

## **Towards a Feasible Bovine Brucellosis Control Strategy in Khartoum State, Sudan**

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### **Abstract**

Brucellosis is one of the most important worldwide zoonosis. The disease in Sudan was reported early in the first half of the twentieth century, nevertheless; no nationwide control program has been adopted. Control of the disease remains inevitable as it causes huge economic losses and adversely affects animal trade. Besides, it raises concerns as public health threat. The aim of current study was to propose technically feasible approaches for control of the disease through vaccination. We evaluated six different vaccination strategies for control of brucellosis in Khartoum state using variable models basically relying on the cost-benefit and cost-effectiveness criteria. The results showed that vaccinating adult females twice every six years along with annual vaccination for female calves was the best option. Whole herd vaccination every 2 years is the second best option. However; vaccination of female calves once-off was excluded from cost-benefit and cost effectiveness analysis as it was not technically feasible since the projected prevalence in 2034 largely exceeded that reported in 2012. We therefore that adoption of control strategy having the highest net benefits, benefit cost ratio and lowest cost-effectiveness rate will lead to control of brucellosis and consequently will promote the development process. The study recommends the development of advanced model for disease transmission to overcome the challenges posed by neglecting transmission of brucellosis from the environment to animal.

**Keywords:** Brucellosis; Control Strategy; Cost-Benefit Analysis; Cost-Effectiveness; Khartoum State

### **Abbreviations**

B/C: Benefit-Cost Ratio; CE: Cost-Effectiveness Ratio; CL: Losses Due to Reduction in Calves Harvest; DC: Cost of the Disease and Vaccination; I: Seropositive; LMD: Losses Due to Morbidity; LMT: Losses Due to Mortality; ML: Losses Due to Milk Reduction; RB: Losses Due to Repeat Breeding; S: Susceptible; TC: Total Cost of the Disease; TL: Total Losses; V: Vaccinated; VC: Cost of Vaccination; VI: Cost of Veterinary Intervention

### **Introduction**

Development of all societies must have at least the objectives of increasing the availability and widen the distribution of basic life-sustaining goods such as food, shelter, health, and protection; raising the levels of living, including, in addition to higher incomes, the provision of more jobs, better education, and greater attention to cultural and human values; freeing the individual from servitude and dependence even from of ignorance and human misery [1]. Animal diseases have a negative impact on the development process and act as a development impeder; this impact usually extends to the other parts of the economy through ward and backward linkages [2]. They pose significant threats to livestock sectors throughout the world, both from the standpoint of the economic impacts of the disease itself and the cost of measures taken to mitigate the risk of disease [3,4]. The resurgence of serious infectious livestock diseases and veterinary public-health problems constitute major challenges for developed as well as developing countries [5]. Brucellosis is one of the five common bacterial zoonoses in the world caused by organisms belonging to the genus *Brucella* [6]. The disease is of both public health and

economic significance in most developing countries. It has considerable impact on the economy through loss of milk and meat, restrictions in international trade and by diminished animal working power [7]. Currently, 12 species have been described; these are: *Brucella melitensis*, *B. abortus*, *B. suis*, *B. canis* known to cause human brucellosis [8], *B. neotomae*, *B. ovis*, *B. pinnipedialis*, *B. ceti*, *B. microti*, *B. inopinata*, *B. papionis* [9,10] and very recently *B. vulpis* [11]. The disease is endemic in many countries and across various animal production settings, and is responsible for considerable economic losses and public health burden [12,13]. For the control of the disease regular programs of test and removal in low level of infection conditions can be used [14]. However, vaccination of adult animals is the most effective method of controlling brucellosis [15]. Currently, S19 and RB51 are the *B. abortus* vaccine strains more widely used to prevent brucellosis in cattle [16]. Heat-killed *B. abortus* strain 45/20 vaccine is recommended for pregnant livestock [17]. For the control of the disease on herd basis, Madhavaprasad, *et al.* [18] recommended in case of epidemic vaccination of non-reactors with S19 vaccine and in heavily infected herds with less abortion occurrence, all calves should be vaccinated with S19 and culling of the positive reactors as soon as possible. Periodic testing is to be conducted. Vaccination should be carried out regularly during a period long enough to produce a fall in prevalence, As a general rule, a control strategy based on mass vaccination is considered to be effective at low to medium (5% to 10%) animal or herd prevalence rates.

Although Sudan is one of the richest countries in its agriculture and animal resources, the country failed to expand its animal export and to invade new world markets. This is attributable to many factors, complying with sanitary and phyto-sanitary measures are among these factors. Brucellosis was proved to be endemic in Sudan and Khartoum State in particular, both with animal [19-22] and human brucellosis [23-25].

Angara, *et al.* [26] estimated the prevalence rate of bovine brucellosis at 25.1% based on Rose Bengal Test and estimated the annual financial cost of bovine brucellosis in Khartoum State at US\$ 3,293,084.6. The impact of the disease on human health cannot be over seen [23] all of which adversely affect the development process in the state. In spite of that no formal control strategy was formulated to combat the disease, this justifies the conduction of this work.

### Aim of the Study

The aim of this work is to formulate a cost effective long-term bovine brucellosis control strategy in Khartoum state. Specifically to simulate six proposed alternative control strategies and to find out the most cost-effective one using cost- benefit and cost effectiveness analyses and to assess the impact of the most cost- effective strategy on the development. These six proposed alternative strategies are; whole herd vaccination every two years, whole herd vaccination every six years, vaccination of female calves once, vaccination of female calves every two years, vaccination of female calves every six years and mature females' vaccination twice every six years together with annual calves vaccination.

### Materials and Methods

#### The study area

Khartoum State is one of the eighteen states of Sudan. Although area wise is the smallest state (22,142 km<sup>2</sup>), it is the most populous. The human population of Khartoum is approximately six million. The state lies between longitudes 31.5 to 34 °E and latitudes 15 to 16 °N. The northern region of the state is mostly desert, whereas the other regions have semi-desert climates. The annual rainfall ranges between 110 and 200 mm, in winter the minimum temperature ranging between 8°C and 10°C and maximum temperatures varying from 23°C to 25°C. In the summer, the maximum temperatures may exceed 45°C [27]. Animal population in the state is estimated in 2011 at 242868 heads of cattle, 444170 head of sheep, 647083 heads of goats and 6601 head of camels [28].

#### The models used in the analysis

Three models were used to achieve the objective of the study, these were: the disease transmission model, the disease cost model and the cost- benefit/cost-effectiveness model.

#### The disease transmission model

This model is used to project the development of the disease without control and to simulate the alternative proposed control strategies; It is a dynamic model of brucellosis transmission in cattle population in steps of one year (t).

**Assumption of the model**

1. Constant herd size (births = mortality + extraction).
2. The model considers three groups of animals.
  - a. S = Number of susceptible animals.
  - b. I = Number of seropositive animals.
  - c. V = Number of vaccinated animals.
  - d. P = Total animal population = (S+I+V).
3. Vaccine efficacy of S19 is 0.7 [29].
4. Vaccination coverage 100%.
5. Six alternative vaccination strategies were proposed.
  - a. Strategy 1: Whole herd vaccination every two years.
  - b. Strategy 2: Whole herd vaccination every six years.
  - c. Strategy 3: Vaccination of female calves once.
  - d. Strategy 4: Vaccination of female calves every two years.
  - e. Strategy 5: Vaccination of female calves every six years.
  - f. Strategy 6: Mature females vaccination twice every six years together with annual calf hood vaccination.

The incidence (newly infected cattle) is calculated as follows:

$$\text{Incidence}_{\text{cattle}} = \gamma_c \beta_c SI \dots\dots\dots(1)$$

Where:

$\gamma_c$  = Proportion of seropositive animals.

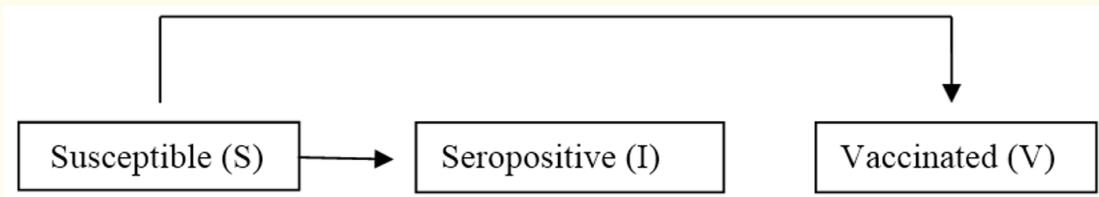
$\beta_c$  = Cattle contact rate.

Contact rate ( $\beta_c$ ) =  $k / (N-1)$  / Number of seropositive animals [30].

Where:

K = Effective contact (Annual abortion and delivery of seropositive animals).

N = Animal population



**Figure 1:** The disease transmission model.

**The annual change in the number of animals**

The annual change in the number of susceptible animals (S) equals the flow out of the susceptible animals compartment. The flow out is the newly infected animals (incidence of the disease) and the vaccinated animals.

$$dS/dt = -\gamma_c \beta_c SI - V \dots\dots\dots(2)$$

The annual change in the number of seropositive animals (I) (the flow in) is the newly infected animals (incidence of the disease)

$$dI/dt = \gamma_c \beta_c SI \dots\dots\dots(1)$$

The annual change in the number of vaccinated animals

Change in the number of vaccinated animals (V) is the flow of vaccinated animal to this compartment

$$dV/dt = V \dots\dots\dots(3)$$

### The Parameters fitted in the model and their sources

- (i) Total cattle population = 244,688 head [31].
- (ii) Number of mature cows is obtained by multiplying the total number of cattle in the state x the ratio of mature female 58.8% [32].
- (iii) Number of seropositive mature females = Number of mature cows x prevalence rate 25.1% [26].
- (iv) Number of calves is obtained by multiplying the total number of cattle x 17.5% [32].

### The disease cost model

This model is based on the disease transmission model the objective of which is to estimate the cost of the disease without control.

$$TL = LMD + LMT$$

Where;

TL = Total losses

LMD = Losses due to morbidity

LMT = Losses due to mortality

$$LMD = ML + CL + RB + VI$$

Where;

ML = Losses due to milk reduction

CL = Losses due to reduction in calves harvest

RB = Losses due to repeat breeding

VI = Cost of veterinary intervention

### Assumptions of the model and their sources

Based on Angara, *et al* [26].

The total annual cost of the disease in the baseline year 2012 = SDG 33,548,189

Losses due to mortality = 1% of the total loss

Milk Losses = 90.3%

Losses in calves harvest = 8.2%

Losses due to repeat breeding = 0.1%

Cost of veterinary intervention = 0.4%

The cost/seropositive = SDG 929.97

Accordingly the annual cost of the disease (DC) = number of seropositive x cost of seropositive.

### Cost of vaccination

Cost of vaccination (VC) = number of animals vaccinated x cost of vaccination per head = SG 5.0 [33].

### The total costs

$$TC = VC + DC$$

Where;

TC = Total cost of the disease.

VC = Cost of vaccination.

DC = Cost of the disease and vaccination.

### The benefits

All costs in case of without control were transferred to benefits in all control strategies [34].

## The Cost- benefit/cost effectiveness model

### The profitability criteria

Non-discounted criteria were used to estimate the profitability of each control strategy these are:

- (i) The net benefits = benefits - costs
- (ii) Profitability index = Benefits/costs
- (iii) Cost-effectiveness = cost per 1% fall in prevalence.
- (iv) Cost-effectiveness ratio (CE)
  - a. CE ratio = Cost of intervention/effectiveness intervention

### Data analysis

Microsoft excel was used to analyze the data.

## Results and Discussion

The transmission model used in this study consists of three compartments: susceptible (S), Seropositive (I) and Vaccinated (V). This model is similar to that developed by Zinsstag, *et al.* [35] which consists of three compartments (X) susceptible animal and compartment (Y) the seropositive cattle and (Z) immune cattle. In the other hand it differs from that developed by Gonzalez -Guzman and Naulin [36] whom model consists of four compartments: Susceptible (S), aborting infectious ( $I_1$ ), infectious carriers ( $I_2$ ) and immune by vaccination ( $\emptyset$ ). Also this model differ from kuku model developed by Angara [37] which consists of only two compartments (X) susceptible animal and compartment (Y) the seropositive cattle that is because kuku model did not account for vaccination of animals.

Table 1 presents the development of bovine brucellosis in Khartoum state during the period 2012 and 2034 under the assumption of constant population and without adoption of any control measures. The disease evolves until all mature females become infected by 2034. In the baseline year 2012 the susceptible animals were about 200000 which approximately equal 85% of the total population. The number of the susceptible started to decrease as a result of new infection and expected to reach 98797 head by year 2034 (about 40% of the total population).

Year	Total population	Susceptible	Seropositive	dS/dt	dI/dt
2012	244,688	208,575	36,113	-1,567	1,567
2014	244,688	205,314	39,374	-1,834	1,834
2016	244,688	201,489	43,199	-2,167	2,167
2018	244,688	196,958	47,730	-2,586	2,586
2020	244,688	191,537	53,151	-3,118	3,118
2022	244,688	184,982	59,706	-3,800	3,800
2024	244,688	176,971	67,717	-4,676	4,676
2026	244,688	167,092	77,596	-5,797	5,797
2028	244,688	154,831	89,857	-7,204	7,204
2030	244,688	139,613	105,075	-8,882	8,882
2032	244,688	120,948	123,740	-10,671	10,671
2034	244,688	98,797	145,891	-12,117	12,117

**Table 1:** The development of bovine brucellosis in Khartoum state during the period 2012 and 2034.

At the same time the number of seropositive animals increase gradually from less than 40000 (about 14% of the total population) in year 2012 and expected to reach more than 145000 (about 60% of the total) in 2034. These figures indicate that unless a serious control strategy to protect animals from brucellosis is adopted the majority if not the whole population in the state will be infect by the disease.

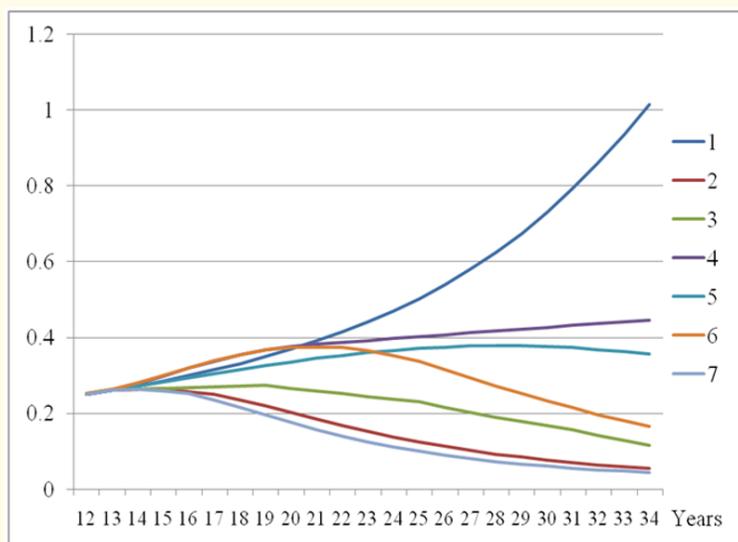
The incidence (newly infected) is increasing from about 1500 and expected to reach more than 12000 by year 2034 (Table 1). This result shows the necessity of control strategy to insure animal health and development.

The prevalence of the disease will increase from 25.1% in the base line year to101.4% in the last year where all mature females will be infected (Table 1).

**Simulation of the alternative control strategies**

To control the disease this study proposes six control strategies these were:

1. Whole herd vaccination every two years.
2. Whole herd vaccination every six years.
3. Vaccination of female calves once.
4. Vaccination of female calves every two years.
5. Vaccination of female calves every six years.
6. Mature female vaccination twice every six years together with annual calf hood vaccination.



**Figure 2:** Prevalence of brucellosis with and without control (vaccination) from year 2012 up to 2034.

1: Without vaccination; 2: Whole herd vaccination every two years vaccination; 3: Whole herd vaccination every six years; 4: Vaccination of female calves once; 5: Vaccination of female calves every two years; 6: Vaccination of female calves every six years; 7: Mature female vaccination twice every six years together with annual calf hood vaccination.

The vaccine used was *B. abortus* strain S19 and the efficiency of vaccination was assumed to be 70% (efficacy of the vaccine 70% and the coverage was 100%).

Strategy	1	2	3	4	5	6	7
Years							
2012	25.1	25.1	25.1	25.1	25.1	25.1	25.1
2014	27.4	26.4	26.4	28.0	27.2	28.0	26.3
2016	30.0	25.8	26.8	32.0	29.4	32.0	25.2
2018	33.2	23.5	27.2	35.4	30.3	35.4	21.6
2020	36.9	21.2	26.6	37.7	29.4	37.2	17.5
2022	41.5	16.8	25.1	38.7	26.6	37.2	13.9
2024	47.1	13.7	23.7	39.7	23.0	35.1	11.0
2026	53.9	11.2	21.6	40.7	19.5	31.5	8.8
2028	62.5	9.2	19.0	41.7	16.4	27.2	7.2
2030	73.0	7.6	16.7	42.7	13.7	23.2	6.0
2032	86.0	6.4	14.2	43.6	11.5	19.6	5.0
2034	101.4	5.4	11.6	44.5	10.0	16.5	4.3

**Table 2:** Prevalence rates at the different vaccination strategies during 2012- 2034(%).

1: Without vaccination; 2: Whole herd vaccination every two years; 3: Whole herd vaccination every six years; 4: Vaccination of female calves once; 5: Vaccination of female calves every two years; 6: Vaccination of female calves every six years; 7: Mature females vaccination twice every six years together with annual calf hood vaccination.

Test and slaughter policy is not included in any of these strategies because it is not applicable in such situation of high prevalence rate and there is no compensation policy is in effect. Other control measures mainly restriction of animals movement should be adopted.

### The impact of vaccination on the prevalence rates in each control strategy

Table 2 and figure 2 present the prevalence rates of the disease in the case of no vaccination and in each alternative vaccination strategy adopted. The results of the study revealed that the prevalence rate started to increase at first in all control alternatives then it declined this is due to fact that at the first the impact of new infection (incidence) out weights the impact of vaccination. The prevalence of the disease in case of vaccinating the whole herd every two years showed slight increase in the first four years of vaccination then it started to decline in the fifth year and continued to decrease rapidly and expected to reach 5.4% in 2034. In case of whole herd vaccination every six years the results showed initial increase in the prevalence in the first eight years then it started to decline in year nine and continue to decrease rapidly and expected to reach 11.6% in the year 2034. This also reflects the effect of the disease incidence out weighting the vaccination at first then the effect of the vaccination dominated after the second round.

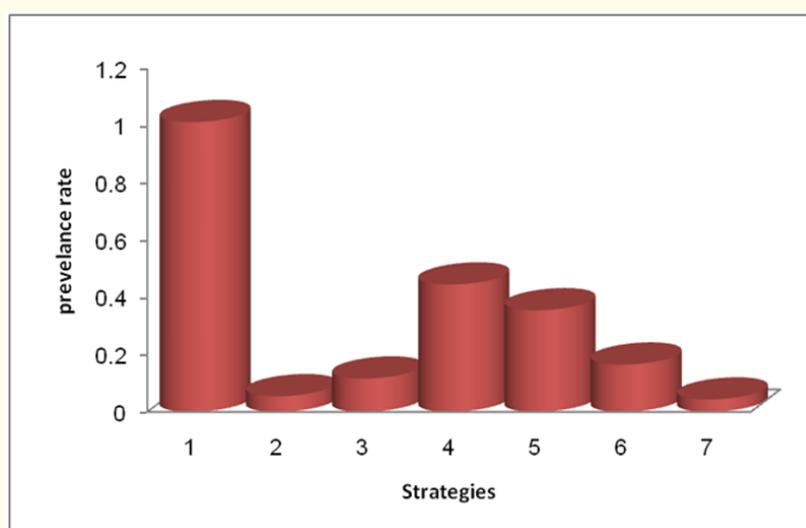
The prevalence in case of female calves' vaccination once showed no drop in the prevalence instead it increased from 25.1% the 2012 to 44.5% in 2034 indicating that this strategy is technically not feasible. On the other hand vaccination of the female calves every two years and every six years looks to be sound and technically feasible because the prevalence will drop to 10.0% and 16.5% respectively in 2034.

Figure 3 presents the prevalence rates of the alternatives control strategies in the year 2034. Accordingly these control strategies are ranked based on their technical feasibility as follows:

1. Mature female vaccination twice every six years together with annual calf hood vaccination.
2. Whole herd vaccination every two years.
3. Vaccination of female calves every two years.
4. Whole herd vaccination every six years.
5. Vaccination of female calves every six years.

The strategy of the vaccination of female calves once was excluded because it is not technically feasible as long as the prevalence in 2034 exceeds that in the year 2012.

Accordingly, the best technically feasible control strategy is that of the vaccination of mature female twice every two years together with annual calf hood vaccination where the prevalence will drop from 25.1% to 4.3% in 2034 (Table 2 and Figure 3).



**Figure 3:** The prevalence rates of the alternative control strategies in 2034.

1: Without vaccination; 2: Whole herd vaccination every two years; 3: Whole herd vaccination every six years; 4: Vaccination of female calves once; 5: Vaccination of female calves every two years; 6: Vaccination of female calves every six years; 7: Mature female vaccination twice every six years together with annual calf hood vaccination.

### The cost of the disease in the baseline year (2012)

Table 3 presents the cost of brucellosis in Khartoum state in the base line year 2012. From the cost components it is apparent that milk loss constitutes the major item (more than 90% of the total cost). This is attributed to the fact that cattle raised in Khartoum state are mainly dairy breed with high percentage of foreign blood. Loss in calve harvest come next, which is the outcome of both the loss due to abortion and the increase in the inter calving period. Mortality due to brucellosis is almost negligible, the disease itself is not fatal but mortality due metritis is considered the mainly cause of death [38].

Cost item	Cost	%
Mortality	303349.3	0.9
Milk loss	30302212.2	90.3
Loss of calves harvest	2775646.1	8.3
Cost of repeat breeding	32646.2	0.1
Cost of veterinary intervention	134335.7	0.4
Total cost	33,548,189.5	100

**Table 3:** The cost of the disease in the baseline year (2012).

Source: Angara, et al. 2016.

### The total cost of the different technically feasible alternatives control strategies

Table 4 displays the total cost of the different alternatives strategies during the entire period (2012 - 2034) excluding strategy 4 which is technically unfeasible. Strategy 7 costs less than the others followed by strategy 2, 5, 3 and 6 respectively.

Strategy	The cost of the disease	Cost of vaccination	Total cost
1	1,565,055,104	0	1,565,055,104
2	493,384,378	10,276,896	503,661,274
3	683,064,160	3,425,632	686,489,792
5	677,032,292	1,413,073.2	678,445,365
6	903,123,082	471,024.4	903,594,106
7	440,522,520	9,445,323.83	449,967,844

**Table 4:** The total costs of the different alternative control strategies (SDG).

### The cost- benefits analysis of the different technically feasible alternatives control strategies

To analyze the financial feasibility of the different alternatives two criteria were used; the net benefit and the benefit cost ratio.

#### The net benefits

Table 5 shows the net benefit gained from each strategy. The strategy of vaccinating the mature female twice every six year and yearly calf hood vaccination proved to have the highest net benefit whereas; the strategy Vaccination of female calves every six years has the lowest net benefits.

Strategy	The benefits (SDG)	Total costs (SDG)	Net benefit (SDG)
2	1,565,055,104	503,661,274	1,061,393,830
3	1,565,055,104	686,489,792	878,565,312
5	1,565,055,104	678,445,365	886,609,739
6	1,565,055,104	903,594,106	661,460,998
7	1,565,055,104	449,967,844	1,115,087,260

**Table 5:** The net benefit of the technically feasible control strategies.

### The benefit -cost ratio (B/C)

Table 6 indicates that the strategy of vaccinating the mature female twice every six year and yearly calf hood vaccination have the highest benefit - cost ratio (3.5%). So it is superior to other strategies and recommended to be adopted.

Strategy	The benefits (SDG)	Total costs (SDG)	B/C
2	1,565,055,104	503,661,274	3.11
3	1,565,055,104	686,489,792	2.28
5	1,565,055,104	678,445,365	2.31
6	1,565,055,104	903,594,106	1.73
7	1,565,055,104	449,967,844	3.48

**Table 6:** The Benefit -Cost ratio of each technically feasible control strategy.

### The cost-effectiveness of the different alternative control strategies

From table 7, the cost of reducing the prevalence rate by 1% in each strategy was calculated. It is apparent that the strategy of vaccinating the mature female twice every six year and yearly calf hood vaccination is least cost strategy it needs only SDG 21,633,069.42 to reduce the prevalence by 1%. So it is the most cost-effective strategy.

Strategy	Prevalence in 2012 (%)	Prevalence in 2034 (%)	Drop in prevalence (%)	Total cost	Cost/1% drop in prevalence
2	25.1	5.4	19.7	503,661,274	25,566,562.13
3	25.1	11.6	13.5	686,489,792	50,851,095.7
5	25.1	10.0	15.1	678,445,365	44,930,156.62
6	25.1	16.5	8.6	903,594,106	105,069,082.1
7	25.1	4.3	20.8	449,967,844	21,633,069.42

**Table 7:** Cost effectiveness of the different alternative control strategies.

### The impact of the best control strategy on development

Table 8 displays the benefits gained from the adoption of the most feasible control strategy in monetary and non-monetary terms. If the best control strategy is adopted this will positively be reflected on the development process. That is because the death of 836 cows due to metritis will be averted. Their contribution in milk production and calving will have a positive impact. Also 335,641,265 liter of milk will be available and about 102,836 additional calves will be born, the problem of repeat breeding of 98,680 cows will be overcome and SDG 4,460,349 spent in curing animals will be saved.

Item	Net benefit (SDG)	Non-monetary benefits
Mortality averted	10,035,785.34	836 cows
Milk saved	1,006,923,795.78	335,641,265 liter
Additional calves harvest	92,552,242.58	102,836 calves
Averting repeat breeding	1,115,087.26	98,680 repeat breeder
Saving the cost veterinary intervention	4,460,349.04	-

**Table 8:** The monetary and non-monetary benefits gained from the most feasible control strategy.

In veterinary intervention will be preserved. All of which will act to enhance the development process at different levels. At macro level, through securing food, providing more employment, creating more forwards and backwards linkages and generating taxes revenue. At micro level the control strategy will act to improve the livelihood of the producers by generating more income and providing food for

their families. This is a part from controlling this zoonotic disease. These findings go along with [1] in their conception about the main objectives of development.

### Conclusions

The study concluded that Bovine Brucellosis in Khartoum state needs to be seriously considered. The results showed that unless serious control strategies adopted to protect animals from brucellosis the majority if not the whole animal population in the state will be infect by the disease. All mature female will be infected by the year 2034.

The vaccination of female calves once is not technically feasible, whole herd vaccination every two years and every six years yields better results than vaccination of female calves at the same intervals. However, mature female vaccination twice every six years together with annual calf hood vaccination is the best strategy studied. This strategy was proved to be the most technically and financially feasible as long as it has the least cost, yields the highest net benefit, highest benefit - cost ratio and it is the most cost-effective one. All these results indicate its superiority to other strategies. So it is highly recommended to adopt this strategy to protect animals in Khartoum state. This will promote the development process.

The study recommends developing of more advance model for the disease transmission to overcome the limitation of not considering transmission of the disease from the environment to animal. Also this model assumed a constant animal population, there is a need to simulate the control strategies with growing animal population.

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