it difficult for farmers in developing countries to design cost-effective strategies. Therefore, this study determined the cost-effectiveness of acaricide prevention methods against heartwater disease in South Africa.

2. Materials and Methods

2.1. Study Area

The South African provinces with recorded heartwater cases during 2018, as reported by RuVASA, were used as the study area for this study [8]. Provinces that reported the occurrence of heartwater are Mpumalanga, Limpopo, North West, KwaZulu-Natal, Eastern Cape, and Gauteng. Roughly a third (33.61%) of South Africa's grazing land is found in these provinces, primarily utilized for livestock production on an extensive basis [19].

Commercial farms in South Africa house roughly five million cattle for beef production, eight million sheep, and 600,000 goats [19]. A breakdown of livestock numbers in each of the five affected provinces is presented in Table 1.

Table 1. Livestock numbers on commercial farms in heartwater-affected provinces.

Province	Goats		Sheep		Cattle	
	Number	Percentage of the National Herd in the Province	Number	Percentage of the National Herd in the Province	Number	Percentage of the National Herd in the Province
North West	25,748	4.10	112,618	1.40	741,715	14.64
Eastern Cape	417,296	66.49	2,096,390	26.07	722,719	14.27
Mpumalanga	28,767	4.58	378,571	4.71	623,630	12.31
KwaZulu-Natal	1939	0.31	77,858	0.97	441,351	8.71
Gauteng	1440	0.23	49,317	0.61	406,916	8.03
Limpopo	5455	0.87	13,445	0.17	164,663	3.25
Total	480,645	76.58	2,728,199	33.93	3,100,994	61

Source: Adapted from Stats SA (2020) [19] with permission from publisher.

Cattle were the most common livestock, followed by sheep and goats (Table 1). The largest share of the national commercial sheep herd housed amongst the provinces afflicted by heartwater was found in the Eastern Cape province (26.07%), followed by Mpumalanga (4.71%) and the North West province (1.40%). North West had the highest national commercial cattle herd (14.64%), the Eastern Cape (14.27%) had the second highest, and Mpumalanga (12.31%) the third highest. The largest share of commercial goats (66.49%) was found in the Eastern Cape, followed by Mpumalanga (4.58%) and North West (4.10%).

The provinces with no documented heartwater cases served as a reference point for cost-effectiveness analyses of acaricide application strategies. These provinces included the Free State, Northern Cape, and Western Cape, which accounted for 66.39% of the country's grazing land (surface-wise) [19]. Table 2 shows the livestock numbers and percentages of the national herd in the provinces where RuVASA did not report heartwater incidents from 2018 to 2020. As shown in Table 2, roughly two-thirds (66.07%) of the commercial sheep in South Africa are farmed in heartwater-unaffected areas. Unaffected provinces hold a lesser proportion of the national goat herd (23.42%), while unaffected provinces house 39.00% of all commercial cattle.

Table 2. Livestock numbers on commercial farms heartwater-unaffected provinces.

Province	Goats		Sheep		Cattle	
	Number	Percentage of National Herd in Province	Number	Percentage of National Herd in Province	Number	Percentage of National Herd in Province
Free State	12,970	2.07	1,827,273	22.72	1,457,142	28.76
Northern Cape	46,334	7.38	2,361,261	29.36	406,056	8.02
Western Cape	87,651	13.97	1,124,841	13.99	101,841	2.01
Total	146,955	23.42	5,313,375	66.07	1,965,039	39.00

Source: Adapted from Stats SA (2020) [19] with permission from publisher.

2.2. Data

This study used a stratified sampling approach to collect data for determining the cost-effectiveness of acaricide prevention methods against heartwater disease. Commercial livestock farmers were divided into sub-populations based on the livestock heartwater risk and provinces' livestock numbers. This sampling method allowed for the comparison of data amongst sub-populations and included livestock farmers who were interviewed telephonically.

One component of a study design is the sample size or the population under investigation. The sample size can impact interactions, relationships, and the identification of significant variances [20]. Both continuous and categorical data were collected in the questionnaire. The formula of Bartlett et al. [20] was applied to calculate the suitable sample size, as shown in Equation (1):

$$N_0 = \frac{(t)^2 \times (p)(q)}{(d)^2} \tag{1}$$

where:

N_0	Required sample size
t	Selected alpha level value (willingness of a researcher to take a risk)
$(p)(q)$	Estimation of variance
$(d)^2$	Error margin acceptable for share being estimated

South Africa had 13,636 commercial livestock farms, according to Stats SA [19].

When Equation 1 was used at an alpha level of 1.65 (0.1), an estimated variance of 0.5, and an error margin of 0.05, a sample size of 272 respondents was calculated. A structured questionnaire based on the framework used by Leask and Bath [21], Mdlulwa [22], and Randela [23] was developed to obtain relevant information regarding the impact of heartwater on commercial livestock producers.

Questions such as the number of mortalities and treatments linked to heartwater, farmers' experiences with heartwater, dipping tactics, heartwater prevention through vaccines, and the requirement of an effective new heartwater vaccine were included in the questionnaire.

Information on the losses and costs livestock producers suffered, as well as approaches to combat the disease, was also captured in the questionnaire to calculate the impact of heartwater in South Africa. Acaracide application strategies included pour-on, spray dipping, and plunge dipping.

The 272 livestock farmers used as the sample for this study were drawn from a list of roughly 1000 commercial livestock farmers distributed across South Africa. This list of farmers was obtained from the Red Meat Producers Organization (RPO). Data collection was performed between August 2020 and February 2021. Respondents were identified based on the distribution of commercial livestock numbers in the country and the risk of heartwater in their area, as guided by Minjauw and McLeod [24]. These respondents were contacted whether they reported heartwater cases on their farms or not. This ensured an unbiased and even representation of commercial livestock farmers in South Africa regarding the views of heartwater.

A cost-effectiveness analysis (CEA) was applied to estimate the economic viability of a control or prevention method for a livestock disease when the monetary value of costs was determined, and the benefits were expressed as targets [14]. A CEA is a programme-specific analysis, which compares the relative costs of interventions to achieve the same results [25]. According to Shi and Nambudiri [26], a CEA is measured in non-monetary values and can be used for therapeutic, diagnostic, and preventative interventions.

Disease control and treatment are only economically justified when the benefits are more than the costs. This will result in a cost–benefit ratio (CBR) of one or more [27]. A viable economic initiative for an animal disease is one where the benefits are at least equal to the costs or, ideally, higher than the costs [14]. The cost–benefit model has been used globally in the field of animal health economics [27–29].

According to the FAO [14], a CEA differs from a CBR by not expressing benefits in a monetary manner but rather in units of effectiveness. This enables researchers to compare the costs of different control methods with the same outcome. This analysis is used to determine the improvement of a single measurable target, such as the price of vaccination. The steps used in a CEA were summarised by Martins and Rushton [25]. The first step of a CEA is the identification of the problem to be assessed and is conventionally shown as a decision tree. The conceptual model is established in the second step, and the perspective is defined in the third step. Next, it is necessary to identify and determine the costs of all the resources used to prevent or control the effects of a disease [26]. Thereafter, the outcomes must be identified and determined. The final step of the process is to calculate the cost-effectiveness of an intervention. The cost-effectiveness is expressed in ratios and can be represented as an average ratio (singular intervention) or as an incremental cost-effectiveness ratio (multiple interventions). An incremental cost-effectiveness ratio is used when mutually exclusive interventions are compared to one another [25].

A CEA uses a series of steps to reach a ratio, which allows for the comparison of different strategies. Acaricide treatment is an important strategy to prevent heartwater disease in livestock. To compare the cost-effectiveness of acaricide strategies, all costs used in each strategy must be considered. To calculate the total cost of each strategy, the cost of acaricide and labour for the respective strategies were used. Equation (2) was used to calculate the cost associated with each acaracide application strategy and is expressed as:

$$\sum_k DC = d_k \times P_k \tag{2}$$

where:

DC Total acaricide costs of livestock (R)
d_k The average annual cost of acaricide treatment per head of livestock (R/Animal)
P_k Number of livestock treated in a province (Head)
$k \in$ {1 = Cattle, 2 = Sheep, or 3 = Goats}

The annual acaricide cost per animal was multiplied by the total number of commercial animals in each province to obtain the total cost of acaricide. The calculation was made with the assumption that all livestock in a herd was treated with acaricide. The total costs of acaricide are expressed on a provincial level.

Equation (3) was used to determine the additional labour costs due to heartwater control. The labour cost was influenced by acaricide treatment frequency and was determined on a provincial level. The full cost of additional labour was calculated by adding all the labour costs in provinces where heartwater occurred.

$$\sum_k L = \left(\frac{h_k \times l_t \times f}{p_f} \right) \times P_k \times H_p \quad (3)$$

where:

L Total labour cost per province (R)
h_k Average number of hours used to apply acaricide per animal (Hours/animal)
l_t Number of labourers used to handle livestock per acaricide application (Person)
f Frequency of acaricide treatment (Times/year)
p_f Number of livestock per farm (Head)
H_p Average wage of farm worker per hour as stipulated by labour legislation (R/hour)
P_k Number of commercial livestock in a province (Head)
$k \in$ {1 = Cattle, 2 = Sheep, or 3 = Goats}

The labour cost was determined by asking the respondents about the amount of labour, number of hours, and frequency of application during a year in a heartwater-affected farming operation. The governmental minimum wage was used to determine the cost, which was set at R21.96 (US Dollar to South African exchange rate 1$ = R15.56 on 31 January 2022) per hour in 2021. To determine the total labour cost per animal, the frequency of acaricide treatment was multiplied by the number of labourers used to handle the livestock per session and the number of hours. This was divided by the number of animals per farm and then multiplied by the minimum wage. The total cost of labour per province was calculated by multiplying the average labour cost per animal of a province by the respective number of livestock treated in the specified province. Equation (4) was used to calculate the cost-effectiveness of each strategy:

$$\sum_J CE_{at} = \frac{(L_{at} + DC_{at})}{E_{at}} \quad (4)$$

where:

CE_{at} Cost-effectiveness ratio of a specific acaricide strategy (ratio)
L_{at} Cost of labour for the specific acaricide strategy (R)
DC Cost of acaricide for the specific acaricide strategy (R)
E_{at} Effectiveness for each acaricide strategy (%)
$J \in$ {1 = Large stock, or 2 = Small stock}
$at \in$ {1 = Spray, 2 = Pour-on, 3 = Plunge dip, or 4 = Foot dip}

The cost-effectiveness of each strategy was determined by tallying the cost of labour and the cost of acaricide from each strategy. The total cost associated with each acaricide strategy (numerator) was then divided by the efficiency of each strategy. Acaricide treatment strategies were summarized into four categories, namely, threshold, planned, interval, and strategic application [30]. The efficiency of each acaricide strategy was determined by subtracting the mortality percentage due to heartwater of each livestock species from the total number of animals in the study as represented per province, which indicated the survival rate of each acaricide strategy. The cost-effectiveness was calculated separately for each province and per species for all the provinces where heartwater disease occurred.

3. Results

Shown in Table 3 are the survival rates of the different species treated according to the various strategies, labour cost, and the total cost per head of animal per strategy.

Table 3. Cost-effectiveness of acaricide application methods.

Calculation	Animal	Treatment	South African Provinces						
			Eastern Cape	Gauteng	Kwazulu-Natal	North West	Mpumalanga	Limpopo	Average
Survival (%)	Cattle	S	98.70	98.88	99.30	98.31	99.97	98.00	98.86
		P	97.95	-	99.60	97.27	100	98.60	98.68
		PO	98.65	99.00	99.29	98.50	99.79	98.16	98.90
	Sheep	S	99.37	-	97.92	92.24	100	94.39	96.78
		P	99.79	-	-	89.41	100	92	95.30
		PO	99.27	-	89.41	98.50	99.79	98.16	97.03
	Goats	S	98.60	-	91.11	87.92	-	93.11	92.69
		PO	99.86	98.33	96.67	81.43	99.12	94.50	94.98
Acaricide cost per animal (Rand)	Cattle	S	28.67	44.84	30.67	29.93	22.52	55.91	35.42
		P	19.14	-	42.17	37.20	3.64	29.37	26.30
		PO	27.10	90.00	38.69	54.92	24.06	45.94	46.79
	Sheep	S	6.78	-	72.16	86.59	16.64	81.86-	52.81
		P	6.71	-	-	70.59	2.50	24	25.95
		PO	6.51	-	70.59	54.92	24.06	45.94	40.41
	Goats	S	17.02	-	235.56	134.81	-	75.00	115.60
		PO	13.95	40.00	200.00	192.86	26.47	102.71	96.00
Labour cost per animal (Rand)	Cattle	S	4.71	30.35	5.74	15.74	10.23	24.75	15.16
		P	4.27	-	6.77	11.83	5.66	13.18	8.34
		PO	5.82	36.86	6.93	11.48	9.22	23.97	15.71
	Sheep	S	1.00	-	0.97	5.25	1.76	6.23	3.04
		P	3.28	-	-	43.50	10.37	37.69	23.71
		PO	4.16	-	43.50	11.48	9.22	23.97	18.47
	Goats	S	0.21	-	2.71	7.92	-	7.76	4.65
		PO	0.10	8.25	3.03	2.63	1.81	4.55	3.40
Total cost per animal (Rand)	Cattle	S	33.39	75.19	36.41	45.10-	32.74-	80.65	50.58
		P	23.41	-	48.93	49.03	9.29-	42.55	34.64
		PO	32.92	126.86	45.62	66.41-	33.28	69.91	62.50
	Sheep	S	7.78	-	73.13	91.84	18.39	88.09	55.85
		P	9.99	-	-	114.09	12.87	61.69	49.66
		PO	10.67	-	114.09	66.41	33.28	69.91	58.87
	Goats	S	17.23	-	238.27	142.73	-	82.76	120.25
		PO	14.05	48.25	203.03	195.49	28.28	107.26	99.39
Spray effectiveness ratio	Cattle	-	0.34	0.76	0.37	0.46	0.33	0.82	0.51
	Sheep	-	0.08	-	0.75	1.00	0.18	0.93	0.58
	Goats	-	0.17	-	2.62	1.62	-	0.89	1.33
Plunge effectiveness ratio	Cattle	-	0.24	-	0.49	0.50	0.09	0.43	0.35
	Sheep	-	0.10	-	-	1.28	0.13	0.67	0.52
	Goats	-	-	-	-	-	-	-	-
Pour-on effectiveness ratio	Cattle	-	0.33	1.28	0.46	0.67	0.33	0.71	0.63
	Sheep	-	0.11	-	1.28	0.67	0.33	0.71	0.61
	Goats	-	0.14	0.49	2.10	2.40	0.29	1.14	1.09

Where: S = Spray; PO = pour-on; P = plunge application. Sources: Author's calculation.

3.1. Cost-Effectiveness—Cattle

The average survival percentage of cattle treated with acaricide spray (S) was 98.86% (Table 3). The highest survival percentage for the spray method was in Mpumalanga province (99.97%), with the lowest survival percentage in Limpopo (98%). The total annual cost per animal was the least expensive in Mpumalanga (R32.74) and the costliest in Limpopo (R80.65). The average annual cost per cattle treated with the spray method amounted to R50.58 per year in the affected provinces. The spray method was the most cost-effective in Mpumalanga, with R0.33 used per percentage of cattle protected against ticks possibly carrying heartwater. Limpopo had the lowest cost-effectiveness for the spray method, with R0.82 used per percentage of cattle protected against ticks that may carry the agent of heartwater. The cost-effectiveness of the spray method in all heartwater-affected provinces was R0.51 per percentage of cattle protected.

Table 3 shows the cost-effectiveness of the plunge method. The highest survival percentage for farmers using the plunge dip method was in Mpumalanga (100%), and the lowest survival percentage was in the North West province (97.27%). The total cost per animal was the most expensive in the North West province (R49.03) and the least costly in Mpumalanga (R9.29), with the total cost per animal in all heartwater provinces equal to R34.64. North West (R0.50) was the least cost-effective per percentage of cattle protected against ticks possibly carrying heartwater using the plunge method, and Mpumalanga (R0.09) was the most cost-effective. The cost-effectiveness of the spray method in all heartwater provinces was R0.35 used per percentage of cattle protected. No farmers in the Gauteng province reported using the plunge method for cattle.

Mpumalanga (99.79%) had the highest survival percentage with the pour-on method. Kwa-Zulu Natal (99.29%) had the second highest, and Limpopo (98.16%) had the lowest survival percentage. The total annual cost per animal for the pour-on method was the lowest in the Eastern Cape (R32.92) and the highest in Gauteng (R126.86). The total annual average cost per animal in all the heartwater-affected provinces for the pour-on method was equal to R62.50. The pour-on method was the least cost-effective in Gauteng, with R1.28 used per percentage of cattle protected. The Eastern Cape and Mpumalanga provinces were the most cost-effective with the pour-on method, with only R0.33 spent per percentage of cattle protected. The cost-effectiveness of the pour-on method in all heartwater provinces was R0.63 per percentage of protected cattle.

3.2. Cost-Effectiveness—Sheep

The provinces with the highest survival percentage for sheep using the spray method was Mpumalanga (100%), with the Eastern Cape (99.37%) having the second highest survival percentage. The lowest survival percentage was noticed in the North West province (92.24%). The average survival percentage for the five provinces was 96.78%. North West had the highest annual total cost per animal at R91.84, with the lowest total annual cost calculated for the Eastern Cape (R7.78). North West was the least cost-effective, and farmers spent R1.00 for every percentage of sheep protected against ticks potentially carrying heartwater. The Eastern Cape was the most cost-effective in the spray method and used only R0.08 per percentage of sheep protected. Amongst all affected provinces, the total cost-effectiveness for the spray method in sheep was R0.58 spent per percentage of sheep protected.

The province with the lowest survival percentage for the plunge method on sheep was North West, with 89.41%, and the highest survival percentage was Mpumalanga (100%). The lowest total cost per animal was in the Eastern Cape (R9.99) and the highest in North West (R114.09). The average total cost per sheep was lower for the plunge method (R49.66) than for the spray method (R55.85). The Eastern Cape was the most cost-effective with the plunge method and spent R0.10 to protect a percentage of sheep. The North West (R1.28) was the least cost-effective against heartwater. The total cost-effectiveness for the plunge method was R0.52 per percentage of sheep protected against ticks possibly carrying heartwater. No farmers in the Kwa-Zulu Natal province reported the use of the plunge method on sheep.

The highest survival percentage for sheep where the pour-on method was used was Mpumalanga (99.79%), trailed by the Eastern Cape (99.27%). The lowest survival percentage was in Kwa-Zulu Natal (89.41%). The Eastern Cape (R10.67) had the lowest annual total cost per animal, and Kwa-Zulu Natal (R114.09) the highest. Between affected provinces, the average annual total cost per animal for the pour-on method was R58.87. Kwa-Zulu Natal was the least cost-effective with the pour-on method and farmers used R1.28 per percentage of sheep protected against heartwater. The Eastern Cape was the most cost-effective with the pour-on method and used only R0.11 per percentage of sheep protected against ticks potentially carrying heartwater.

The plunge method of acaricide treatment for sheep (R0.52) was more cost-effective than the spray method (R0.58) for sheep. The total cost-effectiveness for the plunge method was R0.52 per percentage of sheep protected against ticks possibly carrying the agent of heartwater. The pour-on (R0.61) method for sheep was the least cost-effective method for all heartwater provinces.

3.3. Cost-Effectiveness—Goats

Table 3 indicates the cost-effectiveness of the pour-on and spray methods of acaricide application in goat herds. The highest survival percentage for goats where the spray method was used was found in the Eastern Cape (98.60%) and the lowest in the North West (87.92%). No farmers in Gauteng or Mpumalanga used the spray method for protection against ticks, possibly carrying the agent of heartwater within their goat herds. The total cost per animal was the highest in Kwa-Zulu Natal (R238.27), followed by the North West (R142.73). At R17.23, the Eastern Cape showed the lowest total cost per animal basis. Kwa-Zulu Natal was the least cost-effective with the application of acaricide using the spray method and used R2.62 per percentage of goats protected. The Eastern Cape (R0.17) was the most cost-effective with the spray method. The total cost-effectiveness of the spray method in goat herds across all heartwater affected provinces in South Africa was R1.33 per percentage of goats protected.

The lowest survival percentage for the pour-on method was North West (81.43%), and the highest survival percentage was found in the Eastern Cape (99.86%). The average survival percentage across all heartwater-affected provinces for goats was 94.98%. The total average cost per goat over all the provinces where heartwater occurred was R99.39 per goat. Kwa-Zulu Natal (R203.03) had the highest total cost per goat with the pour-on method, followed by North West (R195.49). The lowest total cost per goat was calculated for the Eastern Cape (R14.05) and was, therefore, the most cost-effective province with the pour-on method. Farmers in the Eastern Cape spent R0.14 per percentage of goats protected against ticks possibly carrying heartwater. North West was the least cost-effective with the pour-on method and used R2.40 per percentage of goats protected. The total cost-effectiveness for the pour-on method on goats over all the provinces where heartwater occurred was R1.09 for each percentage of goats protected against ticks possibly carrying heartwater.

4. Discussion

The results are discussed for each livestock species and heartwater-affected province.

4.1. Cattle

Clearly, the plunge acaricide method was the most cost-effective for cattle within all heartwater-affected provinces. The cost of the plunge method for cattle was estimated at R0.35 per percentage of cattle protected against heartwater. The pour-on method was the least cost-effective strategy, with R0.63 used for every percentage of cattle protected against ticks possibly carrying heartwater. The spray method was the second most cost-effective for the hindrance and control of heartwater, with a cost-effectiveness of R0.51 for every percentage of cattle protected against ticks that may carry the agent of heartwater.

While this study did not break down the number of animals farmed per farm or species, Mbatidde et al. [31] found that the bucket pump method could be cost-effective on smaller cattle farms (40 to 112 animals). However, on larger cattle farms (35 to 170 animals), a motorized pump was economical, while a spray race is a better option on large farms (100 to 600 cattle).

4.2. Sheep

Similar to cattle, the results for sheep suggested that the plunge method of acaricide application was the most cost-effective at R0.52 per percentage of sheep protected against ticks possibly carrying heartwater. This aligned with the findings of Chamboko et al. [9], who found that application of acaricides was the crucial control measure against heartwater disease on both smallholder and large-scale commercial sheep farms. On large-scale commercial sheep farms, plunge dipping was used most frequently, and the number of acaricide applications varied from 3 to 52 times per year. Heartwater disease control measures recorded for sheep and goats across all production systems were highly variable (going from no measures in place to hand removal of ticks or intensive acaricide treatment).

4.3. Goats

The spray method for acaricide application on goats, in general, was slightly less cost-effective than the pour-on method. This was, however, not the same for all provinces, with exceptions in the North West province and Limpopo, where the pour-on method was more cost-effective than the spray method. Smaller average herd sizes and spending more on acaricides per goat are part of the reason why the average cost of acaracide application on goats was relatively high when compared to sheep and cattle. No farmer who participated in the interviews used the plunge method of acaricide treatment on goats. These results also suggest that the pour-on method is more widely used to prevent heartwater goat operations. Our findings that the spray method of acaricide application method was the least cost-effective for goats contradicts the finding of Spickett and Fivaz [32] and Randela [27] where small stock farmers showed a more prominent preference for plunge acaricide applications for goats. The authors found that factors such as water availability and cold weather influenced farmers' non-use of the plunge treatment on goats. Our findings concurred indirectly with Chamboko et al. [9], who highlighted that a fundament control measure for heartwater disease amongst goats is the application of acaricides.

5. Conclusions

The cost-effectiveness of acaricide strategies against heartwater disease in South Africa has not been determined before. Thus, this article calculated the cost-effectiveness of acaracide application strategies on three livestock species in the five provinces in South Africa where heartwater disease was prevalent. The plunge acaricide application method was the most cost-effective for cattle and sheep. This was, however, not the case for goats, where the most cost-effective strategy was the pour-on method. The least cost-effective acaricide strategy for cattle and sheep was the pour-on method, while for goats, the least cost-effective method was the spray method. The cost-effectiveness of each method was highly influenced by the total cost per animal. In general, acaricide costs contributed the largest share of the total costs calculated. Higher total costs caused lower cost-effectiveness, whereas higher cost-effectiveness was seen because of lower total costs. The study recommends that suitable extension actions empower farmers with the necessary information with which to choose the most effective and sustainable acaricide application for the prevention of ticks transmitting the disease agent of heartwater. Future studies should investigate how the types of acaricides used differ per region and how it affects livestock producers' strategies against heartwater.

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References

1. Department of Agriculture, Land Reform and Rural Development (DALRRD). *Abstract of Agricultural Statistics for South Africa*; Department of Agriculture, Land Reform and Rural Development (DALRRD): Pretoria, South Africa, 2021.
2. Department of Agriculture, Land Reform and Rural Development (DALRRD). *A Profile of the South African Beef Market Value Chain*; Department of Agriculture, Land Reform and Rural Development (DALRRD): Pretoria, South Africa, 2017.
3. Dinkisa, G. Review on control of cowdriosis in ruminants. *J. Vet. Med. Res.* **2018**, *5*, 1150.
4. Spickett, A.M.; Heyne, I.H.; Williams, R. Survey of the livestock ticks of the North West province, South Africa. *J. Vet. Res.* **2011**, *78*, a305. [CrossRef] [PubMed]
5. Van den Heever, M.; Lombard, W.A.; Bahta, Y.T.; Maré, F.A. The economic impact of heartwater on the South African livestock industry and the need for a new vaccine. *Prev. Vet. Med.* **2022**, *203*, 105634. [CrossRef]
6. BAYER. *Farmers Handbook*; Bayer Animal Health Division: Johannesburg, South Africa, 2013.
7. Bath, G.F.; Van Wyk, J.A.; Pettey, K.P. Control measures for some important and unusual goat diseases in Southern Africa. *Small Rumin. Res.* **2005**, *60*, 127–140. [CrossRef]
8. Ruminant Veterinary Association of South Africa (RuVASA). 2018. Disease Reports—2018. Available online: https://ruvasa.co.za/disease-reports-2018/ (accessed on 17 June 2022).
9. Chamboko, T.; Mukhebi, A.W.; Callaghan, C.J.; Peter, T.F.; Kruska, L.; Medley, G.F.; Mahan, S.M.; Perry, B.D. The control of heartwater on large-scale commercial and smallholder farms in Zimbabwe. *Prev. Vet. Med.* **1999**, *39*, 91–210. [CrossRef] [PubMed]
10. Allsopp, B. Trends in the control of heartwater. *Onderstepoort J. Vet. Res.* **2009**, *76*, 81. [CrossRef]
11. Edwardes, W.F.I. The Financial Implications of Endemic Stability as a Control Strategy for Bovine Babesiosis in Veld Grazing Beef Production Systems of the KwaZulu-Natal Midlands. Master's Thesis, Stellenbosch University, Stellenbosch, South Africa, 2019.
12. Lorusso, V. Epidemiology and Control of Cattle Ticks and Tick-Borne Infections in Central Nigeria. Ph.D. Thesis, University of Edinburgh, Edinburgh, UK, 2014.
13. Estrada-Peña, A.; Salma, M. Current Limitations in the Control and Spread of Ticks that Affect Livestock: A Review. *Agriculture* **2013**, *3*, 221–235. [CrossRef]
14. Food and Agriculture Organization (FAO). *Economic Analysis of Animal Diseases*; FAO: Rome, Italy, 2016.
15. Espinosa, R.; Tago, D.; Treich, N. Infectious Diseases and Meat Production. *Environ. Res. Econ.* **2020**, *76*, 1019–1044. [CrossRef] [PubMed]
16. Bennett, R. The 'direct costs' of livestock disease: The development of a system of models for the analysis of 30 endemic livestock diseases in Great Britain. *J. Agr. Econ.* **2003**, *54*, 55–71. [CrossRef]
17. Kivaria, F.M. Estimated direct economic costs associated with ticks-borne diseases on cattle in Tanzania. *Trop. Anim. Health Pro.* **2006**, *38*, 291–299. [CrossRef]
18. Knight-Jones, T.J.D.; Rushton, J. The economic impacts of foot and mouth disease—What are they, howbig are they and where do they occur? *Prev. Vet. Med.* **2013**, *112*, 161–173. [CrossRef]
19. Statistics South Africa (Stats SA). *Census of Commercial Agriculture, 2017: Financial and Production Statistics*; Report No. 11-02-01 (2017); Statistics South Africa (Stats SA): Pretoria, South Africa, 2020.
20. Bartlett, J.E.; Kotrlik, J.W.; Higgins, C.C. Organizational research: Determining appropriate sample size in survey research. *Inform. Technol. Learn. Perform. J.* **2001**, *19*, 43–50.
21. Leask, R.; Bath, G.F. Observations and perceptions of veterinarians and farmers on heartwater distribution, occurrence and associated factors in South Africa. *J. S. Afr. Vet. Assoc.* **2020**, *91*, a1763. [CrossRef] [PubMed]
22. Mdlulwa, Z.M. The Socio-Economic Impact of the 2008–2010 Rift Valley Fever Outbreaks on Livestock Farmers in South Africa. Master's Thesis, University of Pretoria, Pretoria, South Africa, 2015.
23. Randela, R. Socio-Economic Impact Analysis of Livestock Disease Control Programmes with Special Reference to Ticks and Tick-Borne Diseases. Master's Thesis, University of Pretoria, Pretoria, South Africa, 2000.

24. Minjauw, B.; McLeod, A. *Tick-Borne Diseases and Poverty: The Impact of Ticks and Tick-Borne Diseases on the Livelihood of Small-Scale and Marginal Livestock Owners in India and Eastern and Southern Africa*; Centre for Tropical Veterinary Medicine: Edinburgh, UK; University of Edinburgh: Edinburgh, UK, 2003.
25. Martins, B.; Rushton, J. Cost-effectiveness analysis: Adding value to assessment of animal health welfare and production. *Rev. Sci. Tech.* **2014**, *33*, 681–689. [CrossRef]
26. Shi, C.R.; Nambudiri, V.E. Research Techniques Made Simple: Cost-Effectiveness Analysis. *J. Invest. Dermatol.* **2017**, *137*, e143–e147. [CrossRef] [PubMed]
27. Randela, R. Cost-benefit analysis of a disease control programme with special reference to ticks and tick-borne diseases in the former Venda region. *Dev. S. Afr.* **2005**, *22*, 515–528. [CrossRef]
28. Fasanmi, O.G.; Kehinde, O.O.; Laleye, A.T.; Ekong, B.; Ahmed, S.S.U.; Fasina, F.O. National surveillance and control costs for highly pathogenic avian influenza H5N1 in poultry: A benefit-cost assessment for a developing economy, Nigeria. *Res. Vet. Sci.* **2018**, *119*, 127–133. [CrossRef]
29. Mdlulwa, Z.M.; Masemola, M.; Chaminuka, P.; Madyo, S. Economic analysis of new generation vaccines for control of lumpy skin disease and Rift Valley fever in South Africa. *Agrekon* **2018**, *58*, 125–140. [CrossRef]
30. Smith, R.; Evans, D.; Martins, J.; Ceresér, V.; Correa, B.; Petraccia, C.; Cardozo, H.; Solari, M.; Nari, A. Babesiosis (*Babesia bovis*) stability in unstable environments. *Ann. N. Y. Acad. Sci.* **2000**, *916*, 510–520. [CrossRef]
31. Mbatidde, I.; Bugenyi, A.W.; Natuhwera, J.; Tugume, G.; Kirunda, H. Effectiveness and limitations of the recently adopted acaricide application methods in tick control on dairy farms in South-Western Uganda. *Agr. Ext. Rural Dev.* **2021**, *13*, 192–201.
32. Spickett, A.M.; Fivaz, B.H. A survey of cattle tick control practices in the Eastern Cape province of South Africa. *Onderstepoort J. Vet. Res.* **1992**, *59*, 203–210. [PubMed]