بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

Sudan University of Science and Technology

College of Graduate Studies

Enhancement of the Development Process by Controlling Bovine Brucellosis in Khartoum State-Sudan

دفع عجلة التنمية بالسيطرة علي بروسيلا الأبقار بولاية الخرطوم – السودان

A Dissertation Submitted in Partial Fulfillment of the Requirement for the Degree of Master of Economics of Animal Resources Development

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

﴿وَمَا تَوْفِيقِي إِلَّا بِاللَّهِ ۚ عَلَيْهِ تَوَكَّلْتُ وَإِلَيْهِ أُنِيبُ﴾

سورة هود الآية 88

Dedication

I dedicate this work, with love and gratitude,

to my mother Zahra Abdulrahman Slum, my father and my daughters Shahad and Ginwan Ismail Abdel Kareem, for their endless support, encouragement and patience throughout the period of my study. My gratitude and prayers to my late husband Ismail Abdel Kareem, may Allah accept him and put him in paradise.

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ABSTRACT

Brucellosis is one of the most common diseases among animals especially cattle, it can attack human as well. Khartoum State is confirmed to be endemic with bovine brucellosis yet, there is no formal strategy adopted to control the disease. The current study aims at developing a control strategy for bovine brucellosis in Khartoum State. The study was based on prevalence rate of 25.1% obtained by the research project entitled: Compliance with World Trade Organization (WTO) Agreement on the Application of Sanitary and Phytosanitary Measures by Formulating a Long Term Animal Brucellosis Control Strategy in Khartoum State in 2012. The evolution of the disease without control was projected until the year 2034 at which all mature females are expected to be infected. Six different strategies were proposed, these were: 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 calf hood vaccination. The six strategies were simulated until 2034 and their technical and financial feasibilities were compared, technically by comparing the prevalence rates in 2034 and financially by comparing the net benefit and the benefit – cost ratio of the technically feasible strategies. Also the cost-effectiveness criterion was used. Microsoft excel programme was used in the analysis. The study revealed that all the proposed strategies except the strategy of vaccination of female calves once are technically feasible. The cost-benefit and cost-effectiveness analyses indicated that the strategy of mature females vaccination twice every six years together with annual calf hood vaccination is the most feasible and cost effective one. The prevalence rate in this strategy will drop to 4.3%in 2034, the net

benefit is SDG **1,115,087,260**, the benefit -cost ratio is3.48 and it needs SDG 21,633,069.42 to drop the prevalence by 1%.The impact of the most feasible strategy on the development wasexpressed in form ofmortality 836cows averted**,** 335,641,265litermilk saved,addition to calves harvest by 102,836 calves, averting repeat breeding of 98,680 cows and saving ofSDG 4,460,349.04the cost veterinary intervention. Above all the human health will benefit from controlling this zoonotic disease. The study recommended adoption the strategy of mature females vaccination twice every six years together with annual calf hood vaccination to control bovine brucellosis in Khartoum State.

المستخلص

يعتبرالبروسيلوزيس احد الامراض الأكثر شيوعا بين الحيوانات وخاصة الابقار كما وانها يمكن ان تصيب الإنسان كذلك.تم اثبات توطنالمرض في ولاية الخرطوم ،الا أنه لا توجد هنالك استراتيجية رسمية معتمدة من الولاية للسيطرة علي المرض.تهدف هذه الدراسة إلى وضع استراتيجيةطويلة المدي للسيطرة على البروسيلوزس في الابقار بولاية الخرطوم.اعتمدت الدراسة على معدل انتشار بلغ 25.1٪ استناداً علي النتائج التي توصل اليها المشروع البحثي بعنوان: الامتثال لاتفاقية منظمة التجارة العالمية الخاص بتطبيق تدابير الصحة والصحة النباتية بوضع استراتيجية طويلة المدي للسيطرة علي البروسيلوزس في الحيوان في ولاية الخرطوم في عام 2012. تم التنبؤ بتطور المرض بدون السيطرة عليهحتي العام 2034 حيث من المتوقع أن تكون جميع الإناث الناضجة مصابة. ثم تم اقتراح ست استراتيجيات مختلفة وهي: التطعيم الكامل للقطيع كل سنتين، التطعيم الكامل للقطيع كل ست سنوات، تطعيم العجلات مرة واحدة، تطعيم العجلات كل سنتين، تطعيم العجلات كل ست سنوات و تطعيم الاناث الناضجة مرتين كل ست سنوات جنبا إلى جنب مع تطعيم العجول سنويا.

تمت محاكاة الاستراتيجيات الست حتى عام 2034 وتمت مقارنة جدواها الفنية والمالية. قورنت الاستراتيجيات من الناحية الفنية بمعدل الانتشار في عام 2034 ومن الناحية المالية بمقارنة صافي العائد ونسبة العائد الى التكاليف في الاستراتيجيات المجدية فنياً.كما تم استخدام معيار فعالية التكلفة. واستخدم برنامج ميكروسوفت إكسيل في التحليل .توصلت الدراسة أن جميع الاستراتيجيات المقترحة ما عدا إستراتيجية تطعيم العجلات مرة واحدة مجدية من الناحية الفنية.وأشارت نتائج تحليل التكلفة والفوائد وفعالية التكلفة إلى أن استراتيجية تطعيم الإناث الناضجة مرتين كل ست سنوات بالاضافة الى تطعيم العجول سنويا هي الأكثر جدوى وفعالية من حيث التكلفة. يتوقع في هذه الاستراتيجية ان ينخفض معدل الانتشار إلى 4.3% في عام 2034، وصافي العائد هو 1,115,087,260, جنيه سوداني، ونسبة الفائدة للتكلفة هي3.48% وهي تحتاج إلى 21,633,069.42 جنيه سوداني لتقليل الانتشار بنسبة 1%. وقد تم التعبير عن تأثير أكثر الإستراتيجيات جدوى على التنمية في شكل تقليل وفيات الابقار ب836بقرة ، وتوفير335,641,265 لتراً من الحليب بالإضافة إلى زيادة حصاد العجول ب 102,836 عجلا، وتجنب التلقيح المتكرر ل 98,680 بقرة وتوفير 4,460,349.04جنيه سوداني تكلفة الخدمات البيطرية.فوق كل هذا فإن صحة الانسان تستفيد كثيراً من السيطرة على هذا المرض المتناقل ، وعليه أوصت الدراسة بتبني أستراتيجية تطعيم الابقار البالغة مرتين كل ستة سنوات مع تطعيم العجول سنوياً للسيطرة على المرض في ولاية الخرطوم.

CHAPTER ONE

1. Introduction

1.1. Background

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 forward and backward linkages (Evans *et al*., 2002). Worldwide the negative economic impacts of animal diseases result from the animal been infected and the measures taken to mitigate its risk. This is especially paramount in the developing world where livestock diseases have broader, more nuanced effects on markets, poverty, and livelihoods. Brucellosis is one of the five common bacterial zoonosis in the world caused by organisms belonging to the genus Brucella (Jinkyung and Splitter, 2003). 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 (Unger *et al*, 2003). Although Sudan is one of the richest countries in its agriculture and animal recourses, but it failed to expand its animal export and to invade new world markets.

1.2. Statement of the Problem

Brucellosis was proved to endemic in Sudan and Khartoum State in particular both animal (Osman *et al*., 2014) and human brucellosis (Mustafa and Hassan, 2010). A recent study by Angara *et al*., (2016) estimated the prevalence rate of bovine brucellosis at 25.1% and the financial cost of bovine brucellosis in Khartoum State at US$ 3,293,084.6 annually due to reduction of milk production, loss in calves harvest, repeat breeding and cost of veterinary intervention. The impact of the disease on human health cannot be over seen, 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 research.

1.3. Objectives of the Research

1.3.1. Main Objective

➢The aim of this work is to formulate a cost effective long-term bovine brucellosis control strategy in Khartoum state. As we stated previously, control of Brucellosis is positively affect the development process in the state.

1.3.2. Specific Objectives

➢To simulate the following proposed control strategies.

Strategy 1: Whole herd vaccination every two years.

Strategy 2: Whole herd vaccination every six years.

Strategy 3: Vaccination of female calves once.

Strategy 4: Vaccination of female calves every two years.

Strategy 5: Vaccination of female calves every six years.

Strategy 6: Mature females vaccination twice every six years together with annual calf hood vaccination.

➢To estimate the prevalence rate for each strategy.

➢To conduct cost benefit analysis for the technically feasible strategies.

➢To find out the most cost- effective strategy.

➢To assess the impact of the most cost- effective strategy on the development.

1.4. Research Importance

Controlling bovine brucellosis in Khartoum State is necessary to reduce animal death and meat and milk losses. As well as reducing the cost of veterinary and medical intervention to treat both infected human and animal. Disease free animals will promote international animal export to generate foreign currency. More employment opportunities will be provided. All of this will promote the development process.

1.5. Research Hypotheses

- ❖ without control strategies adopted, brucellosis will spread in the state until the whole animal will be infected.
- ❖ All of the proposed strategies are technically feasible.
- ❖ Mature female vaccination twice every six years together annual calve vaccination is the most cost- effective strategy.
- ❖ The most cost- effective strategy has a positive impact on development.

1.6. Research Layout

Chapter one: An introductory chapter includes, background, research problem, objective, hypotheses and the research layout.

Chapter two: Reviewing the related literature.

Chapter three: Displays the methodology of the research.

Chapter four: Presents the results of the research and their discussion.

Chapter five: Provides the conclusion of the research and the recommendations set.

CHAPTER TWO

2. Literature Review

2.1. Meaning of Development

Todaro and Smith (2011) define development as the process that improve the quality of human lives and raise the people's levels of living, to assure self-esteem, and freedom. They also defined economic development as elimination of poverty, inequality, and unemployment within the context of a growing economy. Development has been associated with economic, social, and political change in the countries of Africa, Asia, Latin America, the Caribbean and the South Pacific. Seers, (1979) stated that poverty, unemployment and inequality are considered the central challenges that face these nations and they try to combat or at least to minimize them.

The capacity of a state to increase its human resource with the aim of achieving higher outcome of production to satisfy the basic needs of majority of the citizens and empowering them to make demands on the government was definition of development from Sulemana (2010) point of view. However, Meyer (1990) provided a religious view on development considering it as a positive change in the whole of human life materially, socially and spiritually in what calls transformational development.

The process of economic development cannot abstract from expanding the supply of food, clothing, housing, medical services, educational facilities, etc. and from transforming the productive structure of the economy, and these important and crucial changes are undoubtedly matters of economic growth. The relation between GNP and living conditions is far from simple.

Todaro and Smith (2011) stated that: development in all societies must have at least the following three objectives:

1. To increase the availability and widen the distribution of basic life-sustaining goods such as food, shelter, health, and protection.

2. To raise levels of living, including, in addition to higher incomes, the provision of more jobs, better education, and greater attention to cultural and human values.

3. To expand the range of economic and social choices available to individuals and nations by freeing them from servitude and dependence not only in relation to other people and nation-states but also to the forces of ignorance and human misery.

2.2. Animal Health and Development

Animal disease pose significant threats to livestock sectors throughout the world, both from the standpoint of the economic impacts of the disease itself and the measures taken to mitigate the risk of disease, because the impacts of an outbreak can be quite costly and far-reaching (James *et al*., 2005; Karl and Brian, 2011).

Developing countries often face severe animal health problems, with a number of endemic diseases, and lack resources to put in place the animal health programs as in more developed nations (Harrison and Tisdell, 1995). FAO, (2002) pointed out that there a major challenge for developed as well as developing countries. This challenge is the resurgence of serious infectious livestock diseases and veterinary public-health problems. For Zessin and Carpenter (1985) in the developing countries the livestock production and industries contribute with high percent of the national income yet, these countries typically suffer from inadequate veterinary services, such as “remote infrastructure, poor communications and lack of laboratory facilities”, thus formulation and implementation of control strategies are important for the improvement of animal health and for motivation of the economic goals for livestock industries and human health. Harrison and Tisdell (1995) mentioned that the social costs including lost trade opportunities as a result of animal diseases often exceed the private costs to livestock producers, thus improving animal health is a mean of promoting sustainable development through more efficient resource use, additional export earnings to finance economic growth, improved livelihood of livestock producers and increased animal welfare. Hubbard (1986) suggested that improved animal health may make a significant contribution to both development of the livestock sector and overall national development, and be particularly important to developing countries and countries placing a high priority on export income. For FAO (2002) the farmers are more aware of the possibility of treating and controlling these diseases, but there are major problems of giving poor farmers access to the tools they need for control, such as anthelmintic to treat parasitism, and the knowledge to use these tools effectively to enhance income and food security.

2.3. Brucellosis

According to Boschiroli *et al., (*2001) brucellosis is one of the world's major zoonoses. Nine species were assigned to the *Brucella genus;* these species are *Brucella abortus*, *Brucella melitensis*, *Brucella suis*, *Brucella ovis*, *Brucella canis*, *Brucella neotomae*. *Brucella ceti* and *Brucella microti* (Mantur *et al.*, 2007; Scholz, *et al.*, 2009). Finally, a new species, *Brucella inopinata*, was isolated from a breast implant and from a lung biopsy (Scholz *et al.*, 2010; Tiller *et al*., 2010). Brucella have different host preferences, it mainly affects cattle, sheep, goats, camels and pigs, as well as humans (Bercovich, 2000; Roth *et al.*, 2003; Racloz *et al.*, 2013; Verger, 1987; Delvecchio *et al.*, 2002).

Humans generally acquire the disease through direct contact with infected animals, Person-to-person transmission is rare (WHO, 2006). It is endemic in many countries and across various animal production settings, and is responsible for considerable economic losses and public health burden (Hou *et al*., 2013; Racloz *et al*., 2013). Brucellosis causes heavy economic losses in animal production resulting from clinical disease, abortion, neonatal losses, reduced fertility, decreased milk production, and emergency slaughtering of the infected animals (Ariza *et al*., 1995) and acts as impediment to free animal movement and export (Al-Majali, 2005). Bovine brucellosis is usually caused by *B.abortus*, less frequently by *B. melitensis*, and occasionally by *B. suis* (Bishop *et al*., 1994). Although the serological test remains the most practical method in the diagnosis of *B. abortus* (Gall & Nielsen,2004) yet bacterial culture and identification is the gold standard for diagnosis (Morgan, 1977; Nielsen, 2002). The PCR provides an additional means of detection and identification of *Brucella sp.* (OIE, 2009).

2.4. Control of brucellosis

Regular programs of test and removal in low level of infection conditions can be used for obtaining disease-free livestock (Jelastopulu *et al*., 2008). However, according to Nicolette, (1984) reduction of brucellosis is best accomplished by widespread use of vaccines. Vaccination of adult animals is the most effective method of controlling brucellosis. A good and ideal vaccine totally has two common features, harmless and effectiveness (WHO, 1997). Based on Hasanjani-Roushan *et al*., (2014) vaccines must prevent of infection in both sexes, prevent abortion, vaccination just for one time makes long term prevention, should not contaminate milk and meat and free of reversion to virulence.

Currently, S19 and RB51 are the *B. abortus* vaccine strains more widely used to prevent brucellosis in cattle (Miranda *et al*., 2015). Both vaccines are effective in the prevention of abortion and infection, besides offering long lasting protection

(Miranda *et al.*, 2015; Olsen, 2000). Heat-killed *B. abortus* strain 45/20 vaccine is recommended for pregnant livestock (Moriyon *et al.,* 2004).

Madhava prasad *et al*., (2014) provided full information about the control programmed on herd bases. In case of epidemic they recommended vaccination of nonreactors 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.

A rapidly effective vaccination strategy for brucellosis control in areas with high prevalence has not been identified, although a test-and-slaughter strategy, in herds with high disease prevalence, has been recommended. Financially, this option is unattractive and unlikely to be feasible in resource-poor countries.

Young stock should be vaccinated before sexual maturity. Biannual vaccination of young stock may be required especially in cases of year-round breeding programmed are planned. Vaccinated animals have a high degree of protection against abortion and 65-75% are resistant to most kinds of exposure.

Vaccinating adult cattle with S19 reduces number of infected cows in large dairy. Complete eradication can be done by test and slaughter policy. Vaccination of bulls is no value in protecting them against infection and has resulted in development of orchitis and presence of *B.abortus* strain 19 in the semen.

2.5. Cost- benefit and cost-effectiveness analysis

Cost-benefit analysis. (CBA) is a technique used to evaluate individual projects, or compare alternative projects, which involve costs and generate revenues over a number of years. (Levenstein and Dunn, 2005).

Cost-benefit analysis uses monetary units to quantify costs and outcomes and has a broader scope of application than other types of analysis. Nevertheless, well-known problems associated with CBA, particularly the difficulty of measuring health, biological and environmental effects in monetary units, this dictated a limited use of CBA in human health and other areas (Hutubessy *et al*., 2001; Petitti, 2000; Schleiniger ,1999). However, in the analysis of animal health, welfare or production interventions, CBA has been the preferred tool for economic evaluation to date (Rich *et al*., 2005) and is used either to justify a defined strategy (ex-ante analysis) or to assess the impact of a past programmed (ex-post analysis) (Rushton *et al*., 2009).

Cost-effectiveness analysis (CEA) overcomes the problem of attributing monetary figures to some effects, by calculating the costs in units of currency while expressing benefits in the most appropriate natural non-monetary effects. By using non-monetary effects to express the benefits, CEA is programmed specific and can only compare interventions that use the same units of effectiveness (Drummond *et al*., 2005; Cohen & Reynolds, (2008); Gold *et al*., 1996). The results of a CEA are normally presented in the form of a ratio that expresses the price per effectiveness unit (Babo Martins and Rushton, 2014).

2.6. Relevant Studies

In the North of Portugal, a mass vaccination programmed of small ruminants was conducted from 2001 to 2004; Coelho *et al*. (2011) study the cost-benefit analysis in order to estimate the cost of the zoonosis, the compensation costs paid to farmers for culled animals in the Brucellosis Eradication Campaign, data from vaccine Rev. 1 costs, and costs of people internment due to brucellosis were studied. They observed that a significant decrease from 2001 to 2004 (from more than US$1,200,000 in 2001 to US$180,000 in 2004), roughly US$ 1,020,000 less. Concluding that Mass vaccination decreased human and animal brucellosis and, consequentially, the amounts paid in animal compensation were shown to decrease in this cost-benefit analysis. Despite the limitations of this study, the results of this analysis suggest that mass vaccination with Rev. 1 reduced overall costs and was effective in reducing sheep and goat as well as human brucellosis costs.

CHAPTER THREE

3. METHODOLOGY

3.1. The Study Area

Figure 1. Khartoum State

Source: (Wikipedia, 2017)

Khartoum State is one of the eighteen states of Sudan. It is divided into 7 main localities (Khartoum, JabalAwliya, Omdurman, Ombada, Karary, Bahry and SharqElnil). Although it is the smallest state by area (22,142 km^2), it is the most populous. The human population of Khartoum is approximately six million people. The state lies between longitudes 31.5 to 34 °E and latitudes 15 to 16 °N. It is surrounded by River Nile State in the north-east, in the north-west by the Northern

State, in the east and southeast by the states of Kassala Gedaref and Gezira, and in the west by North Kurdufan. The northern region of the state is mostly desert, whereas the other regions have semi-desert climates. Average rainfall reaches 100–200 mm in the north-eastern areas and 200–300 mm in the northwestern areas. The temperature in summer ranges from 20 to 40 °C from April to October. While in winter it ranges from15 to 25°C between March and November (Wikipedia, 2017).

3.2. Sources of Data

The data were mainly obtained from secondary source as appear in the section of parameters and their sources.

3.3. The study population

Cattle population in Khartoum state.

3.4. The Models Used in the Analysis

3.4.1. The disease transmission model

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

A) Assumption of the model

1- Constant herd size (births = mortality + extraction)

2- The model considers three groups of animals.

P = total animal population = (S+I+V)

S = number of susceptible animals.

I = number of seropositive animals.

V = number of vaccinated animals.

3- Vaccine efficacy of S19 is 0.7 (Kang *et al*., 2014).

4- Vaccination coverage 100%

5- Six vaccination strategies were proposed.

Strategy 1: Whole herd vaccination every two years.

Strategy 2: Whole herd vaccination every six years.

Strategy 3: Vaccination of female calves once.

Strategy 4: Vaccination of female calves every two years.

Strategy 5: Vaccination of female calves every six years.

Strategy 6: Mature female's vaccination twice every six years together with annual calf hood vaccination.

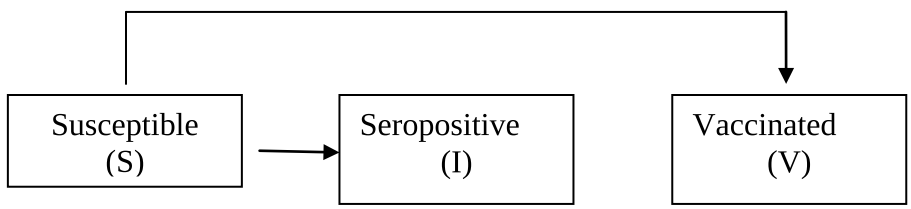

Figure 2: The disease transmission model

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

Incidence $_{cattle}$ = $\gamma_c \beta_c SI$ ………………………………………. (1)

Where:

γ_c = proportion of seropositive animals.

β_c = cattle contact rate.

Contact rate (β_c) = k/ (N-1)/ Number of seropositive animals (Carpenter, 1987).

Where:

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

N= animal population.

B)The annual change in the number of animals

1. The annual change in the number of susceptible animals

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

$dS / dt = - \gamma c \beta c SI - V$ ………………………………………… (2)

2. The annual change in the number of infected animals

Change in the number of infected animals (I) (the flow in) is the newly infected animals (incidence of the disease).

$dI / dt = \gamma c \beta c SI$.. (1)

3.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

$dV/dt = V$………………………………………………… (3)

C) The Parameters fitted in the model and their sources

(i) Total cattle population = 244688 head (Anon, 2012).

(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% (Angara *et al*., 2009).

(iii) Number of seropositive mature females = Number of mature cow x prevalence rate 25.1% (Angara *et al*., 2016).

(iv) Number of calve is obtained by multiplying the total number of cattle x 17.5% (Angara *et al*., 2009).

3.4.2. The disease cost model

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

TL = LMD+ LMT

Where;

TL = total loss

LMD= loss due to morbidity

LMT = loss due to mortality

LMD = ML+ CL+ RB+ VI

Where;

ML= loss due to milk reduction

CL= loss due to reduction in calve harvest

RB= loss due to repeat breeding

VI = cost of veterinary intervention

The assumptions of the model and their sources

(i) Loss due to mortality

Mortality due to metritis 1% (Santos *et al*. 2013) x value of mature cow, price of mature cow =12000 SDG (Angara *et al*., 2016).

(iii) Annual loss of milk= (20% reduction of milk production of aborted cow x nun aborted cows +10% reduction of milk production of non-aborted cow x number of non-aborted cows) x Annual milk yield x price of milk (in 2012).

Annual milk yield of 2,614 Kg/cow (Medani, 1996).

Price of milk SDG 3 obtained from field data

10% loss of the total milk yield of infected non-aborted cows and 20% loss of the total milk yield of infected aborted cows (Shepherd *et al.*, 1979).

(iv) Loss due to reduction in calve harvest = (number of aborted calves + loss due to increase inter-calving period) x price of weaning calves.

Average price of weaning calf of 900 SDG (Osman, *et al.*, 2014).

(v) Loss due to repeat breeding = number of repeat breeder’s x cost of repeat breading per cow.

A rate of repeat breeding of 0.08 (adapted from 0.15 infertility rate due to brucellosis (Zinsstag, *et al.*, 2005) and 7% abortion rate of seropositive

Cost of repeat breeding per cow of SDG 11.3 based on Angara and Elfadil (2014)

(vi) Cost of veterinary intervention = number of seropositive aborted cows x cost of veterinary intervention per cow.

Cost of veterinary intervention per cow of SDG 53.141 according to Elfadil (2014).

(vii) Number of seropositive aborted females = Number of seropositive mature female's x 7% of abortions in infected cows (Osman, *et al*. 2014).

(xiii) 1$US= SDG 4.6 (Anon, 2014).

3.4.3. Cost- benefit model

A: The costs

TC= VC+ DC

Where:

TC= Total cost of the disease.

VC= Cost of vaccination.

DC= Cost of the disease.

Whereas;

Cost of the disease = number of seropositive x cost of seropositive.

Cost of vaccination= number of animals vaccinated x cost of vaccination per head = SDG 5.0 (adapted from Khartoum State ministry of Agriculture and animal Resources and irrigation, 2017)

B: The benefits

All costs in case of without control were transferred to benefits in all control strategies (Dietrich, *et al.*1979).

C: The profitability criteria

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

1- The net benefit = benefits -costs
2- Profitability index = Benefits/ costs
3- Cost-effectiveness analysis = cost per1% fall in prevalence.

Cost-effectiveness ratio (CE)

CE ratio = Cost of intervention / effectiveness intervention

3.5. Data analysis

Microsoft Excel 2010 was used to analyze the data. Where Microsoft Excel is a part of Microsoft Office, developed by Microsoft for Windows, and other operating systems. It uses for calculation, graphing tools and tables (Wikipedia, 2017).

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1. The Model

The model used in this study consisted of three compartments: susceptible (S), Seropositive (I) and Vaccinated (V). This model is like that developed by Zinsstag *et al*., (2005) which consists of three compartments (X) susceptible animal and compartment (Y) the seropositive cattle and (Z) immune cattle. In the other hand this model differs from that developed by Gonzalez –Guzman and Naulin (1994) whom model consists of four compartments: Susceptible (S), aborting infectious (I_1), infectious carriers (I_2) and immune by vaccination (Ǿ). Also, this model differs from kuku model developed by Angara (2005) 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.

4.2. Evolution of Brucellosis without Control

Figure 3 and appendix a present the development of bovine brucellosis in Khartoum state during the period 2012 up to 2034 under the assumption of

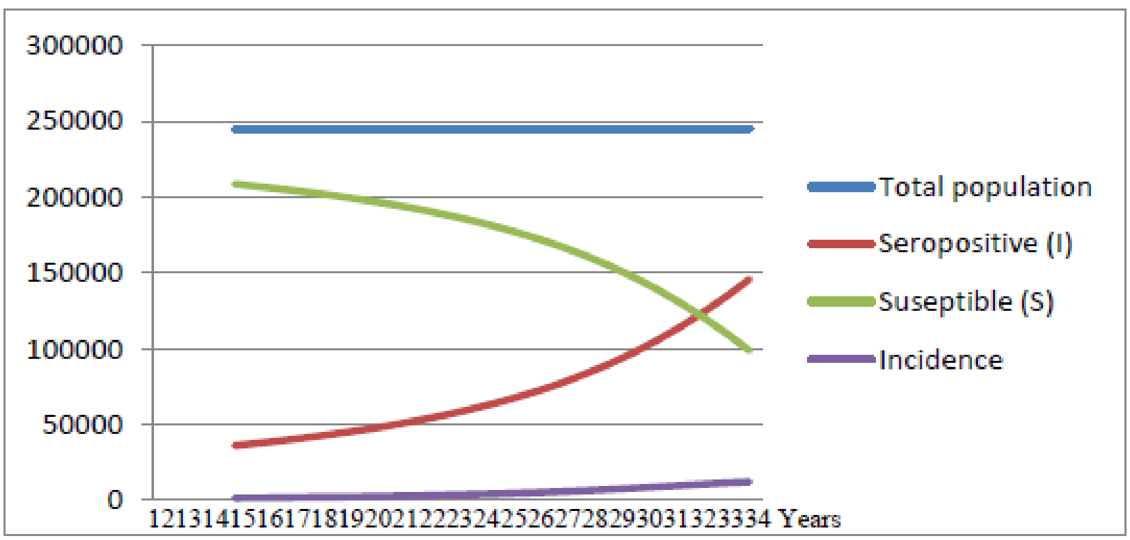

Fig. 3. Evolution of brucellosis without control

constant population herd size and without adoption of any control measures. The disease evolves until all mature females become infected in 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

Table4.1. The change in the number of susceptible and seropositive animals during 2012-2034

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	677,167	-4,676	4,676
2026	244,688	167,092	775,956	-5,797	5,797
2028	244,688	154,831	898,57	-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

Source: computed by the researcher from appendix a ,2017

started to decrease as a result of new infection and expected to reach 98797 head by year 2034 (about 40% of the total) .At the same time the number of seropositive animals increase gradually from less than 40000 (about 14% of the total) in year 2012 and expected to reach more than 145000 (about 60% of the total) in 2034. These figures indicates that unless adopted serious control strategies to protect animals from brucellosis the majority if not the whole population in the state will be infect by the disease.

Incidence (newly infected) is increasing from about 1500 and expected to reach more than 12000 by year 2034 (Table 4.1). This result shows the necessity of control strategies to insure animal health and development.

The prevalence of the disease will increase from 25.1% in the base line year to 101.4% in the last year where all mature females will be infected (Table 4.2).

4.3. 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.

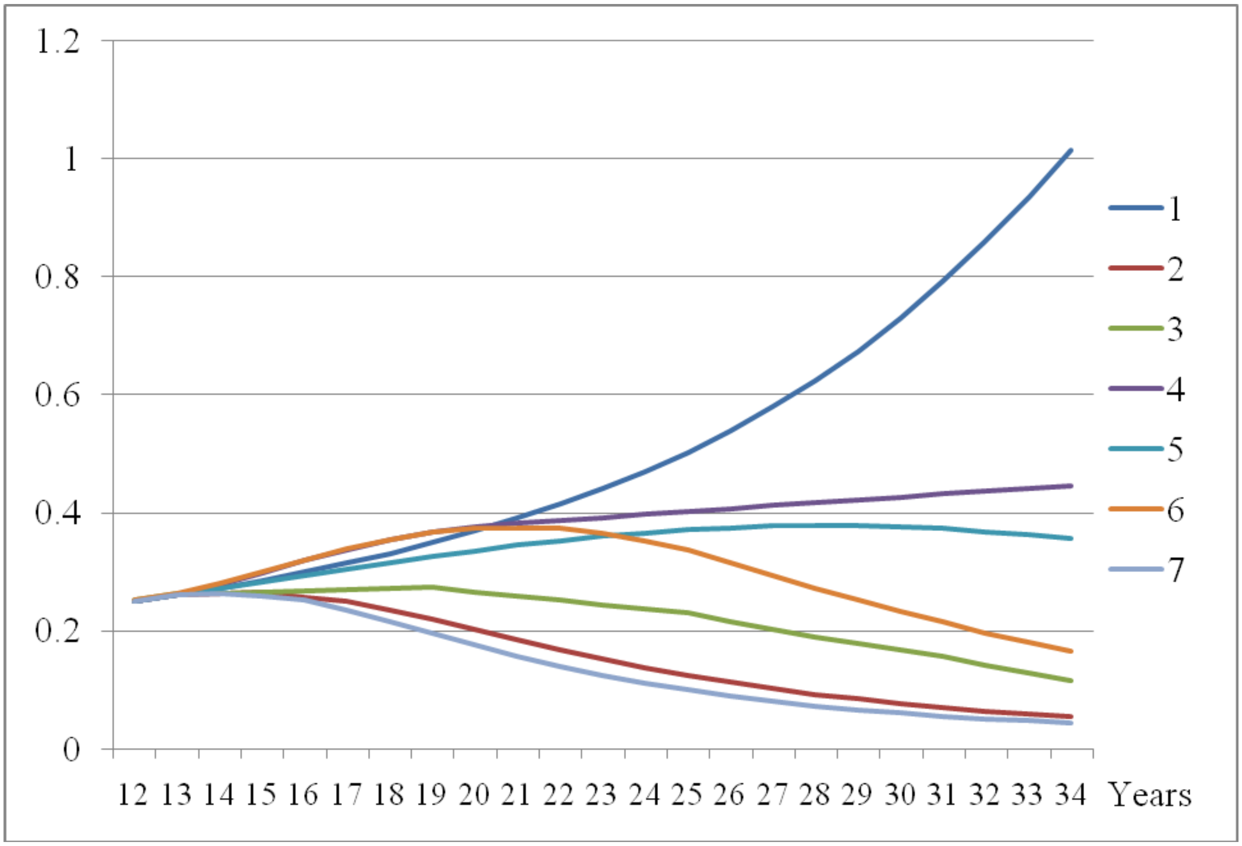

Fig. 4. Prevelance of brucellosis with and without control from year 2012 up to 2034

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 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%).

4.4. The prevalence Rates of the Disease after Vaccination

Table 4.2 and figure 4 present the prevalence rates of the disease in the case of no vaccination and in each alternative vaccination strategy adopted.

Table 4.2. Prevalence rates at the different vaccination strategies during 2012-2034

Strategy / Years	1	2	3	4	5	6	7
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

Source: computed by the researcher from appendix c,d,e,f,g and h,2017

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's vaccination twice every six years together with annual calf hood vaccination.

The results revealed that the prevalence 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 slighty increase in the first four years from vacination then it will start to decrease in the fifth and continued to decrease rapidly and expected to reach 5.4 % in 2034 (Appendix c).

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 decrease in year nine and continue to decline rapidly and expected to reach 11.6% in the year 2034 (Appendix d). This also show the effect of the disease incidence out weight the first vaccination, then the effect of the vacination started after the second round.

The prevalence in case of female calves vacination once showed no drop in the prevalence instead it increase from 25.1% the 2012 to 44.5% in 2034 (Appendix e) indicating that this strategy is techically unfeasible. On the other hand vaccination of the female calves every two year and every six year looks to be sound and technically feasible because the prevalence drop to 10.0% and 16.5% in 2034 respectively (Appendix f and g).

The best result was obtained from the vaccination of mature female twice every six years together with annual calf hood vaccination where the prevalence drop from 25.1% to 4.3% in 2034 (Appendix h).

4.5. The Techincal Feasibility of the Alternatives Control Stratgies

Figure 5 presents the prevalence rates of the alternatives control strategies in the year 2034. Accordingly, these control strategies can be ranked based on their technical feasibility as follows:

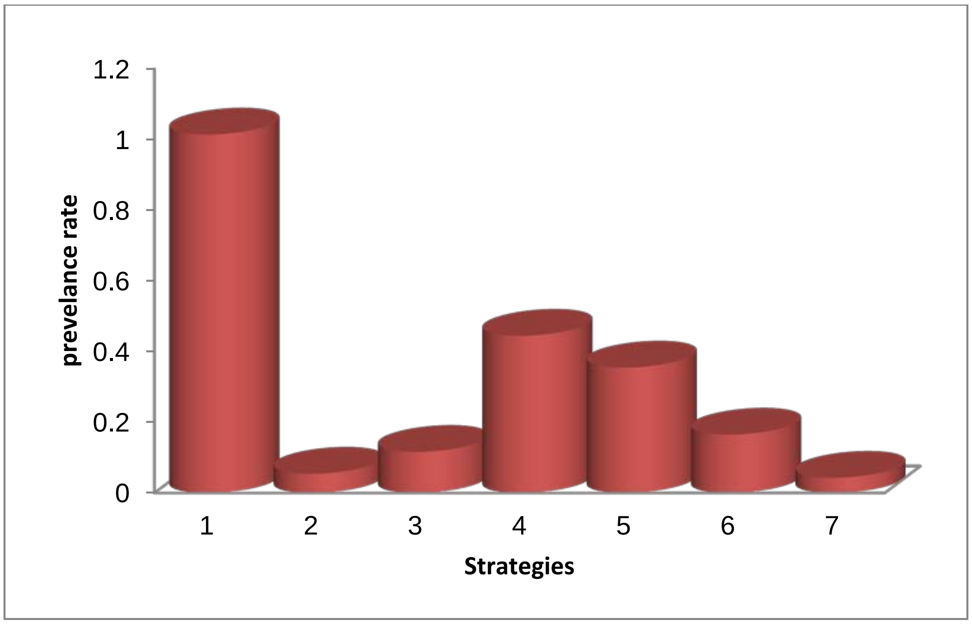

Figure 5. The prevalence rate of the alternative control strategies in 2034

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.

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.

4.6. The Cost of the Disease in the Baseline Year (2012)

Table 4.3, figure 6 and appendix b present the cost of brucellosis in khartoum state. For the cost components it is apparent that milk loss constitutes the major item (more than 90% of the cost components). This is attributed to the fact that

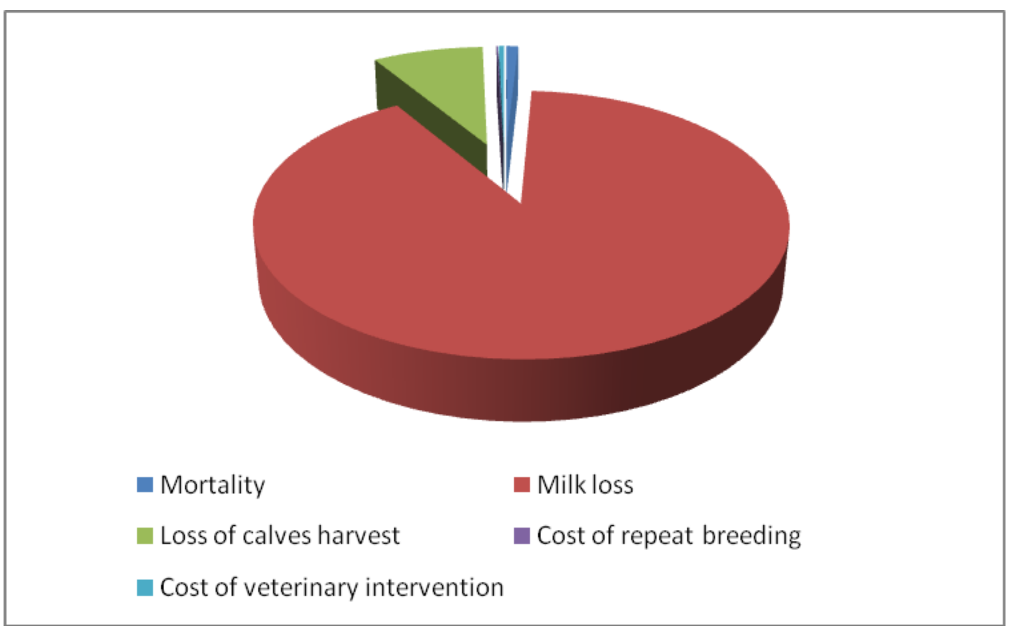

Figure6. The cost of the disease in 2012

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 intercalving period. Mortality due to brucellosis is almost negiligable , the disease it self is not fatal but mortality due mitritis is considered the mainly cause of death.

Table 4.3. The cost of the disease in the baseline year (2012)

Cost item	cost	%
Mortality	303349.3	0.9
Milk loss	30302212.2	90.3
Loss of calve harvest	2775646.1	8.3
Cost of repeat breeding	32646.2	0.1
Cost of veterinary intervention	134335.7	0.4
Total cost	33548189.5	100

Source: computed by the researcher from appendix b,2017

4.7. The Total Cost of the Different Technically Feasible Alternatives Control Strategies

Table 4.4 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 repectively.

Table 4.4 The total costs of the different alternative control strategies (SDG)

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

Source: computed by the researcher from appendix b, 2017

4.8. The Cost- benefit Analysis of the Different Technically Feasible Alternatives Control Strategies.

To analyse the financial feasibility of the different alternatives two criteria were used

1. **The net benefit**

   Table 4.5 shows the net benift 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.

   Table 4.5. The net benefit of the techically feasible control strategies

Strategy	The benefits(SDG)	Total costs(SDG)	Net benefit(SDG)
2	156,505,510,4	503,661,274	**1,061,393,830**
3	156,505,510,4	686,489,792	**878,565,312**
5	156,505,510,4	678,445,365	**886,609,739**
6	156,505,510,4	903,594,106	**661,460,998**
7	156,505,510,4	449,967,844	**1,115,087,260**

   Source: computed by the researcher from appendix b, c, d, f and g. 2017

2. **The Benefit –Cost ratio (B/C)**

Table 4.6 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.

Table 4.6 The Benefit –Cost ratioof each techincally feasible control strategy

Strategy	The benefits (SDG)	Total costs(SDG)	B/C%
2	156,505,510,4	503,661,274	**3.11**
3	156,505,510,4	686,489,792	**2.28**
5	156,505,510,4	678,445,365	**2.31**
6	156,505,510,4	903,594,106	**1.73**
7	156,505,510,4	449,967,844	**3.48**

Source: computed by the researcher from appendix b, c, d, f and g. 2017

4.9. The Cost-effectiveness of the Different Alternative Control Strategies

From table 4.7 the cost of reducing the prevalence rate by 1% in each strategy was calculated. It is apprent 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.

Table 4.7. Cost effectiveness of the different alternative control strategies

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**

Source: computed by the researcher from appendix b, c, d, f and g. 2017

4.10. The Impact of the Best Control Strategy on Development

Table 4.8 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 and 335,641,265 liter of milk will be available, about 102,836 additional calves will be born, the problem of repeat breeding of 98,680 cows will beovercomeandSDG4,460,349 spent 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 apart from controlling this zoonotic disease.

Table 4.8. **The monetary and non-monetary benefits gained from the most feasible control strategy**

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 liters
Additional calves harvest	92,552,242.58	102,836 calves
Averting repeat breeding	1,115,087.26	98,680 repeat breeders
Saving the cost veterinary intervention	4,460,349.04	

CHAPTR FIVE

5. CONCLUSION AND RECOMMENDATIONS

The study concluded that Bovine Brucellosis in Khartoum state needs to be seriously considered. The results showed that unless adopted serious control strategies 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, yeilds the highest net benefit and the highest benefit – cost ratio and it is the most cost-effective one. All this shows its superiortyto other strategies. So it is highly recommended to protect animals in Khartoum state.

Adoption the strategy of lowest cost and highest benefits lead to control brucellosis. Consequently, this will promote the development process through reducing the death of animal and increasing milk and meat production. Hence securing food, providing more employment, creating more forwards and backwards linkages and generates taxes revenue.

RECOMMENDATIONS

1. 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.

2. This study assumed a constant animal population; there is a need to simulate the control strategies with growing animal population.

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Appendix a.

Evolution of Bovine Brucellosis Without Vaccination

Parameters	**Unit**	**Value**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Total population	Head	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688
Calve less than 1 year	%	0.275	67289.2	67289.2							
Female calve			33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6
Heifers	%	0.123	30096.6	30096.6	30096.6	30096.6	30096.6	30096.6	30096.6	30096.6	30096.6
Bulls	%	0.014	3425.63								
Mature female	%	0.588	143877	143877	143877	143877	143877	143877	143877	143877	143877
Prevalence	%	0.251	36113								
Abortion	Rate	0.07	2527.91								
Seropositive (I)	Head		36113	37680.4	39374	41208.2	43199.2	45365.9	47729.7	50315.2	53150.7
Suseptible (S)	Head		208575	207008	205314	203480	201489	199322	196958	194373	191537
Infection rate	%		0.14759	0.15399	0.16092	0.16841	0.17655	0.1854	0.19506	0.20563	0.21722
Seraborted			2527.91	2637.63	2756.18	2884.57	3023.95	3175.61	3341.08	3522.07	3720.55
Serodeliverd			9931.08	10362.1	10827.9	11332.2	11879.8	12475.6	13125.7	13836.7	14616.5
Effective contact (K)			12459	12999.7	13584	14216.8	14903.7	15651.2	16466.8	17358.8	18337
N-1			244687	244687	244687	244687	244687	244687	244687	244687	244687
K/N-1			0.05092	0.05313	0.05552	0.0581	0.06091	0.06396	0.0673	0.07094	0.07494
Contact rate (βc)			1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06
Incidence			1567.42	1693.61	1834.15	1991.06	2166.7	2363.8	2585.52	2835.5	3117.94
dS/dt			-1567.42	-1693.61	-1834.15	-1991.06	-2166.7	-2363.8	-2585.52	-2835.5	-3117.94
dI/dt			1567.42	1693.61	1834.15	1991.06	2166.7	2363.8	2585.52	2835.5	3117.94
Prevalence			0.251	0.26189	0.27367	0.28641	0.30025	0.31531	0.33174	0.34971	0.36942

Appendix a. (continue)

2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
244688	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688
33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6
30096.6	30096.6	30096.6	30096.6	30096.6	30096.6	30096.6	30096.6	30096.6	30096.6	30096.6	30096.6	30096.6	30096.6
143877	143877	143877	143877	143877	143877	143877	143877	143877	143877	143877	143877	143877	143877
56268.7	59706.3	63506.1	67716.7	72392.8	77595.9	83393.3	89856.9	97060.6	105075	113957	123739	134411	145891
188419	184982	181182	176971	172295	167092	161295	154831	147627	139613	130731	120949	110277	98797.2
0.22996	0.24401	0.25954	0.27675	0.29586	0.31712	0.34081	0.36723	0.39667	0.42942	0.46572	0.5057	0.54931	0.59623
3938.81	4179.44	4445.43	4740.17	5067.5	5431.71	5837.53	6289.98	6794.24	7355.22	7976.97	8661.76	9408.74	10212.4
15473.9	16419.2	17464.2	18622.1	19908	21338.9	22933.1	24710.7	26691.7	28895.5	31338.1	34028.3	36962.9	40120
19412.7	20598.7	21909.6	23362.3	24975.5	26770.6	28770.7	31000.6	33485.9	36250.7	39315.1	42690.1	46371.6	50332.3
244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687
0.07934	0.08418	0.08954	0.09548	0.10207	0.10941	0.11758	0.1267	0.13685	0.14815	0.16068	0.17447	0.18951	0.2057
1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06
3437.59	3799.83	4210.57	4676.16	5203.07	5797.35	6463.65	7203.72	8013.99	8882.15	9782.62	10671.2	11480.2	12117
-3437.59	-3799.83	-4210.57	-4676.16	-5203.07	-5797.35	-6463.65	-7203.72	-8013.99	-8882.15	-9782.62	-10671.2	-11480.2	-12117
3437.59	3799.83	4210.57	4676.16	5203.07	5797.35	6463.65	7203.72	8013.99	8882.15	9782.62	10671.2	11480.2	12117
0.39109	0.41498	0.44139	0.47066	0.50316	0.53932	0.57962	0.62454	0.67461	0.73031	0.79205	0.86004	0.93421	1.014

Appendix b. **The Cost of The Disease Without Vaccination**

Parameters	Unit	Value	2012	2013	2014	2015	2016	2017	2018	2019
Non aborted	Head		33585.1							
Repeat breader	Head	0.08	2889.041							
Infertility	Rate	0.15								
Mortality of aborted seropositive		0.01	25.2791							
Price of mature female	SDG	12000								
Annual milk yield	Litre	2614								
Reduction in milk yield (10%) for non-aborted cows	0.1		8779146							
Reduction in milk yield (20%) for aborted cows	0.2		1321592							
Price of milk	SDG/L	3								
Average price of weaning calf	SDG	900								
Loss due to reduction in calves harvest										
Rate of reductio due to increased inter-calving	0.22									
Loss due to increased inter-calving period of aborted cows										
Cost of repeat breeding	SDG/cow	11.3								
Cost of veterinary intervention		53.141								
Mtd	SDG		303349.3							
Ml 1	SDG		26337437							
Ml 2			3964775							
Ml Milk Losses			30302212							
C1 Loss due to abortion of calves			2275120							
C2 Loss due to increased inter-calving period of aborted cows			500526.4							
(C) Loss in calves harvest			2775646							
(D) Cost of repeat breeding			32646.15							
(E) Cost of veterinary intervention			134335.7							
Total Cost			33548189							
Cost/head			137.106							
Cost/mature			233.1734							
Cost/ seropositive			928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782
Total cost of disease			33548189	35004287	36577613	38281494	40131142	42143957	44339875	46741765

Appendix b. (continue)

2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	
928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.97819	928.97819	928.97819	928.97819	
49375885	52272382	55465831	58995792	62907324	67251379	72084920	77470528	83475116	90167213	97612032	105863358	114951198	124864490	135529335	1565055104

Appendix c. **Whole Herd Vaccination Every Two Years**

Parameters	Unit	Value	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total population	Head		244688	244688	244688	244688	244688	244688	244688	244688	244688	244688
Calves less than 1 year	%	0.275	67289.2	0	16464859770	0	4.02875E+15	0	9.85788E+20	0	2.4121E+26	0
Mature females	%	0.588	143876.5	143876.5	143876.544	143876.5	143876.544	143876.5	143876.544	143876.5	143876.544	143876.5
Prevalence	%	0.251	36113.01	36113.01	36113.01254	36113.01	36113.01254	36113.01	36113.01254	36113.01	36113.01254	36113.01
Abortion	rate	0.07	2527.911	2527.911	2527.910878	2527.911	2527.910878	2527.911	2527.910878	2527.911	2527.910878	2527.911
Seropositive (I)	Head	head	36113.01	37680.43	37972.72004	38267.13	37118.34212	36046.61	33761.46624	31771.88	29025.14172	26746.13
Suseptible (S)	Head		208575	35725.97	35433.67996	-136142	-134993.5421	-305203	-302918.2662	-472210	-469463.542	-638466
Infection rate	%		0.147588	0.153994	0.155188322	0.156392	0.151696618	0.147317	0.137977613	0.129846	0.118621026	0.109307
Seraborted			2527.911	2637.63	2658.090403	2678.699	2598.283949	2523.263	2363.302637	2224.031	2031.759921	1872.229
Serodeliverd			9931.078	10362.12	10442.49801	10523.46	10207.54408	9912.818	9284.403217	8737.266	7981.913973	7355.186
Effective contact (K)			12458.99	12999.75	13100.58842	13202.16	12805.82803	12436.08	11647.70585	10961.3	10013.67389	9227.416
N-1			244687	244687	244687	244687	244687	244687	244687	244687	244687	244687
K/N-1			0.050918	0.053128	0.05354019	0.053955	0.052335547	0.050824	0.047602471	0.044797	0.040924421	0.037711
Contact rate (βc)			1.41E-06	1.41E-06	1.40996E-06	1.41E-06	1.40996E-06	1.41E-06	1.40996E-06	1.41E-06	1.40996E-06	1.41E-06
Incidence			1567.419	292.2882	294.411792	-1148.79	-1071.730675	-2285.15	-1989.589999	-2746.73	-2279.00929	-2631.82
Vaccinated			171281.6	0	171281.6	0	171281.6	0	171281.6		171281.6	0
ds/dt			-172849	-292.288	-171576.0118	1148.79	-170209.8693	2285.145	-169292.01	2746.735	-169002.591	2631.815
di/dt			1567.419	292.2882	294.411792	-1148.79	-1071.730675	-2285.15	-1989.589999	-2746.73	-2279.00929	-2631.82
dz/dt			171281.6	0	171281.6	0	171281.6	0	171281.6	0	171281.6	0
Prevalence			0.251	0.261894	0.263925717	0.265972	0.257987446	0.250538	0.234655805	0.220827	0.20173644	0.185896
Total vaccinated			171281.6	0	171281.6	0	171281.6	0	171281.6	0	171281.6	0
Cost of vaccination			856408	0	856408	0	856408	0	856408	0	856408	0
Cost of the disease			33548201	35004299	35275828.83	35549331	34482130.37	33486516	31363665.88	29515380	26963723.69	24846574
Cost /seropositive			928.9782	928.9782	928.9781924	928.9782	928.9781924	928.9782	928.9781924	928.9782	928.9781924	928.9782
Total cost			34404609	35004299	36132236.83	35549331	35338538.37	33486516	32220073.88	29515380	27820131.69	24846574

Appendix c. (continue)

2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
244688	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688
5.90213E+31	0	1.44418E+37	0	3.53374E+42	0	8.64663E+47	0	2.11573E+53	0	5.17693E+58	0	1.26673E+64
143876.544	143876.5	143876.544	143876.5	143876.544	143876.5	143876.544	143876.5	143876.544	143876.5	143876.544	143876.5	143876.544
36113.01254	36113.01	36113.01254	36113.01	36113.01254	36113.01	36113.01254	36113.01	36113.01254	36113.01	36113.01254	36113.01	36113.01254
2527.910878	2527.911	2527.910878	2527.911	2527.910878	2527.911	2527.910878	2527.911	2527.910878	2527.911	2527.910878	2527.911	2527.910878
24114.31733	21983.78	19742.02331	17939.19	16136.3096	14680.3	13264.3009	12109.72	11003.63757	10091.15	9223.759084	8499.498	7813.511606
-635834.3173	-804985	-802743.6233	-972222	-970419.5096	-1140245	-1138829.101	-1308956	-1307850.038	-1478219	-1477351.759	-1647909	-1647223.112
0.098551287	0.089844	0.080682434	0.073315	0.065946469	0.059996	0.054209037	0.04949	0.044970074	0.041241	0.037696001	0.034736	0.031932549
1688.002213	1538.865	1381.941631	1255.743	1129.541672	1027.621	928.5010631	847.6807	770.2546299	706.3806	645.6631359	594.9648	546.9458124
6631.437266	6045.539	5429.056409	4933.277	4437.485141	4037.083	3647.682748	3330.174	3026.000332	2775.067	2536.533748	2337.362	2148.715692
8319.439479	7584.404	6810.998041	6189.02	5567.026813	5064.704	4576.183811	4177.855	3796.254962	3481.447	3182.196884	2932.327	2695.661504
244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687
0.034000333	0.030996	0.027835553	0.025294	0.022751625	0.020699	0.018702194	0.017074	0.015514739	0.014228	0.013005173	0.011984	0.011016775
1.40996E-06	1.41E-06	1.40996E-06	1.41E-06	1.40996E-06	1.41E-06	1.40996E-06	1.41E-06	1.40996E-06	1.41E-06	1.40996E-06	1.41E-06	1.40996E-06
-2130.538738	-2241.76	-1802.833886	-1802.88	-1456.007066	-1416	-1154.576768	-1106.09	-912.4856257	-867.393	-724.2614059	-685.986	-579.4827038
171281.6	0	171281.6	0	171281.6	0	171281.6	0	171281.6	0	171281.6	0	171281.6
-169151.0613	2241.755	-169478.7661	1802.88	-169825.5929	1416.002	-170127.0232	1106.087	-170369.1144	867.3929	-170557.3386	685.9861	-170702.1173
-2130.538738	-2241.76	-1802.833886	-1802.88	-1456.007066	-1416	-1154.576768	-1106.09	-912.4856257	-867.393	-724.2614059	-685.986	-579.4827038
171281.6	0	171281.6	0	171281.6	0	171281.6	0	171281.6	0	171281.6	0	171281.6
0.16760423	0.152796	0.137215023	0.124685	0.112153859	0.102034	0.09219224	0.084167	0.076479718	0.070138	0.064108845	0.059075	0.054307057
171281.6	0	171281.6	0	171281.6	0	171281.6	0	171281.6	0	171281.6	0	171281.6
856408	0	856408	0	856408	0	856408	0	856408	0	856408	0	856408
22401674.92	20422451	18339909.13	16665116	14990279.73	13637681	12322246.27	11249670	10222139.34	9374460	8568671.041	7895848	7258581.888
928.9781924	928.9782	928.9781924	928.9782	928.9781924	928.9782	928.9781924	928.9782	928.9781924	928.9782	928.9781924	928.9782	928.9781924
23258082.92	20422451	19196317.13	16665116	15846687.73	13637681	13178654.27	11249670	11078547.34	9374460	9425079.041	7895848	8114989.888

Appendix d.

Whole Herd Vaccination Every 6 Years

Parameters	**Unit**	**Value**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Total population	Head	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688
Calves less than 1 year	%	0.275	67289.2	67289.2	67289.2	67289.2	67289.2	67289.2	67289.2	67289.2	67289.2
Mature female	%	0.588	143877	143877	143877	143877	143877	143877	143877	143877	143877
Prevalence	%	0.251	36113	36113	36113	36113	36113	36113	36113	36113	36113
Abortion	Rate	0.07	2527.91	2527.91	2527.91	2527.91	2527.91	2527.91	2527.91	2527.91	2527.91
Seropositive (I)	Head	Head	36113	37680.4	37960.6	38240.6	38520.4	38800	39079.5	39358.6	38234.6
Suseptible (S)	Head		208575	35726	35445.8	35165.8	34886	34606.4	34326.9	-137234	-136110
Infection rate	%		0.14759	0.14759	0.14759	0.14759	0.14759	0.14759	0.14759	0.14759	0.14759
Seraborted			2527.91	2637.63	2657.24	2676.84	2696.43	2716	2735.56	2755.1	2676.42
Serodeliverd			9931.08	10362.1	10439.2	10516.2	10593.1	10670	10746.8	10823.6	10514.5
Effective contact (K)			12459	12999.7	13096.4	13193	13289.5	13386	13482.4	13578.7	13190.9
N-1			244687	244687	244687	244687	244687	244687	244687	244687	244687
K/N-1			0.05092	0.05313	0.05352	0.05392	0.05431	0.05471	0.0551	0.05549	0.05391
Contact rate (βc)			1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06
Incidence			1567.42	280.13	279.999	279.837	279.641	279.413	279.153	-1123.98	-1082.94
Vaccinated			171282	0	0	0	0	0	171282	0	0
dS/dt			-172849	-280.13	-279.999	-279.837	-279.641	-279.413	-171561	1123.98	1082.94
dI/dt			1567.42	280.13	279.999	279.837	279.641	279.413	279.153	-1123.98	-1082.94
dV/dt			171282	0	0	0	0	0	171282	0	0
Prevalence			0.251	0.26189	0.26384	0.26579	0.26773	0.26968	0.27162	0.27356	0.26575
Total vaccinated			171282	0	0	0	0	0	171282	0	0
Cost of vaccination			856408	0	0	0	0	0	856408	0	0
Cost of the disease			3.4E+07	3.5E+07	3.5E+07	3.6E+07	3.6E+07	3.6E+07	3.6E+07	3.7E+07	3.6E+07
Cost / seropositive			928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978
Total cost			3.4E+07	3.5E+07	3.5E+07	3.6E+07	3.6E+07	3.6E+07	3.7E+07	3.7E+07	3.6E+07

Appendix d. (continue)

2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
244688	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688
67289.2	67289.2	67289.2	67289.2	67289.2	67289.2	67289.2	67289.2	67289.2	67289.2	67289.2	67289.2	67289.2	67289.2
143877	143877	143877	143877	143877	143877	143877	143877	143877	143877	143877	143877	143877	143877
36113	36113	36113	36113	36113	36113	36113	36113	36113	36113	36113	36113	36113	36113
2527.91	2527.91	2527.91	2527.91	2527.91	2527.91	2527.91	2527.91	2527.91	2527.91	2527.91	2527.91	2527.91	2527.91
37151.7	36107.8	35101.1	34129.8	33192.2	31103.9	29160.4	27350.2	25662.7	24088.3	22618.3	20438.9	18478.6	16714
-135027	-133983	-132976	-132005	-302349	-300261	-298317	-296507	-294819	-293245	-463057	-460877	-458917	-457152
0.14759	0.14759	0.14759	0.14759	0.14759	0.14759	0.14759	0.14759	0.14759	0.14759	0.14759	0.14759	0.14759	0.14759
2600.62	2527.54	2457.07	2389.08	2323.46	2177.27	2041.23	1914.51	1796.39	1686.18	1583.28	1430.72	1293.51	1169.98
10216.7	9929.64	9652.79	9385.68	9127.86	8553.57	8019.12	7521.31	7057.23	6624.27	6220.04	5620.68	5081.63	4596.34
12817.3	12457.2	12109.9	11774.8	11451.3	10730.8	10060.3	9435.82	8853.62	8310.45	7803.33	7051.4	6375.13	5766.32
244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687
0.05238	0.05091	0.04949	0.04812	0.0468	0.04386	0.04112	0.03856	0.03618	0.03396	0.03189	0.02882	0.02605	0.02357
1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06
-1043.9	-1006.72	-971.3	-937.525	-2088.35	-1943.45	-1810.22	-1687.54	-1574.41	-1469.93	-2179.49	-1960.2	-1764.67	-1590.01
0	0	0	171282	0	0	0	0	0	171282	0	0	0	0
1043.9	1006.72	971.3	-170344	2088.35	1943.45	1810.22	1687.54	1574.41	-169812	2179.49	1960.2	1764.67	1590.01
-1043.9	-1006.72	-971.3	-937.525	-2088.35	-1943.45	-1810.22	-1687.54	-1574.41	-1469.93	-2179.49	-1960.2	-1764.67	-1590.01
0	0	0	171282	0	0	0	0	0	171282	0	0	0	0
0.25822	0.25096	0.24397	0.23722	0.2307	0.21618	0.20268	0.1901	0.17837	0.16742	0.15721	0.14206	0.12843	0.11617
0	0	0	171282	0	0	0	0	0	171282	0	0	0	0
0	0	0	856408	0	0	0	0	0	856408	0	0	0	0
3.5E+07	3.4E+07	3.3E+07	3.2E+07	3.1E+07	2.9E+07	2.7E+07	2.5E+07	2.4E+07	2.2E+07	2.1E+07	1.9E+07	1.7E+07	1.6E+07
928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978
3.5E+07	3.4E+07	3.3E+07	3.3E+07	3.1E+07	2.9E+07	2.7E+07	2.5E+07	2.4E+07	2.3E+07	2.1E+07	1.9E+07	1.7E+07	1.6E+07

Appendix e. **Female Calve Vaccination Once**

Parameters	**Unit**	**Value**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total population	Head	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688
Calves less than 1 year	%	0.275	67289.2										
Female calve			33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6
Heifers	%	0.123	30096.62	30096.62	30096.62	30096.62	30096.62	30096.62	30096.62	30096.62	30096.62	30096.62	30096.62
Bulls	%	0.014	3425.632										
Mature female	%	0.588	143876.5	143876.5	143876.5	143876.5	143876.5	143876.5	143876.5	143876.5	143876.5	143876.5	143876.5
Prevalence	%	0.251	36113.01										
Abortion	Rate	0.07	2527.91										
Seropositive (I)	Head	Head	36113	36922.83	37763.03	38635	39540.2	40480.15	41456.46	42470.76	43524.75	44620.2	45758.92
Suseptible (S)	Head		107763.5	106953.7	106113.5	105241.5	104336.3	103396.4	102420.1	101405.8	100351.8	99256.34	98117.62
Infection rate	%		0.147588	0.150898	0.154331	0.157895	0.161594	0.165436	0.169426	0.173571	0.177879	0.182355	0.187009
Seraborted			2527.91	2584.598	2643.412	2704.45	2767.814	2833.611	2901.952	2972.953	3046.732	3123.414	3203.124
Serodeliverd			9931.075	10153.78	10384.83	10624.62	10873.55	11132.04	11400.53	11679.46	11969.31	12270.56	12583.7
Effective contact (K)			12458.99	12738.38	13028.24	13329.07	13641.37	13965.65	14302.48	14652.41	15016.04	15393.97	15786.83
N-1			244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687
K/N-1			0.050918	0.05206	0.053245	0.054474	0.05575	0.057076	0.058452	0.059882	0.061368	0.062913	0.064518
Contact rate (βc)			1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06
Incidence			809.8312	840.1975	871.9666	905.1999	939.9587	976.3043	1014.297	1053.994	1095.452	1138.72	1183.843
Vac 70%			23551.22										
Mature vacinated			0	0	23551.22	23551.22	23551.22	23551.22	23551.22	23551.22	0	0	0
Seropositive (I)			36113	37680.42	40233.02	43102.7	45915.3	48562.26	50917.75	52849.06	54232.17	54969.95	55706.1
Suseptible (S)			208575	183456.4	180903.8	154482.9	128119	101920.9	76014.15	50531.62	25597.29	24859.51	24123.36
Infection rate			0.147588	0.153994	0.164426	0.176154	0.187648	0.198466	0.208093	0.215986	0.221638	0.224653	0.227662
Seraborted			2527.91	2637.629	2816.312	3017.189	3214.071	3399.358	3564.242	3699.434	3796.252	3847.897	3899.427
Serodeliverd			9931.075	10362.12	11064.08	11853.24	12626.71	13354.62	14002.38	14533.49	14913.85	15116.74	15319.18
Effective contact(K)			12458.99	12999.74	13880.39	14870.43	15840.78	16753.98	17566.62	18232.93	18710.1	18964.63	19218.6
N-1			244687	143875.5	143875.5	143875.5	143875.5	143875.5	143875.5	143875.5	143875.5	143875.5	143875.5
K/N-1			0.050918	0.090354	0.096475	0.103356	0.110101	0.116448	0.122096	0.126727	0.130044	0.131813	0.133578
Contact rate βc			1.41E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06
Incidence mature			1567.418	2552.605	2869.673	2812.604	2646.964	2355.485	1931.311	1383.112	737.7809	736.1438	733.6058
dS/dt			-25118.6	-2552.61	-26420.9	-26363.8	-26198.2	-25906.7	-25482.5	-24934.3	-737.781	-736.144	-733.606
dI/dt			1567.418	2552.605	2869.673	2812.604	2646.964	2355.485	1931.311	1383.112	737.7809	736.1438	733.6058
dV/dt			23551.22	0	0	0	0	0	0	0	0	0	0
Prevalence			0.251	0.261894	0.279636	0.299581	0.31913	0.337527	0.353899	0.367322	0.376935	0.382063	0.38718
Total vaccinated			23551.22	0	0	0	0	0	0	0	0	0	0
Cost of vaccination			117756.1	0	0	0	0	0	0	0	0	0	0
Cost of the disease			33548189	35004287	37375601	40041465	42654313	45113284	47301479	49095625	50380505	51065888	51749749
Cost / seropositive			928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782
Total cost			33665946	35004287	37375601	40041465	42654313	45113284	47301479	49095625	50380505	51065888	51749749

Appendix e. (continue)

2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
244688	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688	244688
33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6	33644.6
30096.62	30096.62	30096.62	30096.62	30096.62	30096.62	30096.62	30096.62	30096.62	30096.62	30096.62	30096.62
143876.5	143876.5	143876.5	143876.5	143876.5	143876.5	143876.5	143876.5	143876.5	143876.5	143876.5	143876.5
46942.76	48173.62	49453.41	50784.07	52167.53	53605.69	55100.43	56653.53	58266.71	59941.5	61679.27	63481.18
96933.78	95702.92	94423.13	93092.47	91709.02	90270.85	88776.12	87223.01	85609.84	83935.05	82197.27	80395.37
0.191847	0.196878	0.202108	0.207546	0.2132	0.219078	0.225186	0.231534	0.238127	0.244971	0.252073	0.259437
3285.993	3372.154	3461.739	3554.885	3651.727	3752.398	3857.03	3965.747	4078.669	4195.905	4317.549	4443.682
12909.26	13247.75	13599.69	13965.62	14346.07	14741.56	15152.62	15579.72	16023.34	16483.91	16961.8	17457.32
16195.25	16619.9	17061.43	17520.5	17997.8	18493.96	19009.65	19545.47	20102.01	20679.82	21279.35	21901.01
244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687
0.066188	0.067923	0.069728	0.071604	0.073554	0.075582	0.07769	0.079879	0.082154	0.084515	0.086966	0.089506
1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06
1230.858	1279.792	1330.658	1383.455	1438.163	1494.737	1553.108	1613.172	1674.789	1737.777	1801.903	1866.88
0	0	0	0	0	0	0	0	0	0	0	0
56439.7	57169.86	57895.64	58616.12	59330.39	60037.54	60736.66	61426.89	62107.37	62777.28	63435.86	64082.35
23389.76	22659.6	21933.82	21213.34	20499.07	19791.92	19092.8	18402.57	17722.09	17052.18	16393.6	15747.11
0.23066	0.233644	0.23661	0.239555	0.242474	0.245364	0.248221	0.251042	0.253823	0.256561	0.259252	0.261894
3950.779	4001.89	4052.695	4103.129	4153.128	4202.628	4251.566	4299.882	4347.516	4394.41	4440.51	4485.764
15520.92	15721.71	15921.3	16119.43	16315.86	16510.32	16702.58	16892.39	17079.53	17263.75	17444.86	17622.65
19471.7	19723.6	19974	20222.56	20468.99	20712.95	20954.15	21192.28	21427.04	21658.16	21885.37	22108.41
143875.5	143875.5	143875.5	143875.5	143875.5	143875.5	143875.5	143875.5	143875.5	143875.5	143875.5	143875.5
0.135337	0.137088	0.138828	0.140556	0.142269	0.143964	0.145641	0.147296	0.148928	0.150534	0.152113	0.153663
2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06
730.1542	725.7816	720.4858	714.2703	707.1442	699.1223	690.2253	680.4794	669.9165	658.5736	646.4925	633.7197
-730.154	-725.782	-720.486	-714.27	-707.144	-699.122	-690.225	-680.479	-669.917	-658.574	-646.493	-633.72
730.1542	725.7816	720.4858	714.2703	707.1442	699.1223	690.2253	680.4794	669.9165	658.5736	646.4925	633.7197
0	0	0	0	0	0	0	0	0	0	0	0
0.392279	0.397354	0.402398	0.407406	0.41237	0.417285	0.422144	0.426942	0.431671	0.436327	0.440905	0.445398
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
52431253	53109550	53783786	54453101	55116643	55773564	56423034	57064238	57696389	58318726	58930527	59531104
928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782
52431253	53109550	53783786	54453101	55116643	55773564	56423034	57064238	57696389	58318726	58930527	59531104

Appendix f. **Female calves vaccination every 2 years**

Parameters	Unit	Value	2012	2013	2014	2015	2016	2017	2018	2019	2020
Vac 70%	Head	244688	23551.22	0	23551.22	0	23551.22		23551.22		23551.22
Mature vacinated	%	0.275	0	0	23551.22	23551.22	47102.44	47102.44	70653.66	70653.66	47102.44
Seropositive (I)			36113	37680.42	39181.35	40790.95	42068.47	43174.07	43567.78	43449.21	42307.79
Suseptible (S)	%	0.123	208575	183456.4	181955.4	133243.4	108414.6	36655.39	-10840.76	-104927.1	-174439.3
Infection rate	%	0.014	0.147588	0.153994	0.160128	0.166706	0.171927	0.176445	0.178054	0.17757	0.172905
Seraborted	%	0.588	2527.91	2637.629	2742.694	2855.367	2944.793	3022.185	3049.745	3041.445	2961.545
Serodeliverd	%	0.251	9931.075	10362.12	10774.87	11217.51	11568.83	11872.87	11981.14	11948.53	11634.64
Effective contact (K)	Rate	0.07	12458.99	12999.74	13517.56	14072.88	14513.62	14895.05	15030.89	14989.98	14596.19
N-1	Head	Head	244687	244687	244687	244687	244687	244687	244687	244687	244687
K/N-1	Head		0.050918	0.053128	0.055244	0.057514	0.059315	0.060874	0.061429	0.061262	0.059652
Contact rate (βc)	%		1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06
Incidence mature			1567.418	1500.928	1609.605	1277.523	1105.597	393.7126	-118.5732	-1141.424	-1799.204
dS/dt			-25118.64	-1500.928	-48712.04	-24828.74	-71759.26	-47496.15	-94086.31	-69512.24	-68854.46
dI/dt			1567.418	1500.928	1609.605	1277.523	1105.597	393.7126	-118.5732	-1141.424	-1799.204
dV/dt			23551.22	0	47102.44	23551.22	70653.66	47102.44	94204.88	70653.66	70653.66
Prevalence			0.251	0.261894	0.272326	0.283514	0.292393	0.300077	0.302814	0.30199	0.294056
Total vaccinated			23551.22	0	23551.22	0	23551.22	0	23551.22	0	23551.22
Cost of vaccination			117756.1	0	117756.1	0	117756.1	0	117756.1	0	117756.1
Cost of the disease			33548189	35004287	36398616	37893904	39080695	40107771	40473521	40363369	39303012
Cost / mature			928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782
Total cost			33665946	35004287	36516372	37893904	39198451	40107771	40591277	40363369	39420768

Appendix f. (continue)

2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
	23551.22		23551.22		23551.22		23551.22		23551.22	0	23551.22	0	23551.22
47102.44	47102.44	47102.44	47102.44	47102.44	47102.44	47102.44	47102.44	47102.44	47102.44	47102.44	47102.44	47102.44	47102.44
40508.58	38208.09	35784.59	33155.32	30616.52	28083.72	25750.1	23527.15	21528.29	19671.3	18019.96	16505.12	15162.71	13937.95
-243293.8	-288095.7	-356325.9	-400799	-468913.9	-513483.5	-581803.6	-626683.1	-695337.9	-740583.3	-809585.6	-855173.2	-924484.5	-970362.2
0.165552	0.15615	0.146246	0.1355	0.125125	0.114774	0.105236	0.096152	0.087983	0.080393	0.073645	0.067454	0.061968	0.056962
2835.601	2674.566	2504.921	2320.873	2143.156	1965.861	1802.507	1646.9	1506.98	1376.991	1261.397	1155.359	1061.389	975.6567
11139.86	10507.23	9840.763	9117.714	8419.543	7723.024	7081.277	6469.966	5920.28	5409.606	4955.489	4538.909	4169.744	3832.937
13975.46	13181.79	12345.68	11438.59	10562.7	9688.885	8883.784	8116.866	7427.26	6786.597	6216.886	5694.267	5231.134	4808.594
244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687
0.057116	0.053872	0.050455	0.046748	0.043168	0.039597	0.036307	0.033172	0.030354	0.027736	0.025408	0.023272	0.021379	0.019652
1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06
-2300.491	-2423.5	-2629.269	-2538.801	-2532.797	-2333.627	-2222.95	-1998.858	-1856.994	-1651.336	-1514.837	-1342.416	-1224.753	-1086.244
-44801.95	-68230.16	-44473.17	-68114.86	-44569.64	-68320.03	-44879.49	-68654.8	-45245.45	-69002.32	-45587.6	-69311.24	-45877.69	-69567.42
-2300.491	-2423.5	-2629.269	-2538.801	-2532.797	-2333.627	-2222.95	-1998.858	-1856.994	-1651.336	-1514.837	-1342.416	-1224.753	-1086.244
47102.44	70653.66	47102.44	70653.66	47102.44	70653.66	47102.44	70653.66	47102.44	70653.66	47102.44	70653.66	47102.44	70653.66
0.281551	0.265562	0.248717	0.230443	0.212797	0.195193	0.178974	0.163523	0.14963	0.136723	0.125246	0.114717	0.105387	0.096874
0	23551.22	0	23551.22	0	23551.22	0	23551.22	0	23551.22	0	23551.22	0	23551.22
0	117756.1	0	117756.1	0	117756.1	0	117756.1	0	117756.1	0	117756.1	0	117756.1
37631590	35494484	33243105	30800572	28442081	26089168	23921279	21856207	19999311	18274204	16740150	15332899	14085824	12948055
928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782	928.9782
37631590	35612240	33243105	30918328	28442081	26206924	23921279	21973963	19999311	18391961	16740150	15450655	14085824	13065811

Appendix g. **Female Calves Vaccination Every 6 Years**

Parameters	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Vac 70%	23551.2	0	0	0	0	0	23551.2	0	0	0
Mature vacinated	0	0	23551.2	23551.2	23551.2	23551.2	23551.2	23551.2	23551.2	23551.2
Seropositive (I)	36113	37680.4	40233	43102.7	45915.3	48562.3	50917.7	52849.1	53587.5	53663.3
Suseptible (S)	208575	183456	180904	154483	128119	101921	76014.2	26980.4	2690.69	-20936.2
Infection rate	0.14759	0.15399	0.16443	0.17615	0.18765	0.19847	0.20809	0.21599	0.219	0.21931
Seraborted	2527.91	2637.63	2816.31	3017.19	3214.07	3399.36	3564.24	3699.43	3751.13	3756.43
Serodeliverd	9931.08	10362.1	11064.1	11853.2	12626.7	13354.6	14002.4	14533.5	14736.6	0
Effective contact (K)	12459	12999.7	13880.4	14870.4	15840.8	16754	17566.6	18232.9	18487.7	3756.43
N-1	244687	143876	143876	143876	143876	143876	143876	143876	143876	143876
K/N-1	0.05092	0.09035	0.09648	0.10336	0.1101	0.11645	0.1221	0.12673	0.1285	0.02611
Contact rate (βc)	1.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	4.9E-07
Incidence mature	1567.42	2552.61	2869.67	2812.6	2646.96	2355.49	1931.31	738.486	75.7201	-119.881
dS/dt	-25118.6	-2552.61	-26420.9	-26363.8	-26198.2	-25906.7	-49033.8	-24289.7	-23626.9	-23431.3
dI/dt	1567.42	2552.61	2869.67	2812.6	2646.96	2355.49	1931.31	738.486	75.7201	-119.881
dV/dt	23551.2	0	0	0	0	0	23551.2	0	0	0
Prevalence	0.251	0.26189	0.27964	0.29958	0.31913	0.33753	0.3539	0.36732	0.37246	0.37298
Total vaccinated	23551.2	0	0	0	0	0	23551.2	0	0	0
Cost of vaccination	117756	0	0	0	0	0	117756	0	0	0
Cost of the disease	3.4E+07	3.5E+07	3.7E+07	4E+07	4.3E+07	4.5E+07	4.7E+07	4.9E+07	5E+07	5E+07
Cost / seropositive	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978
Total cost	3.4E+07	3.5E+07	3.7E+07	4E+07	4.3E+07	4.5E+07	4.7E+07	4.9E+07	5E+07	5E+07

Appendix g. (continue)

2022	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
0	0	23551.2	0	0	0	0	0	23551.2	0	0	0	0
23551.2	23551.2	23551.2	23551.2	23551.2	23551.2	23551.2	23551.2	23551.2	23551.2	23551.2	23551.2	23551.2
53543.4	52296.9	50509.9	48298.8	45250.8	42164	39127.4	36204.6	33437.2	30849	28230.8	25874.7	23756.4
-44367.6	-66672.3	-88436.5	-133328	-153831	-174295	-194810	-215439	-236222	-280737	-301670	-322865	-344298
0.21882	0.21373	0.20643	0.19739	0.18493	0.17232	0.15991	0.14796	0.13665	0.12607	0.11537	0.10575	0.09709
3748.04	3660.78	3535.69	3380.92	3167.56	2951.48	2738.92	2534.32	2340.61	2159.43	1976.16	1811.23	1662.95
14724.4	14381.6	13890.2	13282.2	12444	11595.1	10760	9956.27	9195.24	8483.48	7763.47	7115.54	6533
18472.5	18042.4	17425.9	16663.1	15611.5	14546.6	13498.9	12490.6	11535.8	10642.9	9739.63	8926.77	8195.95
143876	143876	143876	143876	143876	143876	143876	143876	143876	143876	143876	143876	143876
0.12839	0.1254	0.12112	0.11582	0.10851	0.10111	0.09382	0.08682	0.08018	0.07397	0.06769	0.06205	0.05697
2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06
-1246.51	-1786.97	-2211.08	-3047.99	-3086.86	-3036.61	-2922.75	-2767.39	-2588.22	-2618.19	-2356.12	-2118.31	-1904.21
-22304.7	-21764.3	-44891.4	-20503.2	-20464.4	-20514.6	-20628.5	-20783.8	-44514.2	-20933	-21195.1	-21432.9	-21647
-1246.51	-1786.97	-2211.08	-3047.99	-3086.86	-3036.61	-2922.75	-2767.39	-2588.22	-2618.19	-2356.12	-2118.31	-1904.21
0	0	23551.2	0	0	0	0	0	23551.2	0	0	0	0
0.37215	0.36348	0.35106	0.3357	0.31451	0.29306	0.27195	0.25164	0.2324	0.21441	0.19622	0.17984	0.16512
0	0	23551.2	0	0	0	0	0	23551.2	0	0	0	0
0	0	117756	0	0	0	0	0	117756	0	0	0	0
5E+07	4.9E+07	4.7E+07	4.5E+07	4.2E+07	3.9E+07	3.6E+07	3.4E+07	3.1E+07	2.9E+07	2.6E+07	2.4E+07	2.2E+07
928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978
5E+07	4.9E+07	4.7E+07	4.5E+07	4.2E+07	3.9E+07	3.6E+07	3.4E+07	3.1E+07	2.9E+07	2.6E+07	2.4E+07	2.2E+07

Appendix h. **Mature Females Vaccination Twice Every 6 Years Together with Annual Calves Vaccination**

Parameters	**Unit**	**Value**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Mature female	%	0.588	143877	143877	143877	143877	143877	143877	143877	143877
Prevalence	%	0.251	36113							
Abortion	Rate	0.07	2527.91							
Seropositive (I)	Head	Head	36113	37680.4	37882.1	37384.8	36216	33719.5	31009.4	28269.7
Suseptible (S)	Head		208575	24646	-60136.9	-145121	-330322	-413641	-494463	-673288
Infection rate	%		0.14759	0.15399	0.15482	0.15279	0.14801	0.13781	0.12673	0.11553
Seraborted			2527.91	2637.63	2651.74	2616.93	2535.12	2360.37	2170.66	1978.88
Serodeliverd			9931.08	10362.1	10417.6	10280.8	9959.41	9272.87	8527.6	7774.15
Effective contact (K)			12459	12999.7	13069.3	12897.7	12494.5	11633.2	10698.3	9753.03
N-1			244687	244687	244687	244687	244687	244687	244687	244687
K/N-1			0.05092	0.05313	0.05341	0.05271	0.05106	0.04754	0.04372	0.03986
Contact rate (βc)			1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06
Incidence			1567.42	201.638	-497.283	-1168.74	-2496.52	-2710.08	-2739.79	-3100.54
Calve vaccination			47102.4	47102.4	47102.4	47102.4	47102.4	47102.4	47102.4	47102.4
Mature vacinated twice every six years			100714	0	0	100714	0	0	100714	0
dS/dt			-183929	-84782.9	-84984.5	-185201	-83318.5	-80822	-178825	-75372.1
dI/dt			1567.42	201.638	-497.283	-1168.74	-2496.52	-2710.08	-2739.79	-3100.54
dV/dt			147816	47102.4	47102.4	147816	47102.4	47102.4	147816	47102.4
Prevalence			0.251	0.26189	0.2633	0.25984	0.25172	0.23436	0.21553	0.19649
Total vaccinated			147816	47102.4	47102.4	147816	47102.4	47102.4	147816	47102.4
Cost of vaccination			739080	235512	235512	739080	235512	235512	739080	235512
Cost of the disease			3.4E+07	3.5E+07	3.5E+07	3.5E+07	3.4E+07	3.1E+07	2.9E+07	2.6E+07
Cost /seropositive			928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978
Total cost			3.4E+07	3.5E+07	3.5E+07	3.5E+07	3.4E+07	3.2E+07	3E+07	2.6E+07

Appendix h. (continue)

2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
143877	143877	143877	143877	143877	143877	143877	143877	143877	143877	143877	143877	143877	143877	143877
25169.1	22436.3	20055	17757.8	15834.7	14211.9	12714.2	11458.4	10393.2	9417.66	8587.3	7872.89	7216.54	6648.57	6152.65
-748660	-820932	-991184	-1058341	-1123202	-1286852	-1348167	-1407983	-1567258	-1624753	-1681274	-1837677	-1892652	-1946971	-2101436
0.10286	0.09169	0.08196	0.07257	0.06471	0.05808	0.05196	0.04683	0.04248	0.03849	0.03509	0.03218	0.02949	0.02717	0.02514
1761.84	1570.54	1403.85	1243.05	1108.43	994.833	889.993	802.088	727.522	659.236	601.111	551.102	505.158	465.4	430.686
6921.51	6169.97	5515.13	4883.4	4354.55	3908.27	3496.4	3151.06	2858.12	2589.86	2361.51	2165.04	1984.55	1828.36	1691.98
8683.34	7740.51	6918.98	6126.45	5462.98	4903.11	4386.39	3953.15	3585.65	3249.09	2962.62	2716.15	2489.71	2293.76	2122.67
244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687	244687
0.03549	0.03163	0.02828	0.02504	0.02233	0.02004	0.01793	0.01616	0.01465	0.01328	0.01211	0.0111	0.01018	0.00937	0.00868
1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06
-2732.85	-2381.24	-2297.19	-1923.1	-1622.84	-1497.71	-1255.79	-1065.22	-975.512	-830.366	-714.409	-656.346	-567.969	-495.92	-458.391
47102.4	47102.4	47102.4	47102.4	47102.4	47102.4	47102.4	47102.4	47102.4	47102.4	47102.4	47102.4	47102.4	47102.4	47102.4
0	100714	0	0	100714	0	0	100714	0	0	100714	0	0	100714	0
-72271.6	-170252	-67157.5	-64860.3	-163651	-61314.3	-59816.6	-159274	-57495.6	-56520.1	-156403	-54975.3	-54319	-154465	-53255.1
-2732.85	-2381.24	-2297.19	-1923.1	-1622.84	-1497.71	-1255.79	-1065.22	-975.512	-830.366	-714.409	-656.346	-567.969	-495.92	-458.391
47102.4	147816	47102.4	47102.4	147816	47102.4	47102.4	147816	47102.4	47102.4	147816	47102.4	47102.4	147816	47102.4
0.17494	0.15594	0.13939	0.12342	0.11006	0.09878	0.08837	0.07964	0.07224	0.06546	0.05969	0.05472	0.05016	0.04621	0.04276
47102.4	147816	47102.4	47102.4	147816	47102.4	47102.4	147816	47102.4	47102.4	147816	47102.4	47102.4	147816	47102.4
235512	739080	235512	235512	739080	235512	235512	739080	235512	235512	739080	235512	235512	739080	235512
2.3E+07	2.1E+07	1.9E+07	1.6E+07	1.5E+07	1.3E+07	1.2E+07	1.1E+07	9655033	8748804	7977412	7313742	6704011	6176380	5715680
928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978	928.978
2.4E+07	2.2E+07	1.9E+07	1.7E+07	1.5E+07	1.3E+07	1.2E+07	1.1E+07	9890545	8984316	8716492	7549254	6939523	6915460	5951193