Economics-Epidemiology integrated approach for bovine brucellosis control and eradication in Sri Lanka

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スリランカにおける牛のブルセラ病コントロールおよび撲滅に関する経済疫学的統合研究

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List of abbreviations

ADG	Additional Director General
AR	Annual Report
ASF	African Swine Fever
B/C	Benefit Cost ratio
BAT	*Brucella* Antibody Test
BCA	Benefit Cost Analysis
BQ	Black Quarter
C-ELISA	Competitive ELISA
CB	Central Bank
CBPP	Contagious bovine pleuropneumonia
CFT	Complement Fixation Test
CI	Confidence Interval
CIDRAP	Center for Infectious Disease Research and Policy
CRA	Censored Regression Analysis
CVM	Contingent Valuation Method
DAPH	Department of Animal Production and Health
DCS	Department of Census and Statics
DEFRA	Department for Environment, Food and Rural Affairs
DG	Director General
EB	Epidemiological Bulletin
ELISA	Enzyme Linked Immunosorbent Assay
FAO	Food and Agriculture Organization
FMD	Foot and Mouth Disease
FMS	Farmer Managed Societies
FPA	Fluorescence Polarization Assay
GDP	Gross Domestic Product
GND	*Grama Niladari* divisions
GOA	Government of Australia
HS	Hemorrhagic Septicemia
ILRI	International Livestock Research Institute
IRR	Internal Rate of Return
IgA	Immunoglobulin A
IgM	Immunoglobulin M
LSB	Livestock Statistical Bulletin

MLDRCD	Ministry of Livestock Development and Rural Community Development
MLRCD	Ministry of Livestock and Rural Community Development
MMDE	Ministry of Mahaweli Development and Environment
MRT	Milk Ring Test
NPV	Net Present Value
OIE	Office International des Epizootics (World Animal Health Organization)
OR	Odds Ratio
PCR	Polymerase Chain Reaction
PPR	Pes des petits ruminants
RBT	Rose Bengal Test
S-19	Strain 19
SAT	Serum Agglutination Test
SEIR	Susceptible-Exposed -Infected -Recovered
SEIV	Susceptible- Exposed -Infected -Environment
SEIV	Susceptible- Exposed -Infected -Vaccinated
SIR	Susceptible-Infected- Recovered
SLR	Sri Lankan Rupee
SNF	Solid Non-Fat
SPS	Sanitary and Phyto-sanitary
TB	Tuberculosis
TBP	Total Bacterial Count
UNDP	Unite Nations Development Program
US$	United States Dollar
USAID	United States Agency for International Development
VS	Veterinary Surgeon
WB	World Bank
WHO	World Health Organizations
WTA	Willingness to Accept
WTO	World Trade Organization
iELISA	indirect ELISA
bn	Billion
km	Kilometer
mn	Million
mm	Millimeter

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CHAPTER 1

General introduction

1.1 Background and challenges

Livestock production forms a large part of the agricultural economy in developing countries. Over 70% of rural households, representing 800 million people globally, rear animals for their livelihood (OIE, n.d). The contribution is more than direct food production and income to include versatile uses, such as manure, draft power, hides, fiber and even assets (McDermotte et al., 1999). Furthermore, livestock plays key role in socio-cultural aspects of several millions of resource-poor farmers. It is a possible pathway out of poverty for many smallholders in developing countries (Randolph et al., 2007; Perry and Grace, 2009).

"Livestock revolution" causes high demand for livestock products with human population growth, increasing incomes and urbanization (Delgado, 2003). Demand for livestock product predictions shows considerable prospects for livestock producers in developing countries, particularly through exports (Wolmer and Scoones, 2005). Annual meat production is estimated to increase from 218 million tons in 1997-1999 to 376 million tons by 2030 globally (WHO, 2017). But, low productivity and poor quality due to livestock diseases are main issues in animal production in developing countries. Approximately, 25% of the world's livestock production is lost due to animal diseases and, losses cause hardships for the three fourth of the world's rural poor as well as one-third of the urban poor (Kilian, 2012). ' Trans-boundary animal diseases ' that are of significant economic, trade and /or food security importance for several countries (e.g. foot-and-mouth disease (FMD), African swine fever (ASF), contagious bovine pleuropneumonia

(CBPP), peste des petits ruminants (PPR), avian influenza, 'Swine Flu' , etc…), and 'zoonotic' diseases those can be transmitted from animals to humans (e.g brucellosis, tuberculosis and rabies) causes severe economic losses and trade disruption across regions (Lubroth and de Balogh, 2009). To overcome this issue, the agreement on the application of sanitary and phyto-sanitary measures (the "SPS agreement") entered into force, to maintain food safety and, animal and plant health in international trade (WTO, 1998). Additionally, Food and Agriculture Organization (FAO) and World Animal Health Organization (OIE) have jointly developed stepwise control pathways for FMD (FAO, 2011) and brucellosis to minimize the global impacts of such diseases in the future (FAO, 2013).

Brucellosis is one of the most economically important zoonosis in the world (ILRI, 2012). It is an OIE listed disease (OIE, 2017) and one of the top 13 zoonotic diseases causing poverty in developing countries (ILRI, 2012). It is endemic in Mediterranean areas, the Middle East and Arabian Gulf, Latin America, parts of Africa, several European countries (Mohammed et al., 2013), and parts of Asia. Brucellosis is a re-emerging zoonosis threating to free areas even (Seleem et al., 2010), and is named as a bio-weapon (Pappas et al., 2006).

Bovine brucellosis is usually caused by *Brucella abortus* and rarely by *Brucella melitensis* (OIE, 2009). The disease can be transmitted by ingestion of *Brucella* organisms present in tissues of aborted fetuses, fetal membranes, or uterine fluids, or by contaminated materials (Nicoletti, 2013). When an animal is infected with *Brucella* organism, it becomes a latent carrier (spread the disease without showing signs) throughout the life time (Necoletti, 2013). The disease can contract to humans mainly through the consumption of unpasteurized milk and milk products, and occasionally by inhalation of aerosols and contamination with infected excreta causing flu-like symptoms (WHO, 2016). Economic burden due to *Brucella* in animals and human populations is larger in low income countries compared to middle and high-income countries (McDermott et al., 2013). Losses owing to brucellosis are estimated at 20% of milk production per animal when infected (ILRI, 2012). It is a major issue in African and South Asian countries (ILRI, 2012) in which Sri Lanka records the highest incidence (Bandara and Mahipala, 2002), thus needs efficient control.

In Sri Lanka, livestock keeping is an integral part of the agriculture which forms 27.1% of rural labor force (DCS, 2016). Farmers depend on animals socially, culturally and economically. Around 65.3% of the agricultural labor force is contributed to family operations (DCS, 2016) which are small scale, traditional practices mostly. Brucellosis is first reported in Sri Lanka in 1956 in a government breeding farm (Pillai and Kumaraswamy, 1957). It is endemic in the dry zone (Kumaraswamy, 1971; Peris, 1981; De Alwis et al., 1993; Priyantha, 2011). The disease has widely spread in the country due to animal transportation from infected areas to other areas (Kumaraswamy, 1971). Brucellosis prevalence is recorded as high in traditional extensive cattle management system (Silva et al., 2000). In the traditional practice, animals are usually fed on uncultivated paddy fields, common park lands, villus, and tank beds, thus tend to comingle, predisposing to get infections (Fernando, 1969). At present, brucellosis control is limited only to testing of herds with abortion history (upon farmers' report) and corresponding vaccination of positive herds (EB, 2015). Despite the 4.7% prevalence rate (Silva et al.,2000), detection of positive animals ranged from 14-132 animals (0.02%) per year as noted by DAPH epidemiological bulletin (EB,2011-2015), could be due to low abortion reporting by farmers, possibly because of poor knowledge and attitudes about the disease. Mass vaccination is not practiced due to financial limitations. Culling of positive animals are not practiced due to financial limitations and strong socio-religious objection against cattle slaughtering; therefore, infected animals are likely to be moved between farms and across areas. Even if animal health regulation prevents movement of infected animals (Animals Act No.29 of 1958), illegal transportation is possible due to various socio-cultural settings and, knowledge and information gaps. Therefore, it was assumed that brucellosis establishment in Sri Lanka is significantly backed by socio-economics and farmers' behavior, besides a sound technical plan.

Animal disease management and control is often described as a social problem (Rittel and Webber, 1973). Control decisions involve many parties, disciplines, approaches and interests (Anton et al., 2013). Individual farmer's disease control and prevention approach can have externalities on other farms (Hennessy, 2007). Relationship between communication and social risk perceptions are important in effective animal health control (Barnett 2013). Efforts related to disease control at farm level are often costly or impossible to monitor, and farmers may be imperfectly informed about whether animals are diseased (Hennessy and Wolf, 2015). Knowledge gaps and uncertainties together with asymmetric access to relevant information by farmers, government, and consumers are challenges in optimal disease control policy implications (Anton et al., 2013). Hence, understanding of farmers' behavior is crucial in prevention and control of animal disease (Hennessy and Wolf, 2015), since they are typically the first to respond to diseases (Anton et al., 2013).

Cattle farming practices are related to farmers' socio-economic factors (Millar and Photokaun, 2008). Exposure of livestock to infections is potentially influenced by farmer's social factors viz. ethnicity and culture (Dean et al., 2013). Hence, it was assumed that, 1) farmers' socio-economic and farming factors are associated to brucellosis prevalence in the dry zone of Sri Lanka. Dernberg et al (2007) stated that farmers' behavior is strongly affected by their knowledge and attitudes. Also, farmers' decision on bio security measures is related to attitudes and information sources (Heffernan et al., 2008). Therefore, it was assumed that, 2) poor knowledge and attitudes on animal diseases lead to risky farming practices that bring about high disease prevalence in the area. It was recorded that when farmers are informed about results of *Brucella* positive animal, they tend to sell the animal to another farmer due to cultural and religious forbids for cattle slaughter (Silva et al., 2000). Farmers' decision to adopt a control measure is influenced by personal and contextual factors, attitudes, beliefs, perceptions, and its benefits (Heffernan et al., 2016; Mankad, 2016); that can be changed by economic incentives (Gilbert and Ruston, 2016). Accordingly, it was assumed that, 3) farmers' hidden behavior related to infected animal movement is possibly because of farming economics (Tago et al., 2016) and lack of knowledge, that could be addressed by economic incentives. Capital markets are shown to be the main determining factor of the extent of the disease (Hennessy, 2007). Most approaches taken by epidemiologists and economists in animal disease control are severely scarce in consideration of social behavior of the farmer; thus, lacks in predictive capacity (Gilbert and Rushton, 2016). Therefore, it was finally assumed that, 4) epidemiology-social behavior integrated brucellosis control approach in Sri Lanka would be effective and economically efficient in brucellosis control.

Fortunately, brucellosis was extensively studied in the light of different disciplines such as microbiology, epidemiology, surveillance techniques, integration of human-animal-wild life interface, transmission modelling, vaccine development, economic impact so on. Yet, farmers' socio- economic behavior on brucellosis bio-security measures and disease control is extremely limited. Diseases control strategies could integrate disease epidemiology with farmers' socio-cultural behavior (Rich and Perry, 2011) for success; the inter-disciplinary approach is still not well studied in practice. Therefore, this dissertation aimed to study on farmer's socio-cultural behavior related to brucellosis prevalence and its control, to make policy recommendations for cost-effective control strategy for Sri Lanka.

Intending that, literature was searched on brucellosis epidemiology, knowledge, attitudes and practices (KAP); information asymmetry, farmers' hidden behavior and economic incentives; and finally, epidemiology and economic integration in brucellosis control.

1.2. Literature review

1.2.1. Brucellosis surveillance, epidemiology and risk factors

Brucellosis was reported for the first time in the 1850s in Malta, therefore named as "*Malta fever*" initially (Wyatt, 2013). In 1887, British army doctor *David Bruce* isolated a micro- organism from a spleen of a British soldier who had the disease from a goat, named *Brucella* (Dobrean, 2002). Between 1900 and 1906 there had been a total of 3,631 infected human beings who had goat milk (Wyatt, 2013). Later, this organism was named as *Brucella melitensis* (Wyatt, 2009). The disease is also called undulant fever, Mediterranean fever, Bang's disease or brucellosis (Dobrean, 2002).

Brucellosis is caused by bacteria (gram-negative) of the genus *Brucella* (Adone and Pasquali, 2013). Several *Brucella* species such as *B. melitensis, B. abortus and B. suis*, have been identified; they transmit among mammalians, both vertically and horizontally (Diaz-Aparicio, 2013). *Brucella* spp. infect not only in their preferred hosts but also other domestic and wild animals, which can be act as reservoirs for other animal species as well as humans (Diaz-Aparicio, 2013). The organism can replicate largely in placenta, therefore associated with abortions in their preferred hosts, and existing in macrophages leads to chronic infections which is a sign of brucellosis in both natural animal hosts and humans (Roop et al., 2009). Six classical species identified so far, some of which include different biovars as shown in the Table 1.1.

Table 1.1 Different species and biovars in *Brucella*

Species	Biovar	Preferred host(s)	Human pathogenicity
Identified species			
B. abortus	1–6, (7), 9a	Cattle	High
B. melitensis	1–3	Sheep, goats	High
B. suis	1,3	Pigs	High
	2	Wild boar, hare	Low
	4	Reindeer	High
	5	Rodents	No
B. canis		Dogs	Moderate
B. ovis		Sheep	No
B. neotomae		Rodents	Moderate
Newly described species			
B. pinnipedialis		Seals	-
B. ceti		Dolphins, porpoises	-
B. microti		Voles, fox, soil	-
B. inopinata		human	-

Source: Godfroid et al., 2010

Bovine brucellosis is usually caused by the species of *B. abortus* (Nicolleti, 2013). Non-bovine animals also can contract *B. abortus* and play a role in harboring and spreading (Diaz-Aparicio, 2013). It is can be transmitted from cattle to wild animals too (White et al., 2013). Reproductive failures such as abortions, still births, weak calves, retained placenta, long calving intervals and loss of milk production are main impacts of the disease (Nicoletti, 2013). Both male and female animals can become sterile due to this disease (Diaz-Aparicio, 2013). Venereal transmission is not common, but artificial insemination in which contaminated semen is deposited in the uterus is a possible source of infection (Poester et al., 2013). Most species of *Brucella* can infect to humans when they come in to close contact with them. *B. abortus, B. melitensis, B. suis, B. canis* and marine mammal species are pathogens for humans (Godfroid et al., 2010). Brucellosis in humans is not fatal, but can be severely debilitating and disabling with febrile signs (Franco et al., 2007).

(1) Diagnosis and surveillance

Brucella diagnosis include direct tests, involving microbiological analysis or DNA detection by polymerase chain reaction (PCR)-based methods and indirect tests, which are applied either in vitro (mainly to milk or blood) or in vivo (allergic test) (Godfroid et al.,2010). Table 1.2 describes the sensitivity and specificity of tests used for *Brucella* diagnosis.

Table 1.2 Different tests used in diagnosis of *Brucella*

Test	Sensitivity	Specificity
Serological tests		
RBT (Rose Bengal Test)	80.2	99.6
SAT (Serum Agglutination Test)	81.5	96.9
CFT (Complement Fixation Test)	90-91.8	99.7-99.9
BAT (Brucella Antibody Test)	87	97.8
iELISA (indirect ELISA)	97.2	97.1-99.8
cELISA (competitive ELISA)	95.2	99.7
FPA (Fluorescence Polarization Assay)	96.6	99.1
Milk tests		
MRT (Milk Ring Test)	88.5	95.5
FPA	100	100.0
iELISA	98.1	99.0
Cellular tests		
Skin test (*Brucellin* test)	78-93	99.8

Source: Vanzini et al., 2001; Godfroid et al., 2010

Serological surveillance which detects anti-*Brucella* antibodies provides useful information to aid in understanding epidemiological patterns and estimating the impact of brucellosis in the targeted areas, paving the way to define the most suitable control approach (Adone and Pasquali, 2013). The presence of antibodies suggests that animal has exposed to *Brucella* species, but does not specify which species (Godfroid et al., 2010). OIE has recommended RBT and buffered plate agglutination test (BPAT) for herd screening and CFT or enzyme linked immuno-sorbent assay (ELISA) for confirmation (OIE, 2009). None of the conventional serological tests used to test of porcine brucellosis is reliable for diagnosis the disease in individual pigs (Godfroid et al., 2010). It has been used RBT for human brucellosis diagnosis that displayed good agreement with SAT and CFT (Maichomo et al., 1998).

Milk testing is one of the most cost-effective and widely used methods for *Brucella* testing in many countries (Zowghi et al., 1990; Mohamand et al., 2014). The MRT that was first used in Germany by Fleischhauer in 1937 (Ferguson and Robertson, 1954). It is used as a routine periodic test. Application of MRT and i-ELISA are described as low-cost tests to identify and confirm the disease in exposed herds respectively, even if the prevalence is low (OIE, 2009). In the MRT IgM and IgA antibodies bound to fat globules form a visible ring, that has wide acceptability as it is cost effective, easy to perform and can cover a large population in a very short time (Cadmus et al., 2008). In lactating animals, the MRT can be used for screening herds for brucellosis. In large herds (>100 lactating cows), the sensitivity of the test becomes less reliable (FAO, n.d (a)). Whole herd testing (individual animals in a herd) is practiced when the herd is positive (OIE, 2009). Although, the sensitivity of MRT is lower (88.5%) compared to iELISA (98.1%), the specificity of MRT (95.5%) is not significantly differ with i-ELISA (99.0%) as discussed by Vanzini et al (2001) and Godfroid et al., (2010). False-positive reactions may occur in recently vaccinated cattle (less than 4 months) or in samples containing abnormal milk, such as colostrum or that due to mastitis (FAO, n.d (a)). False-negative results may occur at early *B. melitensis* infected herds (OIE, 2009). Bulk milk sample testing with MRT was the test of selection for surveillance of many control and eradication strategies in Australia and New Zealand (Sabirovic, 1997; Bunn, 2002). A simple, rapid and cheap test called FPA for the detection of antibodies to *Brucella abortus* in bulk tank milk testing was described by Gall et al (2002). However, culture and isolation of *Brucella* organisms is the "gold-standard" test for the diagnosis of brucellosis (Gordfroid et al., 2010) which is time consuming and hazardous (Gupte and Kaur, 2015).

(2) Epidemiology and associated risk factors

Brucellosis has become most wide spread zoonosis in the world. Bovine brucellosis is reported in almost all countries where cattle are farmed, except some northern and central European countries, Australia, Canada, Japan and New Zealand, are considered as free from the disease (Figure 1.1). The prevalence is high in sub-Saharan Africa and Asia (ILRI, 2012). This disease was reported in all south Asian countries (Abubakar et al., 2011; Kang et al., 2014) including Sri Lanka (Silva et al., 2000). According to Bandara and Mahipala (2002), Sri Lanka reported the highest brucellosis prevalence among south Asian countries.

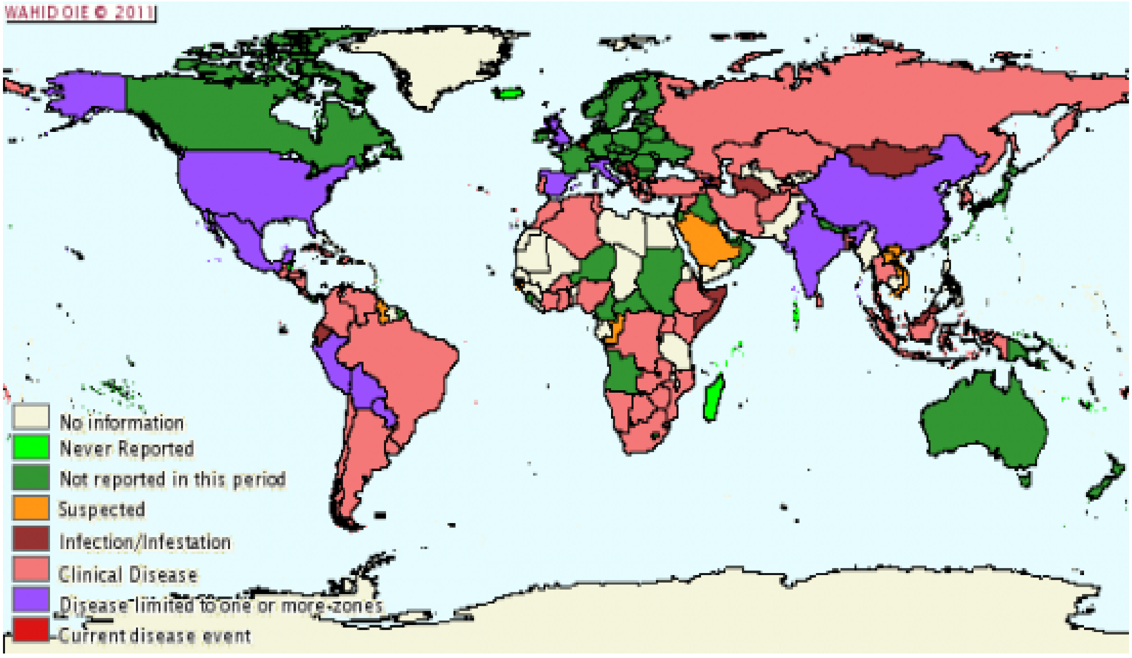

Figure 1.1 Distribution of bovine brucellosis in the world
Source: OIE (2011)

Risk factor identification is extremely important in disease epidemiology and setting of brucellosis control strategies, thus extensively studied by many developing countries (e.g Uganda, Ivory Coast, Ethiopia and Jordan) in recent past (Makita et al., 2011b; Sanogoa et al., 2012; Adugna et al., 2013; Mussalam et al., 2015a) including Sri Lanka (Silva et al.,2000).

Risk factors are at two levels such as animal and herd level (Makita et al., 2011b). Animals over 5 years were at high risk (OR=2.8, 95% CI=1.3-6.4) compared to under 3 years in Ivory Coast (Sanogoa et al., 2012). Female calves (χ^2=2.5, d. f=1), aged calves with >3 years (OR=2.0, 95% CI=1.4-2.8) and aborted animals (OR=18.3, 95% CI=10.9, 30.6) are at high risk in Sri Lanka (Silva et al., 2000). Animals within 1–4 years of age were found to be more susceptible (OR=2.7, 95% CI: 1.43–5.28) than animals less than 1 year old (Boukary et al., 2013).

Herd size and abortions were reported as herd level risk factors in Western Ethiopia (Adugna et al., 2013). Large herd size (Matope et al., 2010; Abubucker et al., 2011; Mohammed et al., 2013) and communal grazing system where they feed in common pastures and water sources (Diaz-Apiricio, 2013; Borba et al., 2013) were noted as management risk factors. It was recorded that herds with direct contact (Arbernethy et al., 2011), and in pastoral systems (Racloz et al., 2013) are at higher risk for the disease. Cattle in rural areas compared to the peri-urban areas (OR 2.8, 95% CI: 1.48–5.17), with large herd size (OR 11.0, 95% CI: 3.75–32.46), with abortion history (OR 3.0, 95% CI: 1.40–6.41), and in transhumance animal movement pattern (OR 3.0, 95% CI: 1.40–6.41) were found to be at higher risk in Niger (Boukary et al., 2013). High brucellosis incidence was found in pastoral production systems and, that decreases as herd size and landholding size decreases in sub-Saharan Africa (McDermott and Arimi, 2002). Study in Portuguese documented that brucellosis odds were increased with herds with more than 116 animals (OR = 2.99), with no cleaned watering places (OR = 3.05), with insufficient manure removal and cleaning of premises (OR = 2.87) and introduction of animals from non-free brucellosis herds or from unknown herds (OR = 12.11) (Coelho, et al., 2007). The sero-positivity among animals from herds that had history of infection, was significantly high (OR=19, 95% CI= 7.8–46.4), compared to herds without a history in Northern Ireland (Stringer et al., 2008). Extensive management practice (OR=1.8, 95% CI=1.2-2.5) and the dry zone (OR=5.0, 95% CI=3.6-7.0) were found to be at risk for brucellosis in Sri Lanka (Silva et al., 2000). However, previously it has been hypothesized that extensive management system in which strong exposure to sunlight could destroy bacteria, leading to low prevalence (Wickramasuriya et al., 1983). The same assumption that intensification may facilitate spread of brucellosis was made by several other findings as well (ILRI, 2012; Ducrotoy, 2015).

Brucellosis can be spilled over from wild life to domestic animals (Godfroid et al., 2013a). It was recorded that herds coming in contact with wildlife had higher odds compared to those without contact (OR = 3.4, 95% CI= 1-11) in Zambia (Muma et al., 2007). Risk of reintroduction of *Brucella* into domestic animals due to persistence of brucellosis in wildlife reservoirs in United States was noted by Olsen (2010). Risk of association of domestic animals with *Brucella* infected wildlife is related to the size of the populations, location of wildlife and livestock, the degree of interactions, the prevalence level of disease in wildlife, and the susceptibility of livestock herds to the disease (Schumaker et al.,2013).

Brucella organism can exist in different environmental conditions such as soil, and pasture for longer (Zhang et al., 2014). Also, it can persist in pasture for 4 months (Aune et al., 2012) and *B. suis* can exist on the environmental surfaces for at least 56 days (Calfee and Wendling, 2012). Water can keep the organism for 60 days and for 87 days in milk (normal storage) once it is contaminated (Falenski et al., 2011). It was reported that soil born *Brucella* species was detected in Pakistan recently (Ahmed et al., 2017).

(3) Risk of human brucellosis

Brucellosis could be transmitted to humans by direct contact with animals and/or their secretions, or by consuming raw milk and dairy products (Diaz-Aparicio, 2013). The disease causes flu-like symptoms, including fever, weakness, malaise, weight loss (WHO, 2016), and arthritis in humans (Makita et al., 2011 a). It was recorded that around 12.6% (6.8–18.9: 90%CI) of informally marketed milk in urban Kampala was contaminated with *B. abortus* at purchase and, the annual human incidence rate was around 5.8% (5.3–6.2: 90% CI) per 10,000 people (Makita et al, 2011a). Human brucellosis transmission from sheep was common (90%) than from cattle in Mongolia (Zinsstag et al., 2005). Farmers, veterinarians, farm workers, slaughter house workers, and animal handlers are in threat for human brucellosis (Godfroid et al., 2013b). Around 25 %(n=60) of women presenter with abortion or still birth was found to be *Brucella* seropositive in Rwanda, with higher risk of those who had contact with domestic animals (cattle, goat, or sheep) or consume cow's raw milk (Rujeni and Mbanzamihigo, 2014).

Brucellosis is an occupation related disease in humans. Study in Pakistan revealed that farmers, livestock owners, farm employees and other patients shows risk for brucellosis as 32.90%, 32.67%, 29.20% and 27.04%, respectively, with higher risk for females (37.06%) and elders (41–60 years) (35.06 %) (Shahid et al., 2014). Also, there is a risk of spread of *Brucella* spp. from wildlife to humans with bush meat of infected animals through preparation and consumption (Plumb et al., 2013; Godfroid et al., 2013a). Also, *Brucella* spp. is reported as the most common laboratory-acquired pathogens (Seleem et al., 2010). It was discussed that the traditional lifestyle and cultural beliefs related to certain farming environments create facilitating conditions for brucellosis transmission from animal to human (Smits, 2013). Also, certain ethnic groups those who get high animal contacts (e.g Fulani) have showed high susceptibility for brucellosis (Dean et al., 2013).

In Sri Lanka, human brucellosis was recognized as "unknown fevers" and pyrexia of unknown origin in early studies in the 1960s (Bandara and Mahipala, 2002). However, in the absence of human surveillance and reliable data, brucellosis prevalence is unknown at present. It has been proposed that a human brucellosis information system to be initiated by analyzing pyrexia due to "unknown causes" under one-health program in Sri Lanka (Gunawardana, et al., 2013). Despite the estimates of more than 500,000 new human cases annually, brucellosis remains frequently under diagnosed, unreported and neglected among livestock diseases in many endemic countries (Plumb et al., 2013).

Roth et al (2003) discussed the possibility of 52% reduction of brucellosis transmission between animals and humans by mass animal vaccination. Notwithstanding a number of successful vaccines for immunization of animals, there is no satisfactory vaccine against human brucellosis; therefore, control of animal brucellosis is very important in corresponding decline in incidence in humans (Seleem et al., 2010).

Despite the availability of literature on brucellosis epidemiology and associated risk factors at 'animal' and 'herd/farm' level, farmer level factors (farmers' factors) have been hardly considered in affecting the disease spread. Therefore, it was tried to study and discusses the farmers' factors (e.g. socio-economics) affecting in brucellosis epidemiology in the endemic areas in Sri Lanka. The chapter three of this dissertation discuss about association of farmers' factors with brucellosis epidemiology. Also, it was tried to identify the possible risk of human infections from animal infections as well.

1.2.2. Knowledge, Attitudes and Practices (KAP) on brucellosis

(1) Knowledge, attitudes and risky farming practices on brucellosis

Knowledge seems to be a barrier to adopt animal disease control measures in most of the rural areas. The majorities of the global poor people are poorly educated and live in rural areas. They are mostly employed in the agricultural sector, and more than half are teenagers (< 18 years of age) (WB, 2017). Knowledge, Attitude and Practices (KAP) are method of surveying to overcome misunderstandings and gray areas that may negatively affect on interventions (USAID, 2011). There are several studies on KAP on brucellosis carried out to reveal gaps in knowledge and attitudes related to risky practices (Hegazy et al., 2016; Arif et al., 2017).

Brucellosis is widely spread due to risky farming practices owing to lack of knowledge in many developing countries such as Egypt, Jordan and Tajikistan (Hagazy et al., 2016, Musallam et al., 2015b, Lindahl et al., 2015). The threat was high in Egypt due to risky practices such as supporting parturition without protective measures, throwing aborted materials into water canals and unwillingness to remove aborted animals from healthy animals (Hegazy et al., 2016). Most (97%) farmers were not aware of the modes of transmission of brucellosis, risk of raw milk consumption (66%), live in shared housing with animals (49%) and not cover hand cuts during contact with animals (74%) in Pakistan (Arif et al., 2017). Also, the majority of farmers (69.2%) belonged to low to medium knowledge level on brucellosis in Punjab in India (Hundal et al., 2016). In Kenya, around 46% of the farmers do nothing if they had aborting animal in their herd (Obonyo and Gufu, 2015). KAP (index) of the veterinarians in India significantly vary across states such as Assam, West Bengal, Uttar Pradesh and Punjab (Govindaraj et al., 2016). Though most of the veterinarians had adequate knowledge and positive attitudes towards brucellosis, the regular preventive practices were not sound in Maharashtra in India (Mangalgi et al., 2017).

Patchy awareness, poor knowledge and poor animal husbandry practices are the main reasons for high risk for zoonosis in most of the cases (Swai et al., 2010). Only 4.8%, 3.6%, 6.8%, and 22.4% of farmers knew about the zoonotic potential of diseases such as brucellosis, tuberculosis (TB), anthrax, and avian flu, respectively and only 18% of the respondents were aware about cattle zoonotic diseases in India (Rajkumar et al., 2016). Hence, awareness and education on animal diseases enhances knowledge and skills among farmers and general public. The study shows that an educational program for high school students in Iran about brucellosis, clinical signs of disease and the preventive measures significantly increased their knowledge (Mahmoodabad et al., 2008). KAP approach says (re) training can change personal behavior by improving knowledge, attitudes, skills and practices (Yambo, 2016).

(2) Factors affecting knowledge sharing

Knowledge acquiring capacity embodies with personal factors, social factors and institutional factors (Yiu and Law, 2012). Also, it was noted that knowledge sharing depends upon farmers' social characters and extension institution infrastructure facilities (Wheeler and Ortmann, 1990). Farmers' social characters such as education, his/her experience in farming, perception on new technology, and availability of extension services have significant effect on adoption of new knowledge and technology (Joshi and Pandey, 2005). Factors of distant to the store, price, level of formal education, number of contacts with extension agent, age of the farmer significantly influenced the fertilizer adoption in cassava production in Nigeria (Chukwuji and Ogisi, 2006). Further, cultural diversity of ethnic groups creates variation in farmer attitudes (Millar and Photakoun, 2008). It was reported that information input, information output, farmers' intra-system communication, farmer-researcher communication, farmer- extensionist communication, availability of input facilities and overall knowledge about dairy farming technologies had positive and highly significant relationship with overall adoption level of dairy farming technologies (Rezvanfar, 2007).

KAP gaps on brucellosis prevalence were sufficiently discussed in previous literature in other developing countries. Yet, there is no sufficient literature available on farmers' knowledge, attitudes and practices about brucellosis in Sri Lanka. There are several studies on factors affecting livestock technology adoption such as yoghurt preparation (Nchinda and Mendi, 2008), artificial insemination (Tefera et al., 2014), heat stress management in animals (Katiyatiya et al., 2014), etc. But, factors affecting on farmers' knowledge sharing on animal diseases is rarely considered in previous studies. Also, efficiency of veterinary extension systems in enhancing farmers' knowledge on livestock diseases is poorly studied in most of the developing countries. Therefore, in this dissertation (Chapter 4), KAP gaps of brucellosis and factors affecting animal disease knowledge sharing among cattle farmers in Sri Lanka is discussed.

1.2.3 Farmers' behavior, information asymmetry and incentives

(1) Farmers behavior and livestock diseases

Animal disease control and eradication strategies are technically feasible, but socially unattainable in most of the cases, because of farmer's attitudes on control measures and allied benefits (Heffernan et al., 2016). Farmers' decision on whether to implement or not a specific measure is attributable to attitudes and perceptions of disease risk, attitudes towards the efficacy of the measure, social influence and information credibility (Garforth, 2013). The intention to adopt and adhere for biosecurity practices is influenced by personal and contextual factors, attitudes, beliefs and perceptions, finally mediated by perceived costs (Mankad, 2016). Perception of benefits, value of epidemiological data, farmers' knowledge, motivation, trust and institutions' functioning are identified as key considerations in successful disease surveillance system (Brugere et al., 2017). Farmers' decision on bio security behavior is related to attitudes and information source (Heffernan et al., 2008) and advisory services (Brennan et al., 2016). Study in Canada explored that farmers do not perceive as a problem about certain diseases (e.g Jones disease) in control communications (Ritter et al., 2016).The literature indicates behavior is influenced by knowledge, information sources, attitudes, perceptions believes and norms (Ajzen,1991); therefore asymmetry in information is a social concern.

(2) Information asymmetry and incentives

Asymmetric information, is an economic term, is sometimes referred to as information or market failure. When one of the two parties are better informed than the other one is described as asymmetric information (Scheig, 2008). It is well studied in relation to international trade stating that foreign investors have an informational advantage over domestic traders due to their experienced trading skills (Bae et al., 2011); and in sectors like banking (Boatenga et al., 2018) as well as animal disease control (Hennessy and Wolf, 2015).

Governments and private farmers work jointly in controlling diseases. Government tries to control diseases by implementing regulations while framers maintain herd health. When the disease is spreading, information gap may exist between farmer and the veterinary authorities. In such situation, farmers have more information about the infectious animal that could be sold or send to another farmer/area without giving correct information (hidden action); thus, likely to spread the disease (Hennessy, 2007). Moral hazard refers to situation where agent can undertake decision that principal can't monitor it (Hennessy and Wolf, 2015). 'Adverse selection' problem arise when the people in the informed side (e.g farmer) select an option that is harmful to the other side of people (e.g government) that are uninformed (Tumay, 2009). This information gap between the farmer (agent) and the government (principal) causes a problem known as 'information asymmetry' or 'hidden knowledge' (Laffont and Martimort, 2001). This problem could be solved by bureaucratic control, information systems, incentives and bonuses, corporate culture, reputation and developing trust (Schieg, 2008).

(3) Principal-Agent theory in addressing information asymmetry

The Principal-Agent (PA) approach describes how incentives or bonuses can elucidate the discrepancy or information asymmetry (Laffont and Martimort, 2001). In the Principal-Agent theory, the principal depends on an action taken by the agent. In the presence of information asymmetry, the principal hires the agent to perform certain action on some observable signal that is correlated with the action of the agent. The principal is the first mover, and chooses an incentive scheme for paying the agent that depends on the observed signal. The agent then chooses the optimal action to take, given the incentives, and then decides whether to accept or not the principal's offer, based on the expected payment/benefit and the subjective cost of performing the action (Allison,n.d).

There are some assumptions to apply in PA model in studying principal and agent relationship (Laffont and Martimort, 2001). 1) the principal and the agent both adopt an optimizing behavior and maximize their individual utility. In other words, they are both are fully rational individualistic agents. 2) the principal does not know the agent's private information, but the probability distribution of this information is common knowledge. 3) the principal is a Bayesian expected utility maximizer. He moves firm as a leader under asymmetric information anticipating the agent's subsequent behavior. Figure 1.2 shows the relationship between principal and agent in performing to decrease the information asymmetry.

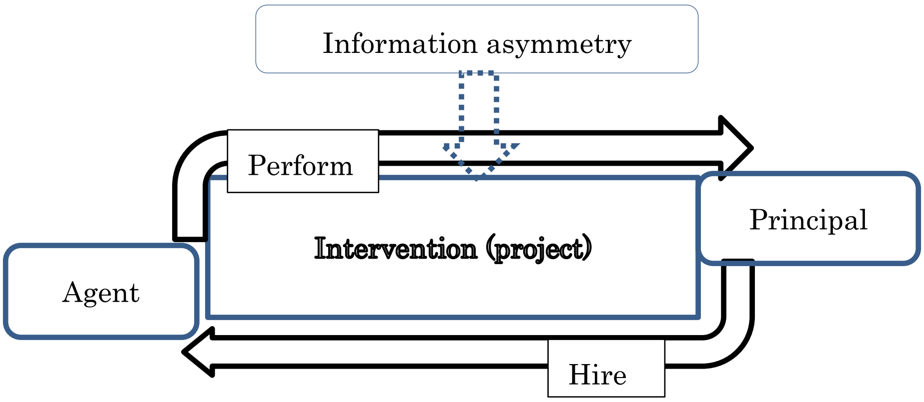

Figure 1.2 Principal-Agent theory applications in projects

Source: modified from Babayan and Kadlečíková (2016)

Indemnity payments can incentivize animal disease reporting in the presence of moral hazard and adverse selection (Gramig et al., 2009). PA theory was used to investigate animal disease control in the presence of asymmetric information by Hennessy and Wolf (2015). Food safety policy in the presence of imperfect information about food quality was studied using PA model (Starbird, 2005). Asymmetric information in project management in the fields such as Civil engineering (Ceric, 2010), Rural agriculture development (Babayan and Kadlecikova, 2016), forestry (Zubayr et al., 2014), construction (Schieg, 2008), agricultural grower performance in quantity and quality (Olmos and Martínez, 2010) was studied using PA model.

The theory of planned behavior (TPB) is sociology and psychology related theory. It explains how behavior of person is based on his/her beliefs, attitudes and norms that could be changed by different motivational factors such as individual, social and information (Ajzen, 1991) (Figure 1.3). It is being increasingly used in studying incentive perception to control livestock disease by managing farmers' behavior (Gilbert and Rushton, 2016). Intention of conventional farmers to convert into organic farming was studied using TPB (Lapple and Kelley, 2010).

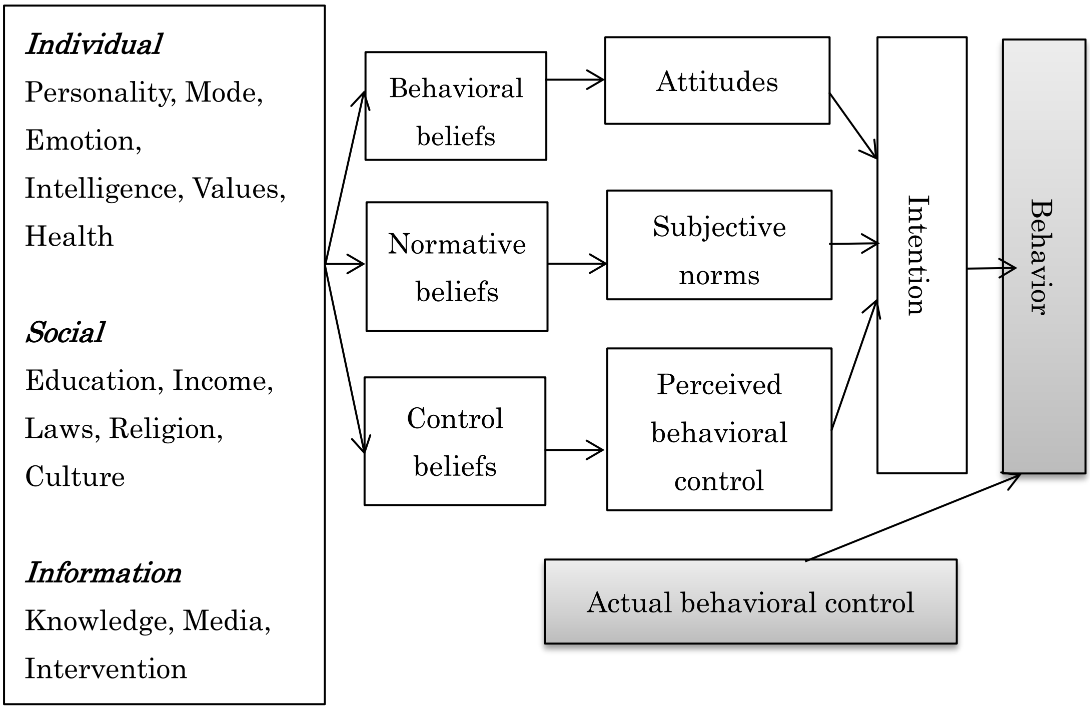

Figure 1.3 Personal behavior changes with different motivational factors
Source: Ajzen (1991)

Disease control is a public good in which benefits can be enjoyed simultaneously by entire community (Smith et al., 2004), is made by the government sector in many cases. Nonetheless, government intervention in public good aspect of disease control can lead to an inconsistency between private and public action thresholds (Wolf, 2005). A set of rational and self-interested individuals will not act on group interest over their personal gain (Olson, 1965). Numerous findings show that individual behavior is responsive to prices and incentives. For example, consumption of cigarettes drops when cigarette prices increase (Becker et al., 1994; Gruber et al., 2003), and the timing of births in a year is responsive to the tax benefit of having a child (Dickert and Chandra, 1999).

Incentives affect producers' decisions such as increase production (Ranjan and Lubowsky, 2004) or control animal diseases (Gilbert and Rushton, 2016) or human disease reporting (Rahim et al., 2016). Risk based incentives (rewards and punishments) are suggested by Barnes et al (2015) to motivate farmers for disease reporting and bio-security management. Also, producers can be incentivized by cost subsidies (Wolf, 2005).

(4) Milk incentives, milk quality and animal diseases

Milk testing and incentives are commonly used in most of the developing countries to incentivize small scale farmers for quality milk production (Draaiyer et al., 2009). Milk is normally paid on quantity and physical quality of color and odor, chemical quality of fat and SNF, and hygienic characters such as microbial counts. Milk incentives were recommended to improve milk quality by testing somatic cell count (SCC) and total bacterial count (TBC) to motivate farmers to increase milk hygiene (Botaro et al., 2013). Bulk milk testing (BMT) for detection of *Brucella abortus* is cheap and simple test (Gall et al., 2002) and also recommended by OIE for surveillance in control (OIE, 2009). Also, human brucellosis can be transmitted by consumption of unpasteurized milk and milk products (WHO, 2016). Therefore, milk payment system can be efficiently used to motivate farmers for *Brucella* free milk production. Incentives should not be rewards always, it could be fines those who do not comply the required standards (Gramig et al., 2009). It was argued that the combination of a premium- penalty milk payment scheme for very high-quality milk provides a strong incentive for improvement of milk quality (Nightingale et al., 2008). A study was carried out to evaluate the impact of two incentive instruments, a price penalty for low quality and a bonus for consistent high-quality milk, on farmers' investment in quality-improvements in Vietnam (Saenge et al., 2012).

Good management practices (GMP) in farms can rectify the high microbial counts in milk (De Silva et al., 2016). Study in the Netherlands recorded that milk incentives can improve mastitis management in herds (Valeeva et al., 2007). Therefore, available literature shows milk payment system can be used to incentivize farmers efficiently to improve farm bio security, thereby milk quality. Yet, the possibility of milk testing and payments to motivate farmers for farm bio security information and disease management is poorly considered in developing countries. Even though, the aspect can be exploited in managing milk borne diseases particularly, it is not well thought in brucellosis control so far. Therefore, this dissertation discusses (Chapter 5) the feasibility of economic incentives to address biosecurity information asymmetry using milk payment system to control brucellosis in Sri Lanka.

1.2.4 Brucellosis control and eradication policies

Farm management decisions are, either ex ante to disease occurrence such as surveillance, preventive vaccination, and biosecurity in susceptible populations or ex post such as treatment and culling (Chi et al., 2002).

(1) Brucellosis control and eradication

Animal disease control is in two phases such as ex-ante (prior to outbreak) and ex-post (after the outbreak). Vaccination is an ex-ante strategy for brucellosis control and eradication (Dorneles et al., 2015). Vaccination tend to reduce the exposure of animals to *Brucella spp.* and to increase resistance to infection in susceptible animals (Adone and Pasquali, 2013). The *Brucella abortus* strain 19 (S-19) vaccine which was invented in 1932, is the cornerstone of brucellosis control programs in cattle (Godfroid et al., 2010). It has been successfully used to decrease abortion rates in heifers (Bunn, 2002) with lifelong immunity (Dorneles et al., 2015). 'S-19' (smooth vaccine) has been the vaccine of selection in bovine brucellosis control and eradication programs in many countries such as New Zealand, Australia, United States of America (Sabirovic, 1997; Bunn, 2002; USDA, 1986). It was recognized as the 'standard vaccine' for mass vaccination for bovine brucellosis by World Animal Organization (OIE, 2009). Vaccination of young herd is recommended with S-19 (Adone and Pasquali, 2013). Vaccination of adult cows may be occasionally recommended for large farms with high prevalence in which test and slaughter strategies are not feasible (Sancho et al., 2015). Australian government has used another common vaccine strain 45/20 in the areas of extensive grazing to lower the prevalence in their brucellosis control/eradication program (GOA, 2009). Nevertheless, abortions were recorded with S-19 in adult cows in the United States; that has been addressed by using reduced dose of vaccine (Ragan, 2002). Reduced dose of S-19 vaccine in adult animals was used in India to control the disease in endemic areas (Chand et al., 2015). Adult animal vaccination with 1/20 dose of S-19 was recorded in large scale state owned farms to control brucellosis in Sri Lanka also (Peris et al., 1981). Major drawback of S-19 was the interference of vaccine antibody with field infection and also with routine brucellosis diagnostic tests, which is successfully addressed by developing the vaccine RB 51 in 1982 (Dorneles et al., 2015). The vaccine RB 51 is a rough vaccine and it has been helpful in last part of eradication programs in California (USDA, 2006) and Potugal (Martins et al., 2009). There are few other vaccines for *B. abortus* like SR 82, DNA vaccines and subunit vaccines (Dorneles et al., 2015). Vaccine used to control *B. melitensis* in sheep and goat is Rev.1, and there is no vaccine developed for pigs and for wildlife (Godfriod et al., 2010).

Mass vaccination that is vaccination of entire population was proved to be very effective in decreasing the existing prevalence to low levels (Sabirovic, 1997; Bunn, 2002). It was used in herds/populations with high potential of transmission such as pastoral systems (Smits, 2013). Effectiveness of mass vaccination strategy with wider coverage to reduce the transmission rate closer to eradication level is proved in India where the culling and slaughtering is forbidden due to socio cultural reasons (Kang et al., 2014). Similarly, large-scale (mass) vaccination campaigns were recommended, if the prevailing epidemiological and socio-economic conditions do not favor for effective test-and-slaughter policy (Adone and Pasquali, 2013). Animal brucellosis control is critical in human brucellosis control, since there is no vaccine available for humans (Godfroid et al., 2010).

Testing and culling is the strategy to eliminate or remove brucellosis entirely from a population (Sabirovic, 1997, Martins et al., 2009). Also, other methods such as prevent infected animal introduction in to disease free areas (Zamri-Saad and Kamarudin, 2016), bio security management, movement restriction, farm accreditation and animal identification seems to be very effective in brucellosis control (GOA, 2009). Herd monitoring, abattoir monitoring, abortion monitoring, boarder control were also important in successful eradication (Bunn, 2002; Rivera et al., 2002).

(2) Simulation models in control decisions

Disease management and control alternatives were studied through different types of models (Dube et al., 2007). Simulation models are used to study the potential impacts of outbreaks (Reeves, 2012) and economic impact of control strategies such as vaccination (Roth et al., 2003). In modeling, it could simulate the outcome of combination of different approaches such as education and vaccination as a control strategy (Atkins, 2010).

Brucellosis transmission and control possibilities were studied using simulation models with numerous scenarios and settings in different countries. Brucellosis transmission and control possibilities studied with simulation incorporating direct and indirect transmission in sheep (Ainseba et al., 2010) and in dairy cattle (Zhang et al., 2014). The risk of introducing brucellosis into a free area was measured by Dalrymple

(1993) in USA. Transmission dynamics of sheep brucellosis was predicated in Inner Mongolia (Hou et al., 2013). Brucellosis transmission control using network control theory approach was recorded in sub-Saharan Africa (Roy et al., 2011). Control with vaccination for multiple livestock host species was discussed using Susceptible, Exposed, Infectious and Vaccinated model (SEIV) in Jordan (Beauvais et al., 2016). Simulation model demonstrated the likelihood of eradicating brucellosis by mass vaccination with very high vaccination coverage in India (Kang et al., 2014). Efficiency of vaccination strategies to control brucellosis in wild life was deliberated in Yellowstone area in US (Treanor et al., 2010). Simulation models were used in investigating effectiveness of surveillance programs using models in UK and Japan (England et al., 2004; Yamamoto et al., 2008).

(3) Economic efficiency of control decisions

Animal disease control is a social decision that involves externality cost, optimal overall control efforts, cost sharing between tax payer and farm owners, etc. (Tisdell et al., 1999). The government disease control policies are aimed to cope with public goods, natural monopolies, international trade, project coordination failure and information failure (Ramsay et al., 1999). Comprehensive economic analysis provides necessary information to the primary producers as well as the government to make appropriate decisions. Therefore, economic analysis is increasingly used in animal disease control models (Rich et al., 2007). It provides information for holistic approach in considering externalities and social aspects (Ramsay et al., 1999).

Economic analysis can be performed as social cost–benefit analysis, partial budgeting, economic losses (impact) analysis, input/output (I/O) analysis, welfare analysis, general equilibrium analysis, eradication cost estimate, etc. (Carpenter, 2013).

Cost-benefit analysis is often used with epidemiological models to assess the cost effectiveness of alternative control strategies (Rich, 2007). Studies revealed that losses per animal due to brucellosis was as US$ 6.8 per cattle, US$ 18.2 per buffalo, US$ 0.7 per sheep, US$ 0.5 per goat and US$ 0.6 per pig in India (Singh et al., 2015). Human benefits (52 % reduction of prevalence) from cattle mass vaccination of were estimated with US$ 8.3 million intervention costs and US$ 26.6 of the overall benefit by Roth et al (2003) in Mongolia. A study in New Zealand recorded that brucellosis control yields 10.1% rate of return by an investment (Sheperd et al., 1979).

Integration of epidemiology and economics is meaningful in animal disease control (Rich and Perry 2011). Incorporation of farmers' production behavior in epidemiology-economics models is very effective in animal disease control decision making (Rich, 2007). But, farmers' social behavior is rarely combined in epidemiology – economics dynamic modelling. Chapter six of this dissertation discussed the efficiency of integrated epidemiology-economic control intervention, together with farmers' behavior using dynamic modelling.

In summary, literature on brucellosis was extensively reviewed and studied in the veterinary disciplines such as microbiology, epidemiology, surveillance techniques, integration of human-animal-wild life interface, vaccine development so on. Also, brucellosis control possibilities were studied using several epidemiological models. Information asymmetry and its impact on animal disease control were also reviewed. Moreover, there are quite a large number of literatures on epidemiology-economic integration in animal disease control. Yet, farmers' behavior is poorly thought-out in such integrations (Rich, 2007), that could be important in addressing poverty impacts of animal diseases (Rich and Perry, 2011). Gilbert and Ruston (2016) stressed the ability and strength of human behavior integration in animal disease control decision making. Therefore, this dissertation tried to bridge the existing ligature gap of considering farmers' behavior in animal disease control to provide inputs for efficient brucellosis control strategy in Sri Lanka (Figure 1.4).

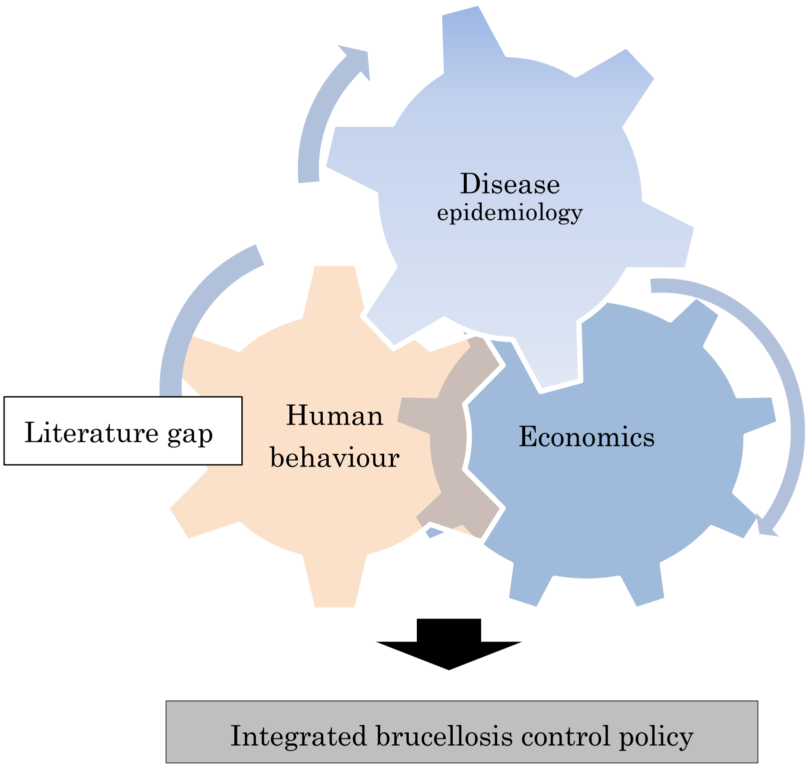

Figure 1.4 Existing literature gap in brucellosis control policy framework

1.3 Objectives and structure of the thesis

The overall objective of this dissertation was to clarify present brucellosis status and related farmers' behavior on bio-security decisions, to provide inputs for integrated brucellosis control strategy in Sri Lanka.

There are four specific objectives in this dissertation

Objective 1) Study about brucellosis epidemiology and its association with farmers' socio-economic factors.

Objective 2) Study gaps on knowledge, attitudes and practices of brucellosis, and factors affecting knowledge sharing on animal diseases.

Objective 3) Study farmers' behavior towards incentive-based cattle culling policy to eradicate brucellosis in Sri Lanka.

Objective 4) Study epidemiological feasibility and economic efficiency of control approach.

The dissertation comprises of eight chapters; chapter 2) describes the livestock production and issues in animal disease control in Sri Lanka. Reasons are stated to select brucellosis for this study.

Corresponding with specific objectives, chapter 3, 4, 5 and 6 describe results of analysis. Chapter 3 describes the epidemiology of brucellosis. Variation of disease epidemiology related to different management practices and farmers' socio-economic factor is offered in this chapter. Corresponding with objective 2, chapter 4) describes factors affecting knowledge sharing. Gaps in knowledge, attitudes and practices on brucellosis are also described in this chapter. Corresponding with objective 3, chapter 5) farmers' behavior on accepting incentive-based cattle culling policy is discussed. Corresponding with objective 4, chapter 6) discussed the efficiency of control strategy to eliminate brucellosis from in Sri Lanka. Dynamic modelling was used to predict the brucellosis prevalence with alternative control scenarios, thereby select the most economical strategy to yield maximum utility for the society. Chapter seven serve as the general discussion followed by conclusion based on combine results of analytical chapters in the last chapter (chapter 8). The analytical frame work of the dissertation is depicted in Figure 1.5.

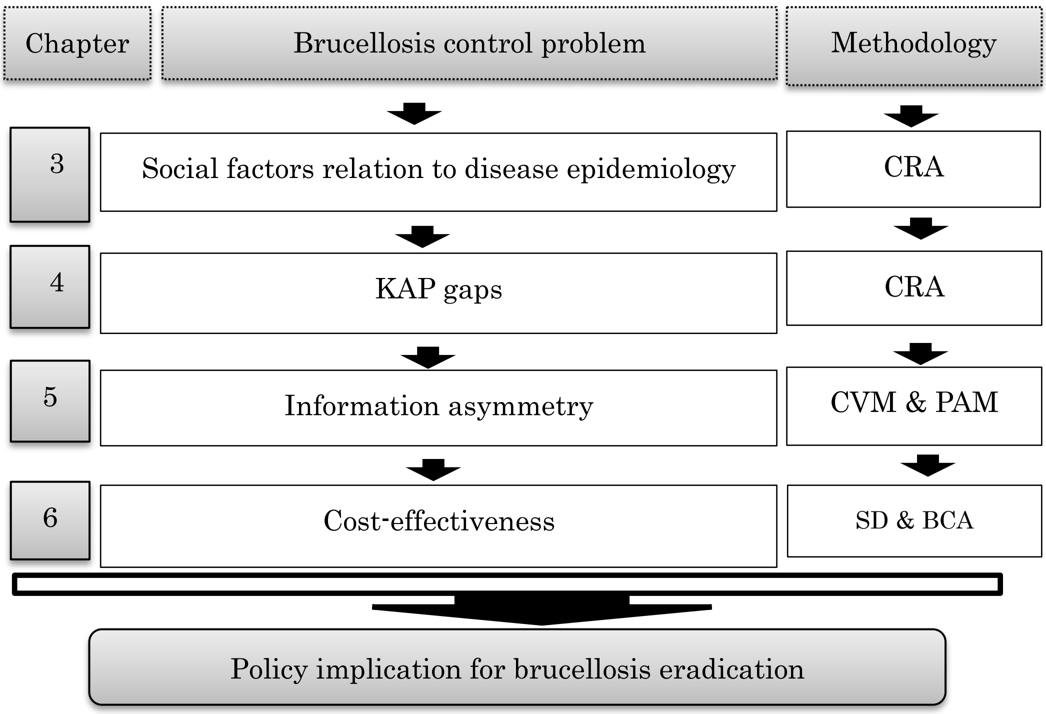

Fig. 1.5 Analytical framework of the thesis

Note: CRA -Censored Regression Analysis; CVM - Contingent Valuation Method; PAM-Principal- Agent Model; BCA – Benefit Cost Analysis; SD - System Dynamics.

1.4 Study area and population

1.4.1 General characteristics of the area

Approximately, 64 % (84/132) of the brucellosis cases were reported from Eastern province of the dry zone of Sri Lanka in 2015 (EB, 2015). Therefore, Eastern province was selected as the study area for this analysis.

Eastern province is comprised of three districts viz. Trincomalee, Batticoloa, Ampara and it has an area of 9950 km^2 with 1,561,000 human populations. The province contributes 15 % of land area and 7.5 % of the total population of the country (DCS, 2012).

Out of three districts, Ampara was selected for this study due to high disease incidence (Wickramasuriya et al., 1983; EB, 2010) and most notably the presence of different socio-cultural backgrounds with three main ethnic groups, i.e., Sinhalese, Tamils, and Muslims. The district has a population of 649,402 people, of which 43.4% are Sri Lankan Muslims, 38.88% are Sinhalese, 17.3% are Sri Lankan Tamils, 0.16% is Burghers, and 0.27% is of other ethnicities (DCS, 2012).

Ampara is one of the major rice producing areas in the country (WFP, 2009). Thus, main livelihood remains as crop cultivation together with livestock, commonly known as mixed crop-livestock integration.

1.4.2 Dairy farming of the area

There are approximately 115,000 cattle and 30,000 buffalo population, and 17,000 farms in the Ampara district (Table 1.3) with farm size of 2-200 animals (DAPH, 2008). Ampara is the highest milk producer amongst three districts in Eastern province, producing around 23 million milk liters annually (Figure 1.6), which is 6 % of the national milk production. Average milk production is around 1.4 litres per animal as per the farm registration data base in 2008 (DAPH, 2008). Traditional extensive system is predominant with some intensive or semi intensive farms.

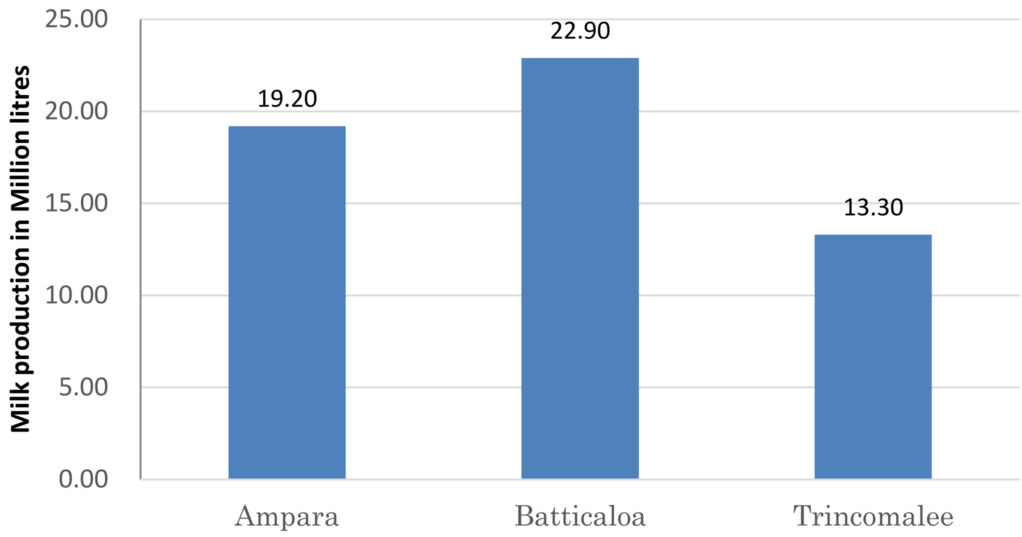

Figure 1.6 Annual milk production of the study area

Source: LSB (2015)

1.4.3 Sample selection and of study population

The district consists of 19 government veterinary ranges managed by a veterinarian. The veterinary range consists of a number of *Grama Niladhari* Divisions (GND = one or two villages) could be ranged from 12-59 in Ampara (Table 1.3).

Table 1.3 Characteristics of the study area (Eastern province)

Veterinary range	Area	GND (No)	Human population (Percentage)				farms (No.)	Animal (No)		Milk collection (daily)
			Muslim	Sinhala	Tamil	Other		Cattle	Buffalo	
Addalaichchenai	62	32	92%	5%	2%	0%	1064	4849	2990	4306
Akkaraipattu	60	28	99%	0%	0%	0%	745	5486	780	2481
Alayadivembu	90	22	0%	1%	98%	1%	596	4202	2921	3252
Ampara (Namal Oya)	174	22	0%	99%	0%	1%	952	6228	428	1129
Damana	542	33	0%	100%	0%	0%	950	7984	578	2667
Dehiattakandiya	394	14	0%	99%	0%	1%	1146	3632	22	3149
Irakkamam (Eragama)	25	12	91%	7%	2%	0%	384	1811	1159	1083
Kalmunai	22	57	60%	0%	38%	2%	770	7745	2355	4218
Karaitivu	7	17	39%	1%	59%	1%	642	2893	678	2646
Lahugala	815	12	0%	93%	7%	0%	469	4426	470	1081
Maha Oya	667	17	0%	100%	0%	0%	1199	14764	14	4542
Navithanveli		20	34%	1%	65%	0%	966	4241	1300	2453
Nintavur	35	25	96%	0%	4%	0%	494	2484	196	1064
Padiyathalawa	379	20	0%	99%	0%	0%	1992	10433	9	1866
Pottuvil	265	27	78%	3%	19%	0%	1128	7849	7136	7138
Sainthamaruthu	6	17	100%	0%	0%	0%	250	956	928	1102
Sammanthurai	229	51	88%	0%	12%	0%	1192	6366	2549	2783
Thirukkovil	184	22	0%	0%	99%	0%	1133	8635	5567	6666
Uhana	485	59	0%	100%	0%	0%	979	10004	589	1715

Source: DCS, 2012; DAPH, 2008

The main responsibility of the government veterinary officer is to diagnose prevent and control diseases, maintain bio-security and to implement livestock development projects in the area. The animal population, farm number and land area of veterinary range differ significantly across the district (Table 1.3).

Out of the total 19 veterinary ranges in Ampara district, the present study included three ranges that represent three ethnic groups, namely Kalmunai (predominantly Muslim), Navithanveli (predominantly Tamil), and Mahaoya (predominantly Sinhala). Study area is shown in Figure 2.16. Cattle framers those who are registered as a farmer in the government veterinary range (DAPH, 2008) was selected as the target population. A cross sectional survey was performed and, the sampling methodology and data obtained is separately described in analytical chapters.

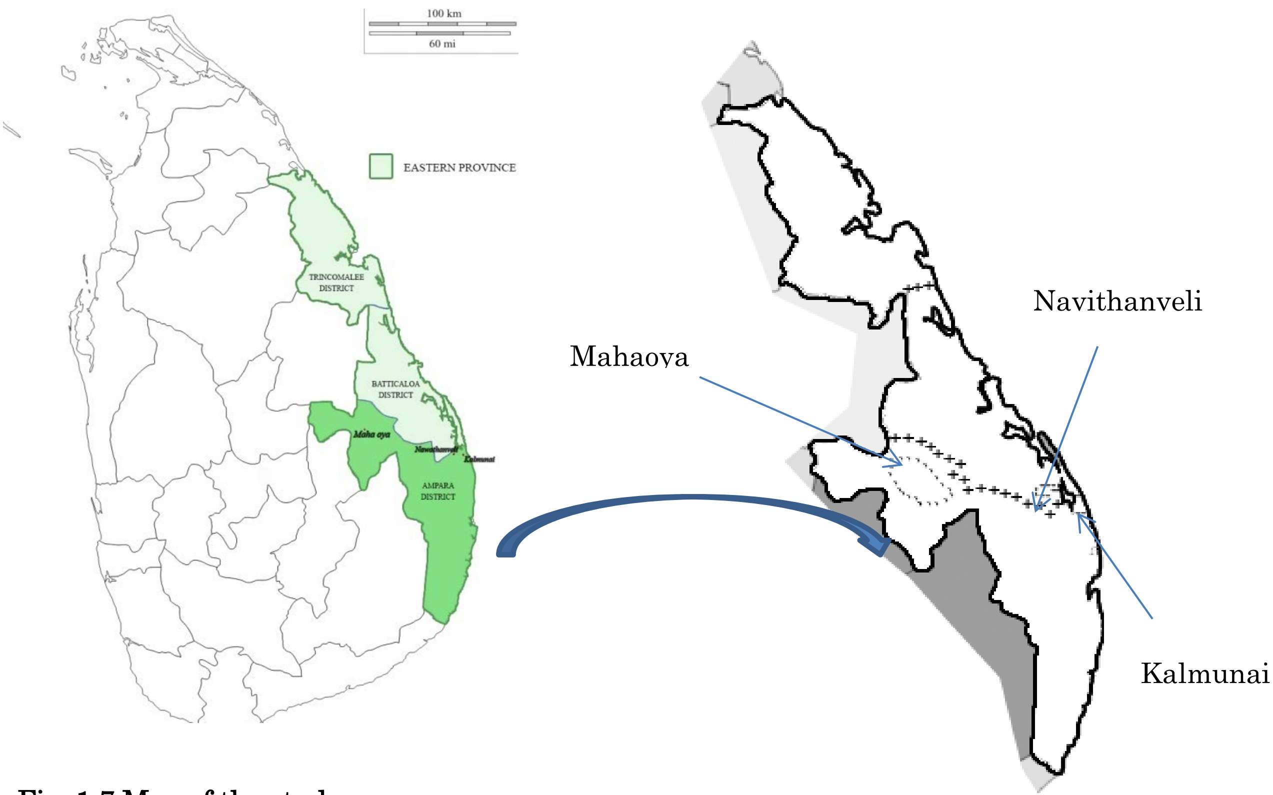

Fig. 1.7 Map of the study area

CHAPTER 2

Livestock production and animal diseases in Sri Lanka

2.1 Background

Sri Lanka is an island located in the Indian Ocean. It is located between the 5° 55' to 9° 51' of North latitude and between 79° 42' to 81° 53' of East longitude (MMDE, n.d). The landscape of the country is consisted of high altitude central hills surrounded by a low-level coastal region. Influence of monsoonal rains and the location near to the equator brings extremely variable weather condition across the country. Sri Lanka is traditionally divided in to three main agro-climatic zones viz. wet, dry and intermediate with 2500mm, 1750mm and 1750-2500mm annual average rainfall respectively according to the rainfall pattern (MMDE, n.d). The country is divided in to 9 administrative provinces, with 25 districts. Each district is divided in to *Grama Niradhari Division*s *(GND)* which is the smallest administrative unit in the country. There are 14,034 GN divisions in the country (DCS, 2012). There are different socio-religious settings with 70.2% of Buddhists, 11.2 % of Hindus, 9.7 % of Muslims, 6.1% of Roman Catholics, 1.3% other Christians and 0.05% others in Sri Lanka(DCS, 2012).

Sri Lanka is a lower middle-income country with a 21 million total population and with a per capita income of US$ 3,924 in 2015 (DCS, 2015). The human development index of the country is relatively high (0.715) compared to other developing countries with high life expectancy at birth (75.1 years), high mean years of schooling (9.3) despite low gross national income per capita of 5,170 (2005 PPP$) (UNDP, 2013). Sri Lankan economy has shown steady growth at 5.2 percent per year in 2015 (DCS, 2015). The service sector shares the major part (57.1%) of the Gross Domestic Product (GDP), followed by industrial (26.7%), agriculture (7.2%) and taxes (9%) (DCS, 2015) (Figure 2.1). The main exports are tea and apparels. The agricultural sector is largely contributed by households and non-profit institutions serving households (81.4 %) (CB, 2016), indicates the importance in rural economy. The value-added agricultural production is comprised mainly by paddy, tea, rubber, coconut, other crops, vegetable, fruits and livestock.

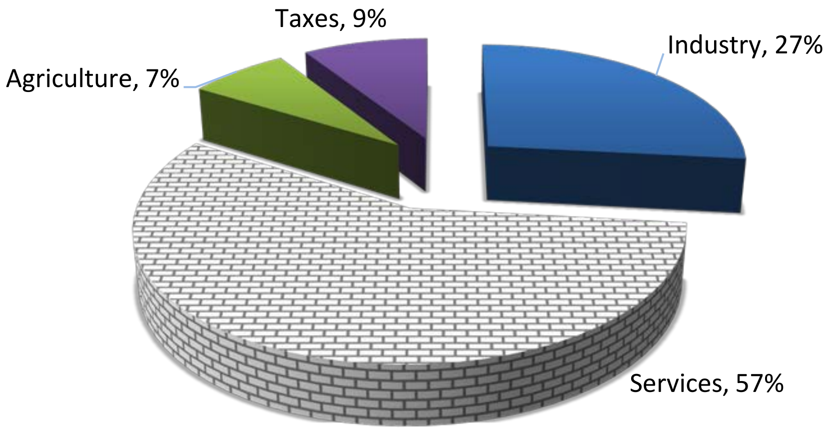

Figure 2.1 Contribution of different sectors to the economy of Sri Lanka
Source: DCS (2015)

Sri Lanka spend huge amount of foreign exchange (US$ 225 million) for milk imports each year. It is 0.4 % of the total GDP (US$ 81.32 billion) in Sri Lanka (CB, 2016). Country is planning to be self-sufficient in milk by improving local dairy sector (MLRCD, 2011) to solve this issue. Yet, low productivity is one of the main constraints for dairy sector development (Ranaweera, 2009), could be partially due to long standing endemic cattle diseases such as brucellosis which is the aim of this study. Therefore, the purpose of this chapter was to understand the impact of animal diseases to the livestock development to recognize the challenges particularly in brucellosis control.

2.2 Livestock production and farming practices in Sri Lanka

2.2.1 Livestock production

Livestock plays an important role in rural economy, despite its very small contribute (1%) to the national GDP (CB, 2016). The sector continues to develop with 8% growth rate in 2015 (AR, 2016). Livestock production offers many rural livelihoods possibilities while helping to improve the nutritional status of the population. Over 70 % of the rural population engaged in livestock directly or indirectly (DCS, 2015). Mixed crop-livestock integration enhances the importance by mutual benefits of livestock-and crop farming. Dairy, poultry, goat and swine sectors are main subsectors of livestock production. The poultry sector contributes over 70% to the livestock GDP, and it has shown a phenomenal growth over the past decades (AR, 2016). Sri Lanka is nearly self -sufficient in chicken meat and eggs at current purchasing power levels (AR, 2016). Per capita availability of eggs per year has increased from 38 eggs (1986) to 90 (2016), while that of chicken meat has increased from 0.1 kg (1986) to 8 kg (2016) (Fig.2.2). Dairy sector shows slow growth compared to the poultry sector. Goat and swine sectors are significantly small and contribute for mutton and pork production.

Milk availability per capita has increased from 17 kg in 1986 to 46 kg in 2016. Sri Lankan milk market is dominated by imported milk (Figure 2.3). Around 70% of the milk consumed is imported as powdered milk. The government spends around SLR 35 billion (US$ 225 million.) per year on milk imports (LSB, 2015). Therefore, dairy sector need intervention in production improvement and marketing.

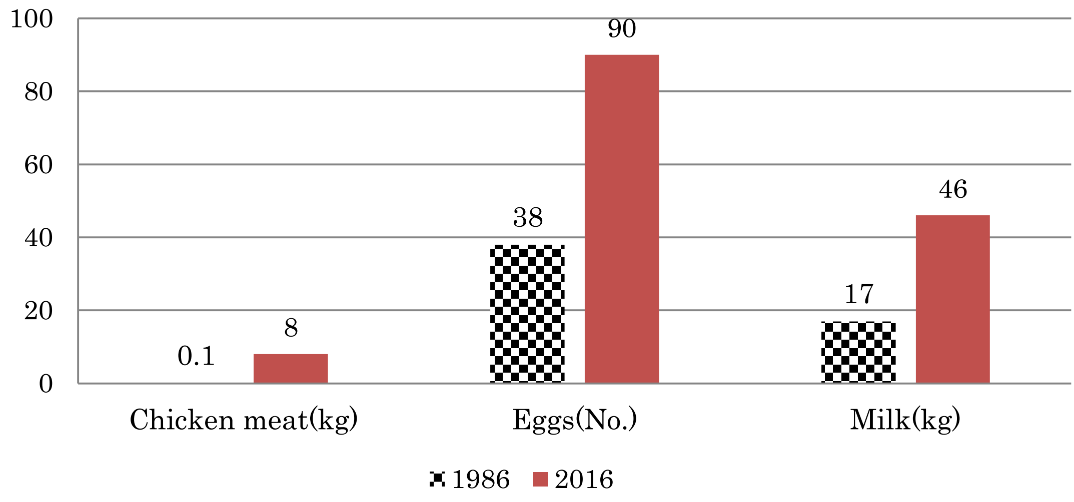

Figure 2.2 Change of annual per capita availability of livestock products (1986/2016)
Source: Unpublished data (1996); LSB (2015)

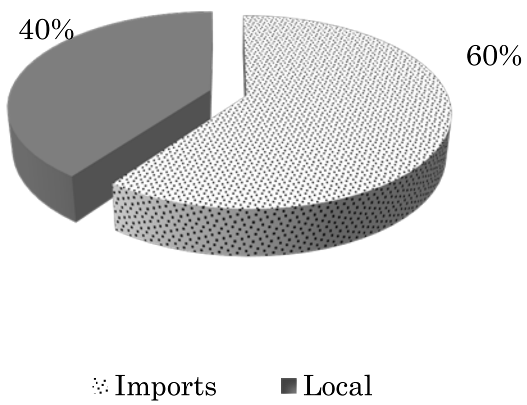

Figure 2.3 Milk market share between imports and local production
Source: LSB, DAPH (2015)

Dairy sector is the single largest livestock sub sector in Sri Lanka. Dairy farming has been a year-old practice among rural people in the country. It is a traditional practice. Animals have performed multiple functions of producing milk for household consumption, males as a source of draught power in agricultural operations, and dung as valuable manure. Milk is a cash crop for smallholders with a regular income, converting their low value agricultural byproducts, crop residues and cheap family labor into a value-added market commodity. Dairying provides income generating avenue for half a million of rural small holder farmers (Abeygunawardana et al., 1997). Small scale dairying as an integrated farming system provides efficient financial, health and social securities to rural dwellers in Sri Lanka. There are around 200,000 dairy farmers with 1.6 million of cattle and buffalo population (LSB, 2015). Over 80% of the milk production is contributed by cattle population (LSB, 2015), while buffaloes are mainly used for draft power in rural areas. Number of farms and number of animals have shown gradual decrease over past few years (Figure 2.4).

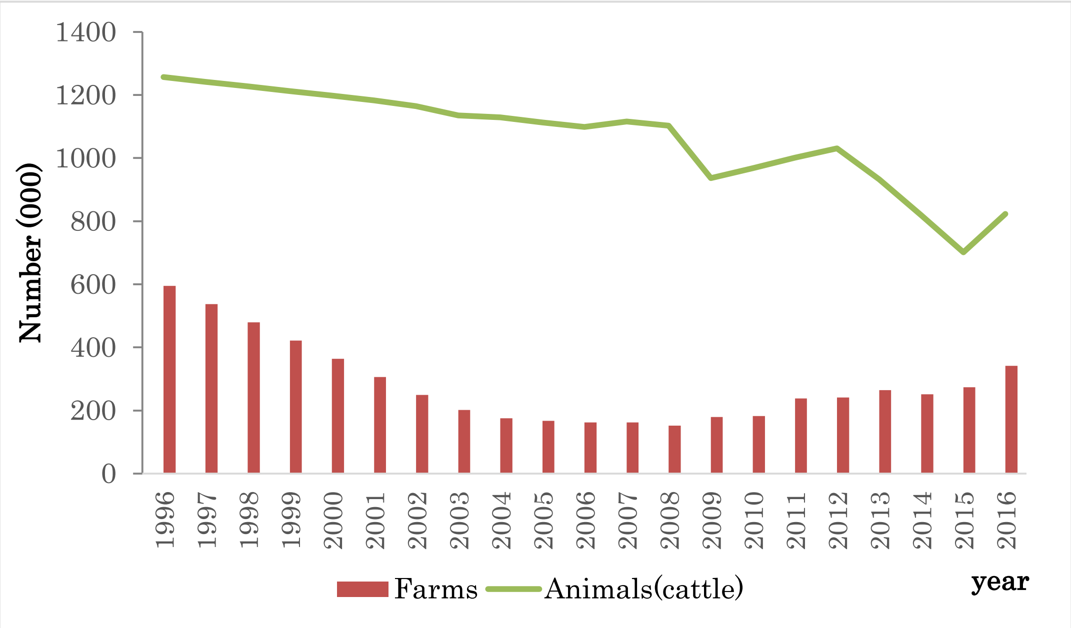

Figure 2.4 Trends in number of dairy farms and animals (1996-2016)
Source: LSB, DAPH (1996-2016)

Milk marketing is mainly through formal milk market and partially through informal milk market. Formal milk collection is carried out by private companies. At the field level, farmers supply milk to Farmer Managed Societies (FMS), Farmers'

Association (FA), Co-op (Cooperative societies) or middle man (MM) at primary points (n~3000) (Figure 2.5), where milk is tested for fat % and Solid Non-Fat (SNF)%.

Figure 2.5 Milk receiving by farmer managed society (FMS)
Source: Author, 2017

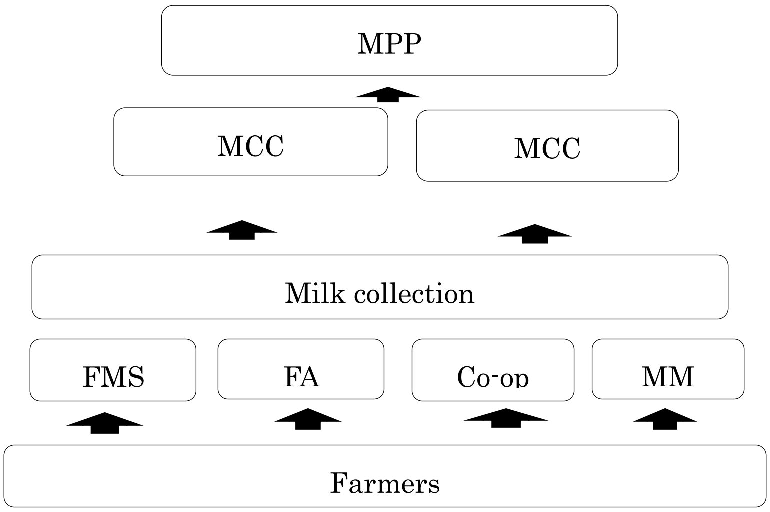

Fig. 2.6 Milk collecting network in Sri Lanka
Note: Milk chilling centre (MCC); MPP –Milk processing plant; FMS-Farmer managed society; FA-Farmers` association; Co-op-Corporative society; MM-Middle man

Milk is transported to milk chilling centre (MCC) which is located at regional level (n~250) (Figure 2.6). In the MCC bulk milk is tested for bacterial contamination (bacterial count < 300,000) with alcohol test[1] (Personnel communication, 2017). Then milk is supplied to Milk Processing Plant (MPP). Farmers are paid on fat % and SNF % basically. Milk is rejected if the quality does not match with standards.

In some areas where the formal market is not well developed, milk is marketed through informal market such as hotels, neighboring houses, etc. Also, the major part of milk in the informal market is converted in to value added products such as curd, yoghurt, milk toffees which enhances farmers' profit.

Milk production and collection shows continuous increase over past 10 years (Figure 2.7) regardless of the decrease in animal and farm numbers as discussed earlier (Figure 2.5). The trend indicates the productivity improvement in the dairy sector in Sri Lanka.

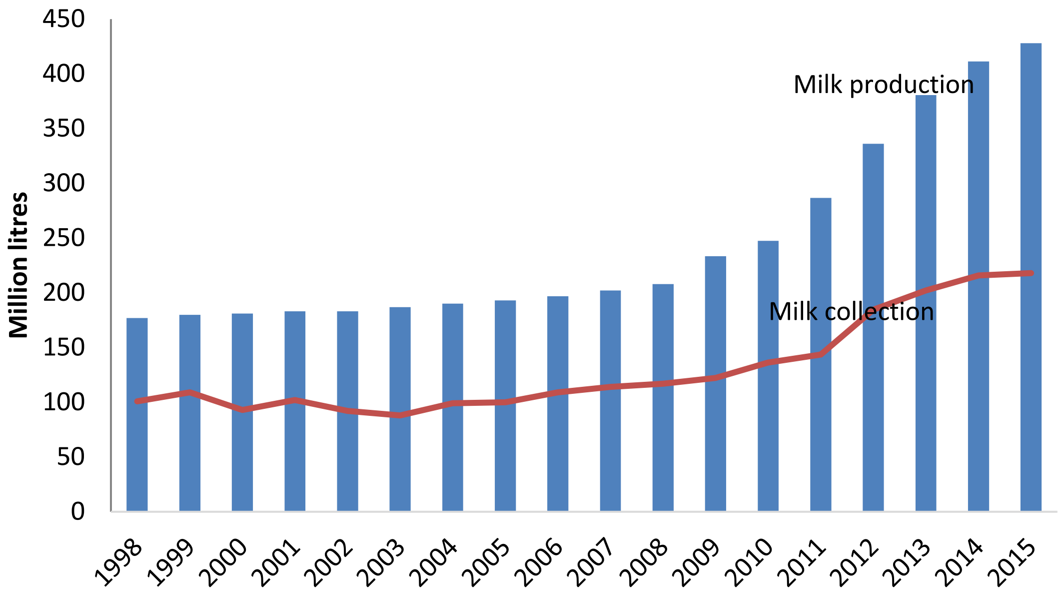

Figure 2.7 Milk production and collection (1998-2015)

Source: LSB, 1998-2015

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[1]Alcohol test is a simple test that is based on instability of the milk proteins when the acid and/or rennet levels are increased and acted with the alcohol. Also, milk colostrum and salt concentrates (due to mastitis) results in a positive test (FAO, n.d b).

Productivity improvement programs were taken place through genetic upgrade with artificial insemination, sexed semen usage and introduction of new breeding stocks. Moreover, milk collecting network has improved extensively in rural areas for past two decades in post war period; thus, farmers may have better marketing opportunities for production increase.

2.2.2 Institutional policy support for livestock development

Livestock sector is supported by the state sector, public enterprises and private sector. They extend their support in livestock development, marketing, human resource development and service delivery (MLRCD, 2011).

(1) State sector

State/government sector is the main service provider to the livestock sector in the country. The veterinary service is provided free of charge to farmers. The department of Animal Production and Health (DAPH) comes under the preview of ministry of rural economic affairs at present. The responsibilities of state sector organizations are described below.

1. Ministry of rural economic affairs - responsible for policy formulation, allocation of funds and resources, international affairs for external resources, inter-ministerial and inter agency coordination.

2. Department of Animal Production and Health (DAPH) - responsible for providing technical leadership to the livestock industry and its stakeholders. There are two set-ups in the DAPH to execute services.

(a) Central DAPH- DAPH is headed by a Director General (DG) and three Additional Director Generals (ADGs), devolving their functions to 6 technical directors as shown in Figure 2.8. Department is responsible for policy planning and monitoring, animal quarantine, animal disease control, implement animal breeding policy, human resource planning and development, implement acts and regulation related to livestock sector and extension services.

(b) Provincial DAPH- responsible for implementing, supervising and monitoring animal husbandry programs, extension activities, provision of animal health services, knowledge dissemination, farmer trainings.

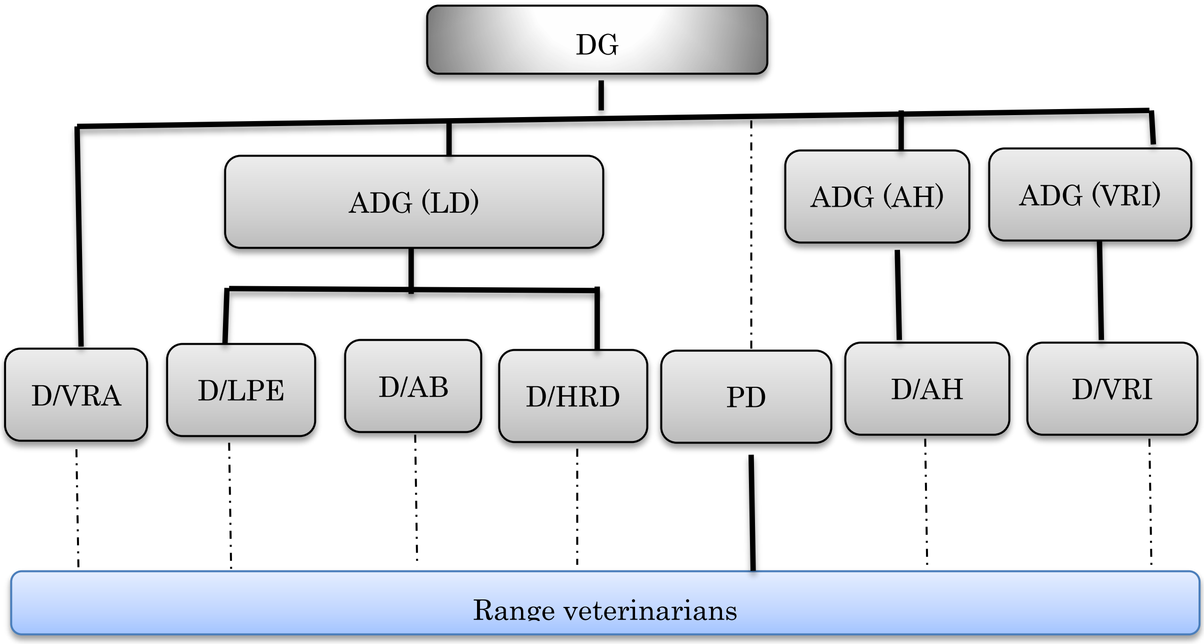

Figure 2.8 Organizational structure of the DAPH

Note: DG-Director General; ADG (LD) - Additional Director General (Livestock Development); ADG (AH)-Additional Director General (Animal Health); ADG (VRI)-Additional Director General (Veterinary Research Institute); LPE-Director Planning and Economics: AB-Director Animal Breeding/HRD-Director Human Resource Development; D/VRA-Director Veterinary Regulatory Affairs; D/AH-Director; D/ VRI-Director Veterinary Research Institute; PD-Provincial Director

——— Devolved authority and administration; -.-.-.-.-. Technical direction

Source: AR, 2015

3. Veterinary Research Institute (VRI)-Carry out research activities pertaining to the livestock sector. Act as a reference laboratory to the district veterinary investigating units. VRI produces several large animal vaccines for foot and mouth disease, brucellosis, hemorrhagic septicemia (pasterellosis) and black quarter and some poultry vaccines for Newcastle disease and fowl pox.

4. Local authorities –responsible for all the slaughter houses and public health issues.

5. Ministry of Health- responsible for public health aspects of food items

(2) Public enterprises

1. National Livestock Development Board –responsible to maintain breeder farms, breeding and supplying improved breeding materials to farmers.

2. MILCO- responsible for procurement and processing of milk and, milk marketing.

3. Mahaweli Livestock Enterprise of Mahaweli Authority -responsible for promoting and popularizing livestock among Mahaweli areas.

4. *Samurdhi* Authority –responsible for promoting livestock related small projects to alleviate poverty in rural areas in Sri Lanka.

(3) Private sector companies

1. Dairy Sector - Nestle Lanka Ltd, Cargills, Newdale, etc.- Responsible milk processing and marketing.

2. Poultry sector - Prima, Bairaha, Pussella, Crisbro, New Anthony's, etc. - Responsible for poultry processing and poultry meat marketing.

3. Animal feed sector- New Bernard's, Prima, Gold coin- Responsible for manufacture and distributes animal feed.

4. Veterinary drugs- -Drug companies - Distribute veterinary drugs to farmers.

2.2.3 Cattle farming practices in Sri Lanka

Cattle farming are generally distributed throughout all the agro-climatic zones of the country. In the central hills in the wet zone and Jaffna peninsula in the dry zone, cattle are kept mainly for milking purpose. In the dry and wet zones cattle and buffaloes form integral part of paddy production. There are three main cattle farming practices depending in the agro-climatic areas (Figure 2.9; Table 2.1). The majority of farms are managed under semi-intensive system (Figure 2.9) while extensively managed farms are only 13% of the total number of farms in the country.

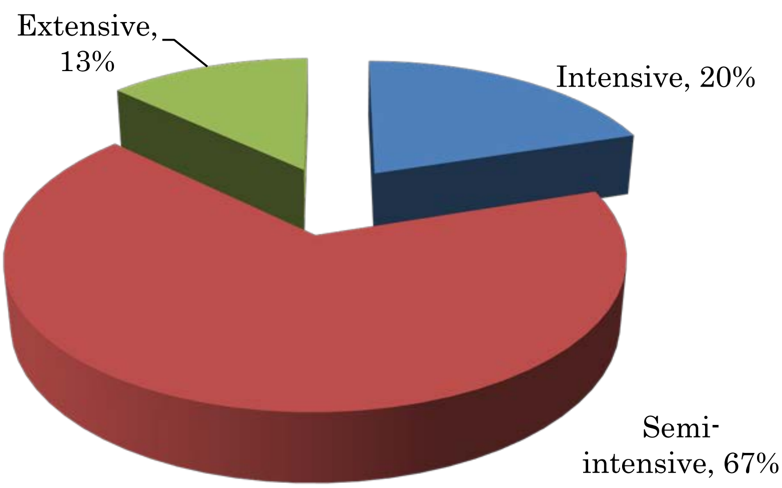

Figure 2.9 Composition of different farm management practices
Source: DAPH, 2009

Table 2.1 Characteristics of different cattle and buffalo management systems

Character	Intensive	Semi-intensive	Extensive
Preferred area	Wet zone	Dry zone	Intermediate
Main purpose	Milk	Milk	Duel (Milk and Meat)
Housing	Day and night- shed	Day – free grazing; night- shed	Day- free grazing; night-paddock
Feeding	Cut and fed; concentrate	Free grazing, Cut and fed, by products and concentrate	Free grazing
Main breeds	Temperate crosses	Temperate and Indian crosses	Local Indian crosses
Farm size(average)	4.9	9.2	43.3
Milk production, day/ animal (L)*	8.3	5.6	1.2
Milk production, day/ farm(L)*	14.2	12.4	13.9
Milk production cost (SLR/L) *	28.80	22.56	10.83
Input/output	High inputs	Low inputs, profitable	Minimal inputs, profitable

Note: * Average figures in 2009

SLR/L- Sri Lanka Rupee; L - Liter

Source: Adapted from references, Abeygunawardana et al., 1997; Ibrahim et al., 1999; DAPH, 2009

Figure.2.10 Intensive management practices
Source: Author, 2013

As shown in the previous table, intensive cattle mangemnt system is commonly seen in wet zone areas (Table 2.1). Cattle are kept in a shed (Figure 2.10), day and night, feeding with cut grass in the intensive sytsem.

Semi intensive system (Figure 2.11) is the predominant system which is prevalent in intermediate zones. This system is common as a mixed system with coconut plantation in coconut triangle in the country.

In the extensive system cattle are reared in an open area, enabling them for free grazing (Figure 2.12). There are two systems practices in extensive system such as free grazing in which animals can be moved free for grazing or restricted grazing by surrounding animals by a barb wire/ fence or tethered in to trees (Abeygunawardana et al., 1997).

Figure 2.11 Semi intensive management practices
Source: Author, 2016

Figure 2.12 Extensive (traditional) management practices
Source; Author, 2016

Cattle are reared for dual purpose (milk and meat) (Vithanage et al., 2013) in this extensive system. Animals are usually fed on uncultivated paddy fields, common park lands, villus, and tank beds in this system. They are sent away to marginal lands especially in the cropping period with the start of monsoon rain, thus sharing common water holes and jangle vegetation with wild animals (Gamage, 2013). Breeding activities mainly occurs by natural mating (Fernando, 1969) in the dry zone. Small land holding size, low availability of pastures for animals, large herd sizes, and weather pattern influence the free movement of the animals in this area (Fernando, 1969; Gamage, 2013).

Crop cultivation is a rain-fed system in traditional villages. During the rainy season, farmers engage in crop cultivation; consequently, animals are sent away to marginal lands to protect the crop (Gamage, 2013). In marginal lands, animals share common pasture and water sources; thus, likely come into contact with other herds, which increases the probability of diseases' spread among animals, between villages, districts, and provinces.

2.3 Animal health in Sri Lanka

2.3.1 Common animal diseases in Sri Lanka

Animal disease seems to be one of the main drawbacks for the development of the livestock sector in Sri Lanka. The country is endemic for Food and Mouth Disease (FMD), Black Quarter (BQ), Hemorrhagic Septicemia (HS) and Brucellosis for past few decades with huge economic impacts on livestock sector.

a) Foot and Mouth Disease (FMD)

Foot and mouth disease is a viral disease with very high morbidity but low mortality. It causes milk loss and loss of body condition in most of the cases and deaths in calves when infected. The disease can be recognized by foot and mouth lesions and salivation. It is annually reported with 300 cases and 8 deaths approximately (Table 2.2). The disease is endemic in the dry zone of Sri Lanka. The overall prevalence rate (ratio of infected animals to total susceptible population) is was 0.3 % despite the regular vaccination in the country. It has developed an epidemic in year 2014 with 68,296 cases and 1995 deaths in 20 districts (out of a total of 25) (AR, 2014). It was estimated a huge loss (SLR 19.6 million, US$ 0.14 million) to the smallholder farmers as well as the government only in Kandasala and Teldeniya veterinary ranges in 2010 outbreak (Kothalawala et al., 2011).

Table 2.2 Occurrence of endemic bovine diseases (2009-2015)

Year	FMD	BQ	HS
2009	140(2)	434(148)	-
2010	681(35)	79(62)	-
2011	395(0)	50(41)	-
2012	99(2)	30(30)	-
2013	354(2)	25(25)	-
2014	68,296(1995)	228(228)	-
2015	1,606(12)	49(38)	-

Note: Number of deaths is indicated in parenthesis
Source: AR, 2009-2015

b) Black Quarter (BQ)

Black quarter is a bacterial disease caused by clostridium species, with very high mortality. The main sign is sudden death of animal. It has been reported annually in the dry zone of Sri Lanka with an average of 49 cases and 38 deaths (Table 2.2). The disease was reported with 100% mortality in 2013 (25 cases) and 2015 (228 cases) (AR, 2013 and 2014).

c) Hemorrhagic Septicemia (HS)

Hemorrhagic septicemia is also a bacteria disease caused by *Pasturella multocida*. It is disease with high mortality and morbidity. HS has been endemic in Sri Lanka for decades, and later it was successfully controlled by vaccination. It has been declared the 'provisional freedom' from 2004 to 2014 (AR, 2014). But, it has been re-emerged in some areas in 2016 in the dry zone (AR, 2016).

d) Other diseases

Bovine babesiosis and Mastitis also causes significant losses to the dairy sectors in Sri Lanka. Bovine babaesiosis is reported mainly in the wet zone with an average of 3,000 cases with 150 deaths per year (AR, 2015). Farmers spend a lot on tick control drugs (acraisides) to control babesiosis.

There are over 10,000 mastitis cases with significant milk loss in the improved breed animals in the wet zone and intermediate zones mainly (AR, 2015).

e) Zoonotic diseases

Brucellosis, Leptospirosis and tuberculosis are main zoonotic diseases reported in the country.

Leptospirosis is caused by spirochetes belonging to different pathogenic species of genus *Leptospira*.

Bovine tuberculosis is confirmed in government and private dairy farms in Sri Lanka (AR, 2015). Herd screening was carried out to detect positives in large scale government farms (n=20) and private herds (n=152) in 2015. Out of a total of 469 animas screened, one (1) positive was confirmed with 30 inconclusive animals (AR, 2015). It has been recorded around 9,000 cases per human cases of tuberculosis in the country (AR, 2014).

2.3.2 Brucellosis prevalence and its control

Bovine brucellosis is endemic since 1956 (Kumaraswamy, 1971). It was first confirmed in Polonnaruwa government farm with a prevalence of 22.5% (n = 870) according to Kumaraswamy (1971). Since then, the disease has been endemic in many state-owned farms from which animals are issued for breeding purposes. Biotype 3 *B. abortus* was the causative agent of initially isolated (Kumaraswamy, 1971), and remains so to date (Priyantha, 2011). Table 2.3 depicts that brucellosis incidence was 40% (n=5,000) and 35 % (n=300) among animals in Thamankaduwa and Nikaweratiya government farms in 1958. Priyantha (2011) reported that 61.11 % of the herds (n=19) with abortion history was positive for brucellosis (Table 2.3). Perusal reading of Table 2.3 justify that research carried out about brucellosis in the country is limited to disease incidence in some populations.

However, Silva et al (2000) studied the overall prevalence through an island-wide sero-surveillance covering 22 administrative districts and recorded as 4.7% (n = 3,076) in cattle and 4.2% (n = 840) in buffaloes (Table 2.3). S-19 vaccine was developed by the Veterinary Research Institute (VRI) to give protection to animals (Kumaraswamy, 1971).

Table 2.3 Summary of studies carried out on brucellosis in Sri Lanka (1956-2010) **contd.**

Year	Area/farm	Species (sample size)	Disease prevalence	Data source
1958	Polonnaruwa state farm	Zebu cattle (840),	22.5%	Kumaraswamy (1971)
	Thamakaduwa farm	Zebu cattle (5000)	40%	
1968	Polonnaruwa state farm	Buffalo (3000)	12%	Kumaraswamy (1971)
	Nikaweratiya state farm	Zebu cattle (300)	35%	
1968	Polonnaruwa state farm	Zebu cattle	30-40%	Peris (1981)
1970	Welisara farm	pigs	3%	Kumaraswamy (1971)
	Kottukachcha state farm	goats	4%	
1970	All island	Local cattle (4000)	6%	Kumaraswamy (1971)
	Kandy and Colombo slaughter houses	Cattle (670)	6%	
1981	Polonnaruwa state farm	Zebu cattle	2.9%	Peris (1981)
	Thamakaduwa farm	Zebu cattle	6.9%	
	Nikaweratiya state farm	Zebu cattle	1.2%	
1981	Batticoloa Private farms	Cattle and buffalo	7.3%	Peris (1981)

1981	Polonnaruwa	Cattle and buffalo	6.4%	Peris (1981)
	Kurunegala	Cattle and buffalo	5.5%	
	Colombo	Cattle and buffalo	2.2%	
1981	Coconut triangle	Cattle and buffalo	15-20%	Wickramasuriya and Kumaraswamy (1982)
	Colombo, Gampaha	Cattle and buffalo	0.9%	
1990	Polonnaruwa	Cattle	7.7%	Wickramasuriya et al. (1983)
	Batticoloa		12%	
	Ampara		14%	
2000	All island	Cattle (3076)	4.7%	Silva et al. (2000)
		Buffalo (840)	4.2%	
2010	All island	Buffalo (4027) (aborted animals)	18.4%	Priyantha et al. (2010)
2010	Anuradhapura,Puttalm, Monaragala,Mannar,Kurunegala	Cattle and buffalo (19 herds) (abortion reported)	(61.11%) *	Priyantha et al. (2011)

Note: * Prevalence presented in parenthesis is herd prevalence while others are animal prevalence

Brucellosis surveillance in Sri Lanka is based on abortion reporting by farm owners. Farms those are with a history of abortions (according to the farmer) are serologically tested for *Brucella* antibodies using RBT, and positives are confirmed by the CFT. Although surveillance is carried with milk sample testing (MRT) in endemic areas (EB, 2015), the practice is not routine. The annual brucellosis reported and confirmed cases varied from 14 (2011) to 148 (2014) averaging 75 (Table 2.4), which is significantly low (0.02%) compared to noted prevalence rate (4.7%) by Silva et al (2000), indicates the possible underreporting of abortions by farmers, thus prone to spread the disease.

Table 2.4 Brucellosis reported cases and number of animals vaccinated

Item	2010	2011	2012	2013	2014	2015
Number of reported (confirmed) cases	59	14	15	68	148	132
Number of animals vaccinated	1117	2070	6129	5932	4525	5262

Source: EB, 2010-2015

In positive farms, all female animals together with exposed animals are vaccinated using the locally produced strain 19 live vaccine (S-19), with the exception of calves below six months of age and pregnant animals. Thereafter, annual vaccination of unvaccinated female animals between six months to two years of age in the same farm is continued for four years. Cattle in the neighborhood farms are not vaccinated unless they have abortions. Despite the above strategic vaccination, annual vaccination throughout the country approximates to only 5,000 (Table 2.4) which covers only 0.5% of the susceptible population, indicate the negligible coverage.

Although the separation and elimination of positive reactors have previously reduced the incidence of brucellosis in government farms (Peris, 1981), they are not currently practiced due to the limitations in compensations and religious constraints for slaughtering. Animal slaughter is a social issue in Sri Lanka due to religious taboos backed by Hindus and Buddhists which summed up to 90% total population in the country. It was assumed that brucellosis has spread from infected areas to free areas due to cattle transportation (Kumaswamy.1971). Further, Silva et al (2000) discussed the possibility of selling infected animals to another farmer, when the farmers came to know about the *Brucella* positivity due to religious forbids for cattle slaughter.

Thus brucellosis seems to be endemic in the country for longer due to very low level of vaccination, subjected to abortion reporting and, non-culling of infective, which is mainly depend on farmers knowledge and socio-cultural behavior.

2.3.3 FAO stepwise approach for brucellosis control

Considering the severity of brucellosis impact of global health (human and livestock), Food and Agriculture Organization (FAO) has set a step wise pathway in four steps (Table 2.5) to follow by all the member countries, in the light of eradication (FAO, 2013). In the very first step, baseline surveys and epidemiological understanding is pre-requisite to start the pathway (Table 2.5); that is still a gray area in Sri Lankan animal health control system.

Table 2.5 FAO step wise pathway for brucellosis control

Category	Step 1	Step 2	Step 3	Step 4
Situation	Unknown situation of the disease. No structured control activity.	Known situation of the disease with a control program underway.	Brucellosis at low levels within susceptible populations.	No evidence in livestock. No human cases.
Outcome	Disease situation understood properly	Falling brucellosis prevalence rates.	Reduced impacts of brucellosis in livestock and humans.	Self-declared free status with or without vaccination.
Activities	Baseline survey. Epidemiological investigations Develop appropriate control strategy, and action plan for stakeholders	Implemented the agreed control plan. Monitor the plan for quality and progress. Collaborate animal health and public health.	Risk analysis to revise the strategy. Appropriate control plan to enhance surveillance and monitoring.	Provide data to support brucellosis free status to OIE. Investigate and clear all suspected cases. Monitor and maintain free status

Source: FAO, 2013

Prominently, no attempts have taken to uncover the social risk factors associated with brucellosis epidemiology. Farmers' knowledge, attitudes and risky farming practices and behavior which could extremely affect in disease propagation, was not studied. Further, there is no understanding of human brucellosis that could be associated with animal brucellosis in certain communities. Accordingly, country is still at step one.

Therefore, proper understanding of high risk populations, potential social risk factors, farmers' knowledge and attitudes and behavior about farm bio security of the disease would be immensely help to lay down a realistic action plan on the ground.

2.3.4 Veterinary service delivery system

Animal disease control is the main responsibility of the Department of Animal Production and Health (DAPH). It executes its services through 315 veterinary ranges as the lowest functional unit in all over the country (AR, 2015). Each unit is governed by a qualified veterinarian with a supporting staff. They are responsible for disease diagnosis, prevention and control (vaccination), farmer awareness and implementation of development programs/projects/ activities at grass root level. The disease surveillance, testing and confirmation are carried out by veterinary investigation officers located at the district level. Passive disease surveillance through veterinary officers is taken place in all over the country (AR, 2015). The annual expenditure on animal health control activities is around 31% of the total DAPH budget (MLRCD, 2011) (Figure 2.13).

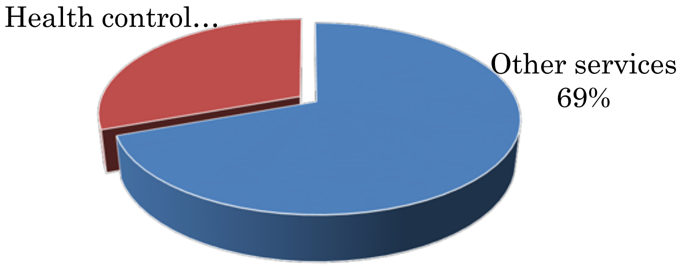

Figure 2.13 Expenditure for animal health control activities (2011-2016)
Source: MLRCD,2011

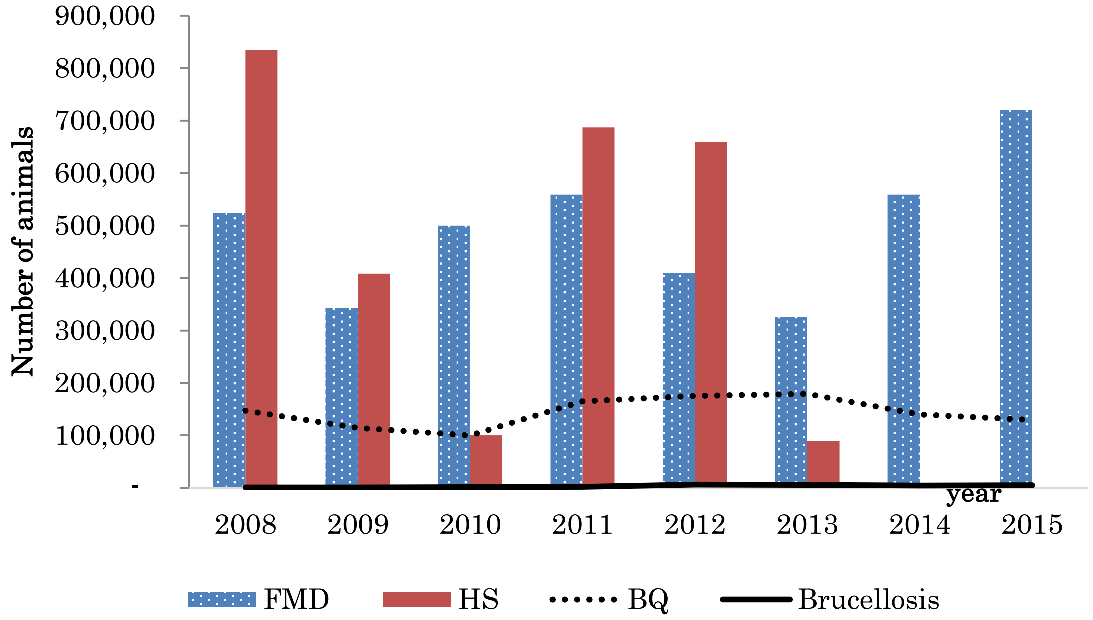

Figure 2.14 Number of animals vaccinated for different diseases (2008-2015)
Source: AR, 2008-2015

Annual average vaccination coverage for FMD, HS and BQ are given priority with 492,000, 465,000 and 145,000 respectively (Figure 2.14), in contrary to brucellosis (5000).

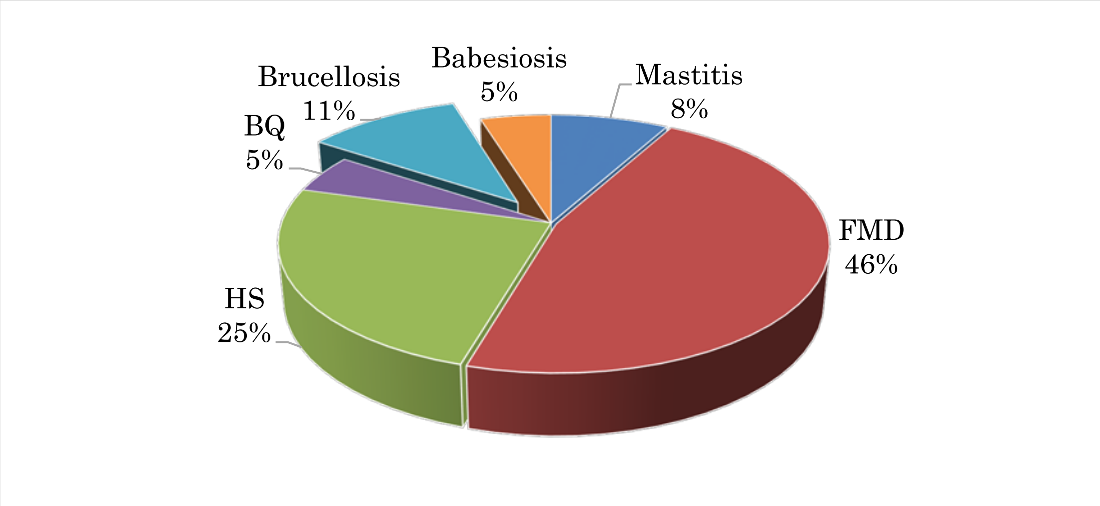

Figure 2.15 Fund allocations for control of different animal diseases (2011-2016)
Source: MLRCD (2011)

The government has given priority for foot and mouth disease and hemorrhagic septicemia control by allocating 71 % of the total expenditure (Figure 2.15). Unlike above two, brucellosis is an `asymptomatic disease with non-specific signs such as abortions and low milk production; therefore, information deficiency could exist among farmers. However, the financial allocation for brucellosis (five-year period) for testing and vaccination was around SLR 40 million (US$ 0.27 mn) which is 11 % of the total health control expenditure (Figure 2.15) (MLRCD, 2011), despite annual losses of SLR 141 million (US$ 1.63 mn) (Gajanayake et al., 2000).

2.3.5 Veterinary regulatory activities

Veterinary Regulatory activities in Sri Lanka is implemented by statutory provisions of Animal Act (No.29, 1958), Animal Disease Act (No.59, 1992) and Animal Feed Act (No.15, 1986) and regulations (e.g farm registration and animal identification) (AR, 2015). Even though the regulatory setup is established to control animal movements between areas, illegal animal transportation occurs due to socio – economics.

2.3.6 Training and extension

Training and extension is one of the main responsibilities of the DAPH. The function is carried out by human resource development division at national level (DAPH) and by government veterinary officers at provincial level. Training of veterinarians and middle level technical officers is carried out mainly by the national DAPH while farmer training is mainly by provincial DAPH. The department disseminates knowledge through trainings, mass media (TV programs, Radio, News release, media conferences), exhibitions and printed material (booklets, leaflets) (AR, 2015). Information communication center and livestock knowledge center located at Kandy are accessible to farmers and general public who can receive booklets, leaflets and other printed materials through them. Printed materials are sold at very nominal cost, (SLR.4-25) for farmers. Further, the department operates a telephone hot-line to cater farmers' matters promptly. Table 2.6 shows the details of information dissemination in year 2015.

Table 2.6 Information dissemination to farmers by the DAPH (2015)

Dissemination method	Topic
Exhibition	Food production, dairy and milk processing
Training	Small scale milk processing
Follow-up training	Milk processing and liquid milk consumption
Printed materials	Bio gas, pasture development, poultry management, Pig management, hay production, integrated farming, artificial insemination, clean milk production, calf rearing, dairy animal feeding, compost making
Printed materials	Poultry diseases, Bird flue

Source: AR, 2015; DAPH, n.d (daph.gov.lk) (books for sale)

Perusal reading of the table uncover that training/exhibition/printed materials have significantly ignored the discipline of animal disease aspect. It is clear that farmer training programs are manly limited to farm management and milk processing techniques, but not on disease management. Further, financial allocation for training on animal disease management according to the DAPH annual report in 2015 is almost nil (AR, 2015).

2.4 Conclusion

Animal diseases are one of the main constraints for livestock development in Sri Lanka. Brucellosis could be one of the major challenges. Brucellosis control seems to be 'neglected', given the priority to control diseases with prominent clinical signs such as FMD and HS. Existing control strategy appears to be not efficient in detecting the *Brucella* positives and removing them; thus needs revision.

Understanding of the disease epidemiology, social risk factors, farmers' knowledge, and bio security measures taken by farmers seems to be very poor. Farmers' behavior may have high influence on disease spread in the dry zone, but there is no evidence to address them.

Information dissemination about animal diseases and their management by the state sector seems to be extremely neglected; thus, probable to exist sever knowledge gap.

Therefore, a study covering the disease epidemiology and potential social risk factors and, knowledge gaps and farmers' biosecurity behavior is timely and due, to formulate a sound control plan.

CHAPTER 3

Brucellosis epidemiology and farmers' socio-economic factors

3.1 Background

Brucellosis is a long-standing issue that challenges livestock production and possibly the public health in Sri Lanka (Chapter 2). Socio economic background with multi-ethnic (Sinhala, Tamil, and Muslims) and multi-religious (Buddhists, Hindus, and Islam) communities together with varying cattle farming practices (Chapter 2) might be significant reasons for endemic nature of the disease in the dry zone of Sri Lanka.

Main livelihood of the dry zone is crop farming mixed with livestock providing mutual benefits (Chapter 2). Most of the herds are under traditional practice with extensive management (Abegunawardena et al., 1997) in which animals are move and graze freely; thus, liable to contact with other herd animals those are probably diseased. Brucellosis incidence is high in large herds (Matope, et al.,2010; Abubucker et al.,2011), and in herds with high direct contact (Arbernethy et al., 2011) as noted by other researchers. Also, it was noted that *Brucella* occurrence is high in intensive management system where the bacteria can survive longer (ILRI, 2012; Ducrotoy, 2015), while another assumption is bacteria can destroy easily by strong sunlight in extensive systems (Wickramasooriya et al., 1983). It seems that management practice favor disease prevalence. Millar and Photakoun, (2008) discussed the relationship of cattle farming practices and ethnicities. Dean et al (2013) observed that certain farmer communities who have high contacts with animals are prone to livestock diseases.

Dry zone of Sri Lanka is dominated by Tamil (Hindu) and Muslim communities (Chapter 2). Cattle have religious value for Hindus (mainly Tamil), and dairy farming is a part of their culture. On the other hand, Muslims do keep cattle and goat in their premises frequently. Cattle slaughtering is a sensitive issue in Sri Lanka, and strongly opposed by Buddhists (mainly Sinhala) and Hindus (mainly Tamil). Kristenson and Jacobsen (2011) noticed that some farmers are not always motivated by profits, but with animal welfare and other social recognition. On the other hand, cattle slaughtering is a religious ritual in Hajj festival in Muslims (Azees, 2012) who predominate in the cattle trade and beef industry in the country. It seems that varying farming practices are associated with certain communities (based on ethnicity and culture) that may count in high brucellosis prevalence. In contrast, Heffernan et al (2008) noted that livestock diseases are largely perceived as an individual farmer problem rather to group concern.

Moreover, dry zone was the theater for a civil war lasting three decades; thus, severely damaged and underdeveloped. Poverty is approximated at 30% in some pockets, despite the national average being 6.7% (DCS, 2012). In Sri Lanka, person is defined as poor, if the per capita income is less than SLR 3,624 per month ($1.50 per day in 2005 purchasing power parity term) (DCS, 2012). 'Poverty' is broadly defined as 'deprivation in wellbeing', could be characterized by severe deprivation of basic human needs including food, safe drinking water, sanitation facilities, health, shelter, education and information (WB, 2017). Poor farmers' animals are vulnerable to diseases due to high cost of disease control and/ or absence of control (Seimens, 2012). Therefore, farmers' low education, poor sanitation facilities, lack of resources may influence on *Brucella* propagation in this area.

It can be assumed that farmers' socio-economic and farming factors influence the long establishment of brucellosis in the dry zone of Sri Lanka. Despite some available literature on brucellosis epidemiology and animal level risk factors (Silva et al., 2000), there is no evidence on farmers' socio-economic factors influencing disease epidemiology. Rich and Perry (2011) have discussed the importance of integration of disease epidemiology and farmers' economic behavior in animal diseases control, to reduce poverty. However, literature on farmers' socio-economic factors affecting disease epidemiology is scarce in most of the developing countries including Sri Lanka.

The objective of this chapter was to study about brucellosis epidemiology and its association with farmers' socio-economic factors to provide inputs for an efficient control strategy. There were two specific objectives of the chapter,

1. to explore brucellosis epidemiology among cattle in the dry zone, and
2. to study the farming and framer factors in relation brucellosis epidemiology.

3.2 Materials and methods

3.2.1 Study design and sampling

A cross-sectional survey on sero-epidemiology and socio-economics was designed to fulfill the objective.

Adult female animals were the target population of this study. Sero-prevalence in female animals was reported to be higher compared with that in male animals. Disease prevalence in bovides of over three years of age was reported to be two times higher compared with that in bovides of less than three years of age (Silva et al., 2000).

Therefore, in the present study, we selected only adult females having calves, that were either milking or were dry, to yield a maximum number of positive animals, that would allow us to investigate the farmers' socio-economic factors and their association with *Brucella* prevalence in the area.

The sampling procedure was performed in two stages. First, the number of farms sampled was calculated using equation 1 (Thrusfield, 2005)

$$n = 1.96^2 \frac{p_{\exp}(1-P_{exp})}{d^2} \tag{3.1}$$

Where p_{exp} is the expected prevalence in herds, d is the desired absolute precision and n is the required sample size. It was considered that the expected herd prevalence of 5% at 95% confidence level and 5% precision, based on the farm level prevalence of 7%, 12%, and 14% in Polonnaruwa, Batticaloa, and Ampara districts (dry zone areas), respectively, according to a previous study (Wickramasuriya et al., 1983).

The calculated sample size of farms corresponded to 138. The list of farm registrations available at the government veterinary office was used as the sampling frame. A herd was defined as the total number of cattle belonging to the same owner and registered as a farm with a specific identification number at the government veterinary office. The total number of farms calculated (n=138) was proportionately allocated to the three veterinary ranges depending on the number of farms in a respective range (Table 3.1). Simple random sampling was used to select farms in each range. We selected a sample of 155 farms for the present study (Table 3.1).

Table 3.1 Sampling distribution among three veterinary ranges in the study area

Item	Kalmunai	Navathanveli	Mahaoya	Total
No.of farms	1,318	1,415	2,410	5143
Sample farm number	40	42	73	155
Sample size (animals)	174	386	593	1153
Land area (km ^{2})	20	187	667	

Source: DAPH (2008); DCS (2012)

Subsequently, to detect the exposure to *Brucella* organisms, the number of cows in a herd was estimated using equation 2 (Thrusfield, 2005).

$$n= \frac{(1-(1-\beta)^{\frac{1}{d}})}{\lceil(N-d/2)+1/2} \qquad (3.2)$$

Where β is the confidence level with the probability of observing at least one diseased cow in the herd, N is the number of animals in the farm, d is the number of diseased cows, and n is the sample size in the farm. Since the recent records were not available on within-herd *Brucella* prevalence, we assumed that the number of diseased cows in a herd could be slightly higher than the recorded value of 6.7% in a government farm (Wickramasuriya et al., 1983).

Therefore, the percentage of diseased cows in a herd was assumed to be 10%, and a sample size table was prepared to decide the number of cows to be sampled according to the total number of milking and dry cows of the farm. Sampled cows in a herd were selected randomly by an identification tag number, wherever it was applicable. In the farms in which animals had not been tagged, a list of milking animals by their nicknames (e.g., Raththi, Kalu) was prepared, and the sample was selected randomly. A total of 1,153 animals from 155 farms were selected for the study (Table 3.1).

3.2.2. Blood sampling and questionnaire survey

For blood sampling, approximately 5 ml/animal was collected from the jugular vein of milking cows using plain vacutainer tubes, which were then labeled and transported to the laboratory on ice within 12 hr of collection. The tubes were set on a table overnight at room temperature for clotting. Clotted tubes were centrifuged (at 3,000 × g over 20 min) to separate the serum, which was subsequently stored at -20°C until further serological testing.

Two survey questionnaires were prepared: one for the herd level data and, one other for the farmers' socio-economic analysis. Both questionnaires were prepared with closed-ended and open-ended questions, initially in English, and then translated into Sinhala and Tamil languages to facilitate the interviewing of the farmers who speak these two languages in this area.

The questionnaire for the farm (herd) level (first questionnaire) was pre-tested in four farms, while the farmer-level questionnaire (second questionnaire) was pre-tested with seven farmers in all three ranges. A field survey for blood sampling and interviews using the pre-tested structured questionnaires were carried out during the period from May to September in 2016. I visited each farm twice to complete the blood sampling and questionnaire survey. Attributes related to herd management (Silva et al., 2000; Makita et al., 2011b; Musallam et al., 2015a) were collected via farmers' memory recall during the interviews, using the first questionnaire at the first visit when the blood samples were also withdrawn. Attributes on socio-economics viz. ethnicity, receiving living subsidy from the government, annual family income, education, farming experience, parent farmer, etc. were collected using the second questionnaire by revisiting the same farms at another time point due to the practical inconvenience of long interviews with a farmer for both surveys at once.

Further, farmers were asked whether any of the family members had clinical signs related to human brucellosis such as undulant fever, joint pain, back pain, and unfitness for the past two years, through the same questionnaire.

3.2.3. Serological testing

RBT and c-ELISA were selected for screening and confirmation of the presence of *Brucella* antibodies, respectively. The RBT was carried out using the Pourquier Rose Bengale Antigen, which is a suspension of *B. abortus* (Weybridge 99 strain) inactivated by heat and phenol and colored with Rose Bengal stain in an acidified buffer, provided by IDEXX. Briefly, 30 μL of RBT antigen and 30 μL of the test serum were placed alongside on a plate, and then mixed thoroughly. The plate was shaken for 4 min and the degree of agglutination reactions was recorded. The sample was classified as positive when an agglutination reaction was visually observed.

Samples identified as positive for RBT or doubtful (agglutination reaction not clear) were further tested with c-ELISA using the SVANOVIR *Brucella*-Ab-c-ELISA kits according to the manufacturer's instructions (Svanova Biotech, Uppsala, Sweden) at the Veterinary Research Institute (VRI), Sri Lanka. The optical density (OD) of all samples was tested in duplicates to obtain the average OD, and doubtful duplicates were re-assayed. The ODs were converted into ELISA units (EUs) using Microsoft Excel. The cutoff OD of 0.3 was used to identify positive reactors (Matope et al., 2010).

3.2.4 Data analysis

(1) Estimation of true prevalence

An animal was considered seropositive if it was positive for both RBT and c- ELISA, and a herd was considered positive if it included at least one seropositive animal. Data were digitized in Microsoft Excel and used for prevalence calculations and risk factor analysis.

The true prevalence (TP) for the entire study area and veterinary ranges were estimated using the publicly available software Epitools developed and maintained by Ausvet (Sergeant, 2016) based on the method described by Rogan and Gladen (1978). True prevalence was estimated using the common sensitivity (c-Se) of RBT and c-ELISA tests (Matope et al., 2010) and the specificity of c-ELISA (0.996) test. The c-Se was estimated as 0.981, which was the product of RBT (0.986) (Gorsich et al., 2015) and c-ELISA (0.995) (Svanova Biotech, Uppsala, Sweden). The farm (herd) level prevalence for the overall study area and veterinary ranges were calculated based on the above-mentioned sero-prevalence status and confidence intervals (CIs) were calculated using one-sample Chi-square test in R version 2.6.2.

(2) Statistical analysis

Uni-variable analysis was used to study the association of potential herd-and farmer-level risk factors (socio-economics) with *Brucella* infection of the farm. Among our variables, two continuous variables, family income and herd size, were skewed and did not follow the normal distribution; therefore, they were arranged in groups and considered as categorical. All the categorical variables were tested with the outcome variable of *Brucella* sero-positivity, which was used as the proxy for *Brucella* exposure in Fisher's exact test using contingency tables with Epitools. In epidemiological studies significant variables of uni-variable analysis ($p < 0.25$) is used for regression analysis to study the potential risk factors (Matope et al., 2010).

It was used the binomial *logit* model (Equation 3.3) with outcome variable of *Brucella* positive (1) or (0) with herd level and farmer factors with $p < 0.25$ in uni-variable analysis as dependent variables (Table 3.2) in STATA 12(StataCorp,2011).

$$Ln \frac{p}{(1-p)} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \; ....\beta_k X_k + \varepsilon \qquad (3.3)$$

Where p/(1- *p)* is the odds of outcome variable BRUCELLA that is whether the farm was positive for brucellosis (dummy variable); Yes (1) or No (0),while β_0 is intercept , $\beta_{0-}\beta_k$ are coefficients associated with independent variables, $x_1 - x_k$ are independent variables and ε is the error term. The independent variables were viz. Ethnicity Muslim, poor, education, grazing practice, brought in, breeding practice and abortion history. Variables used in uni-variable analysis and *logit* model were shown in Table 3.2

Before applying *logit* model correlation analysis was applied to study the collinearity between independent variables. The variable was considered collinear if the absolute value of correlation coefficient $|\rho|$ was >0.8–0.9. It was assessed the interaction between variables by generating interaction terms (product of two variables) for the significant main effect for the model, adding them into the model and examining changes in the coefficients and p-values of the main effect. Evidence of confounding was verified by dropping one of the variables and assessing the changes of coefficients. The best-fitted model was selected by coefficients of main effects, prob > chi2 value, and goodness of fit of the model. Odds ratios (OR) for potential risk factors used in the *logit* model were estimated using *Epitools* software.

Association of human brucellosis related clinical signs among farm families with cattle brucellosis prevalence was studied using Fisher exact test (F test). If any one of a family shows at least two (out of four signs questioned) human brucellosis related clinical signs (undulant fever, joint pain, back pain, unfitness) within last two years, it was considered as a brucellosis infection possibility at family level. Association of human infection possibility with cattle brucellosis sero-positivity at farm level were used in Fisher test using *Epitools*.

3.3. Results

3.3.1 Socio-economics and farming practices in the study area

Sinhala was the predominate ethnicity (48%) among sample farmers (Table 3.2). All the Sinhalese farmers (100%) were from Mahaoya area. The majority of Muslims were in Kalmunai (68%) and Tamils were in Navithanveli (83%) (Table 3.3). Poor farmers who receive living subsidy known as *Samurdhi* [2] was around 29% in the study area with the highest in Navithanveli (47%) (Table 3.3).

Farmers those who have not had formal education was quite low (5%) in the area. Most (73%) of the farmers were doing farming either livestock or crop cultivation as their main livelihood activity. Majority (64%) of the farmer's parent/s were farmer/s (Table 3.2). Only 25 % of the farmers have undergone training related to livestock. Trainings were conducted by various institutions such as government veterinary office, milk collecting companies, other public institutions, and non-governmental organizations.

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[2] *Samurdhi* is a government living subsidy program that is for poverty alleviation in Sri Lanka. Poor most people selected by the government using criteria; they are supported with monthly payment.

Table 3.2 Descriptive statistics of the sample

Variable	Description	Mean±STD
Farmer (social) factors		
ETHNICITY_M	Muslims (1); Tamils and Sinhalese (0)	0.22 ± 0.41
ETHNICITY_T	Tamils (1); Muslims and Sinhalese (0)	0.31 ± 0.46
ETHNICITY_S	Tamils (1); Muslims and Sinhalese (0)	0.48 ± 0.50
POOR	Receive *Samurdhi,* Yes (1); No (0)	0.29 ± 0.46
EDUCATION	No formal education (1); Had (0)	0.06 ± 0.24
TRAINING	Trained on animal husbandry (1); No (0)	0.25 ± 0.43
FARM_EXPERINCE	Farming experience > 10yeras (1); < 10 years (0)	0.34 ± 0.47
KNOW_BRUCELLA	Farmer know term "brucellosis" or "contagious abortions" (1); No (0)	0.18 ± 0.38
PARENT_FARMER	Farmer's parent/s are dairy farmer/s, Yes (1); No (0)	0.64 ± 0.48
MAIN_JOB	Farming (crop/livestock) (1); Off farm (0)	0.73 ± 0.44
Farming factors		
GRAZE_PRACTICE	Free moving for grazing (1); Restricted grazing (0)	0.43 ± 0.49
BROUGHT_IN	Animals brought in to the farm in last 2 years (1); No (0)	0.31 ± 0.46
ABORT_HISTORY	Had abortions for last 3 years (1); No (0)	0.24 ± 0.42
BREEDING	Artificial insemination (AI) (1); Natural breeding (0)	0.28 ± 0.45
HERD_SIZE	Number of animals in the herd	22.7 ± 27.15

Note: STD= Standard deviation

Source: Field survey, 2016

The training titles were mainly dairy management, pasture cultivation, milk processing and milking, while the discipline of animal disease management was totally neglected. Very few (18%) farmers have heard about the disease called 'contagious abortions' or 'brucellosis'. There were 43 % (Table 3.2) farms with free moving herds for grazing, with the highest (75%) in Kalmunai (Table 3.3). Around 31% of the farms had brought-in animals from outside within last two years, mainly from the neighborhood or adjacent ranges. Furthermore, it was noted that farmers mainly considered milk yield, body condition, parity, udder size, legs, testicles, eyes, skin, etc. when buying animals in to their farms. Most of them were not aware of the importance of a health certificate in animal purchase.

Table 3.3 Characteristics of Kalmunai, Navithanveli and Mahaoya VS ranges

Variable	Kalmunai (n=40)	Navithanveli (n=42)	Mahaoya (n=73)
ETHNICITY_M	0.68***	0.17	0
ETHNICITY_T	0.32	0.83	0
ETHNICITY_S	0	0	1.00***
POOR	0.41	0.45	0.12
EDUCATION	0.15*	0.05	0
PARENT_FARMER	0.66	0.78	0.81
TRAINING	0.35	0.26	0.17
FARM_EXPERIENCE	0.33	0.38	0.28
KNOW_BRUCELLA	0.21	0.15	0.17
MAIN_JOB	0.84	0.73	0.71
GRAZE_PRACTICE	0.75	0.57	0.18
BROUGHT_IN	0.35	0.24	0.22
ABORT_HISTORY	0.18	0.09	0.12
BREEDING	0.76**	0.16	0.11
HERD _SIZE	9.52	23.31	28.13

Note: Significantly different ****p<0.01, **p<0.05, *p<0.01* (*Kruskal Wallies* test which is a non-parametric test for more than two sample comparison)

Source: Field survey, 2016

Only 24 % have had abortions in last 3-year period. Artificial Insemination (AI) was practiced by only 28 % of the farmers with a highest number in Kalmunai (76%) (Table 3.3). Average herd size in the area is 22.7. Average herd size in Mahaoya was the largest (28.1) while the smallest (9.5) in Kalmuani (Table 3.3). Herd sizes of Mahaoya vary from smallest size of 2 to the largest of 200.The large farm sizes were found in Kalmuani (25) and Navithanveli (72) areas.

3.3.2 Livelihood in the study area

Family income of the area was SLR 337,000 (US$ 2248) per year, which varied from SLR 463,000 (US$ 3086) in Mahaoya to SLR 180,000 (US$ 1220) in Navithanveli (Figure 3.1).

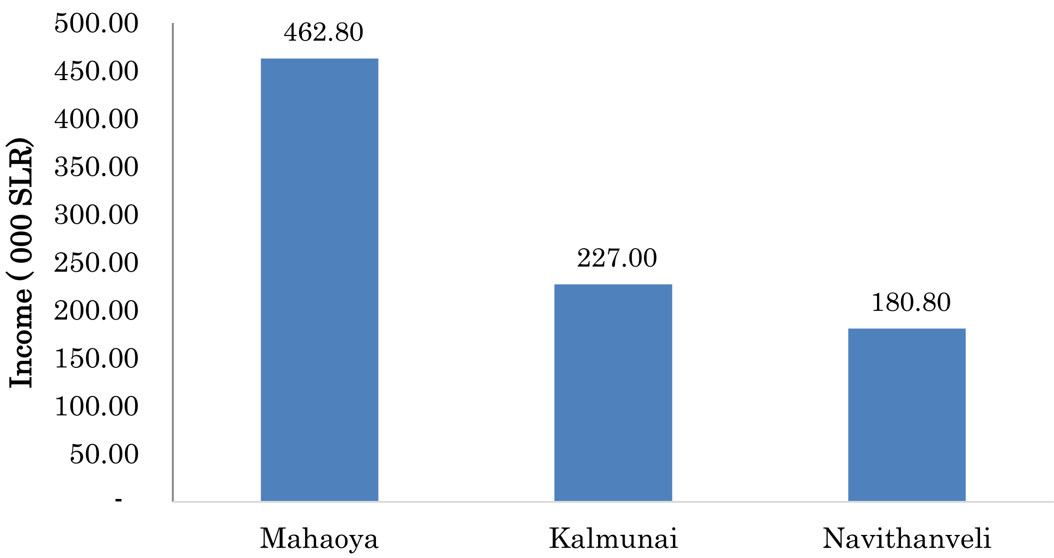


Figure 3.1 Average annual family incomes in Mahaoya,Kalmunai and Navithanveli areas

Source: Field survey, 2016

Figure 3.2 depicts livestock income share to the total income among three veterinary ranges. The livestock income share was highest in Navithanveli followed by Kalmuani (Figure 3.2), in contrast to Mahaoya where the agriculture share is the highest (40%).

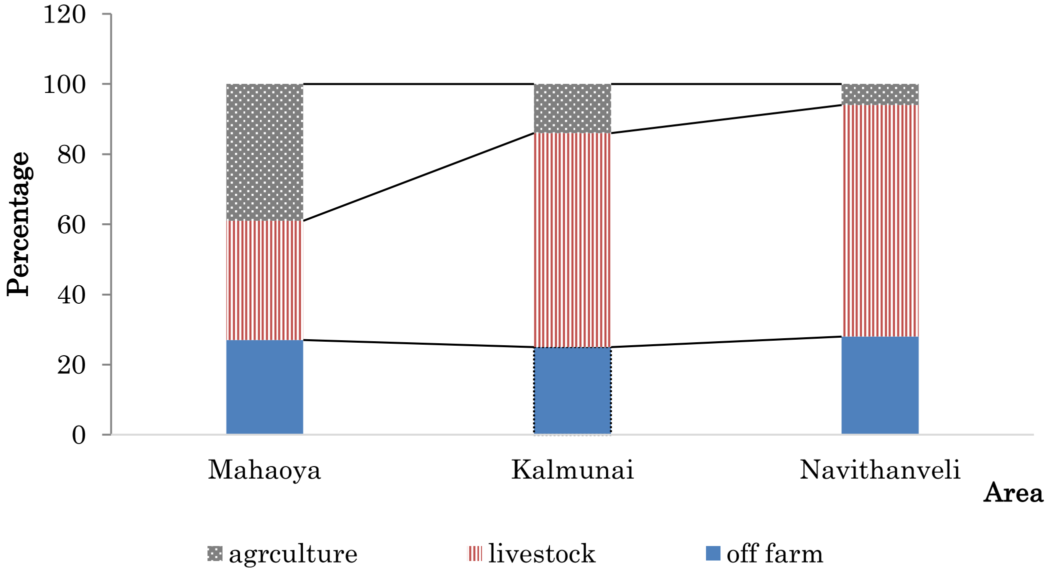


Figure 3.2 Income contributions from different livelihood activities

Source: Field survey, 2016

Figure 3.3 Average annual income and livestock income share in three ethnicities

Source: Field survey, 2016

Out of three ethnic groups, Sinhala farmers had the highest total income with SLR 462,300 (US$ 3,080) and the lowest was among Tamils with SLR 332,120 (US$ 2,213) (Figure 3.3). Livestock income share (to the total) was highest among Muslims (68.9%) followed by Tamils (67.6%) (Figure 3.3).

3.3.3 Brucellosis sero-prevalence in the study area

Sero prevalence of brucellosis in Kalmunai, Navithanveli and Mahaoya veterinary ranges are shown in the Table 3.4. In average, *Brucella* sero-prevalence in the study population was 2.7% (35/1,153; 95% CI: 1.7–3.7%).

Table 3.4 *Brucella* sero-prevalence (animal and farm) in three VS ranges

Area	Herd sero-prevalence		Animal sero-prevalence	
	(fraction)	(95 % CI)	(fraction)	(95% CI)
Kalmunai	8/40	20.0 (9.6, 36.1) ***	19/174	10.9 (6.0, 15.5)***
Navithanveli	5/42	11.9 (4.5, 26.4)	10/386	2.2 (0.6, 3.9)
Mahaoya	2/73	2.7 (0.5, 10.4)	6/593	0.6 (-2.0, 1.5)
Overall	15/155	9.6 (5.7, 15.73)	35/1,153	2.7 (1.7, 3.7)

Note: Areas significantly differ at *** $p < 0.001$ (Kruskal Wallies test)

95% CI = 95 % confidence interval.

Source: Field survey, 2016

The overall herd (farm) level sero-prevalence was 9.6% (15/155; 95% CI: 5.7–15.7%), with significant variations among ranges (p < 0.001). The highest sero-prevalence among animals was estimated at 10.9% (95% CI: 6.0–15.5%) and in herds (farms) at 20.0 % (95% CI: 9.6–36.1%) in Kalmunai, where the median herd size was the smallest (n = 8). In

Navithanveli, herd (farm)-level prevalence was 11.9% (95% CI, 4.5–26.4%) and an animal-level prevalence was 2.2% (95% CI, 0.6–3.9%) with median herd size (n) 19. The lowest herd-level prevalence and animal-level prevalence were 2.7% and 0.6% respectively (Table 3.4) were reported in Mahaoya.

3.3.4 Factors associated with brucellosis epidemiology (Fisher test results)

(1) Farmers' socio-economic factors in association to brucellosis

According to the Fisher test results, farmer's ethnicity (ETHNICITY) was found to be significantly associated with *Brucella* sero-positivity ($p < 0.001$). Muslim farmers had the highest (27.8%) prevalence (Table 3.5).

Tamil and Sinhala famers had 8.9% and 2.8% sero- prevalence in their herds respectively. POOR farmers showed higher association ($p < 0.01$) of cattle brucellosis (20.5 %) compared to non-poor (5.4%) farmers.

Farmers without formal education (EDUCATION) showed comparatively high susceptibility ($p<0.19$) to brucellosis. Those who underwent training (TRAINING) showed no significant association with the disease prevalence. Farming experience (FARM_EXPERIENCE) and traditional knowledge from parents who were farmers (PARENT_ FARMER) were also not associated with *Brucella* sero-positivity in their farms. Even though some farmers (18%) (Table 3.3) have heard about brucellosis or contagious abortions (KNOW_BRUCELLA), it had no significant impact on brucellosis prevalence (Table 3.5).

Table 3.5 Results of risk factor analysis (Fisher test) with respective disease prevalence

Variable	Category	No positive (fraction)	Prevalence (%)	p value
Farmers social factors				
ETHNICITY	M;T;S[1]	9/33; 4/49; 2/73	27.3; 8.9;2.8	<0.001*
POOR	1; 0	9/44; 6/111	20.5; 5.4	0.003*
EDUCATION	1; 0	2/8; 13/147	25; 8.8	0.190*
TRAINING	1; 0	11/117; 4/41	10.4; 10.8	0.957
FARM_EXPERIENCE	1; 0	9/112; 6/43	8.3; 14.0	0.983
KNOW_BRUCELLA	1; 0	3/27; 12/128	12.5; 10.3	0.731
PARENT_FARMER	1; 0	11/110; 5/45	11.1; 9.8	0.548
MAIN_JOB	1; 0	10/113; 5/42	11.9; 8.9	0.382
Farming factors				
GRAZE_PRACTICE	1; 0	12/57; 3/98	19.3; 4.1	0.010*
BROUGHT_IN	1; 0	9/51; 6/104	17.6; 5.8	0.017*
BREEDING	1; 0	7/44; 8/111	15.9; 7.2	0.095*
ABORT_HISTORY	1; 0	7/37; 8/118	18.9; 6.8	0.036*
HERD SIZE	<10;10-50; >50	3/44; 11/102; 1/9	6.8; 10.8;11.1	0.751

Note: 1.M; T; S are Muslims, Tamils and Sinhala respectively;

2. Factor categorization (see Table 3.2)

Factors are significant at $^{*}p<0.25$ (Fisher exact test)

Number of observations=155

Source: Field survey, 2016

(2) Farming factors associated to brucellosis

Farming factors such as GRAZE_PRACTICE ($p < 0.01$), BREDING ($p < 0.10$), BROUGHT_IN ($p < 0.05$) and ABORT_HISTORY ($p < 0.05$) showed high association with brucellosis sero-positivity (Table 3.5) in the area. There was no association of HERD_SIZE and brucellosis.

In the epidemiological analysis, factors with $p<0.25$ in uni-variable association (e,g Fisher test) is considered for further analysis using regression models. Farmer factors of ETHNICITY_M, POOR and EDUCATION as well as faming factors of GRAZE PRACTICE, BREEDING, BROUGHT_IN, and ABORT_HISTORY were considered in the regression analysis in the *logit* model.

3.3.5 Factors affecting brucellosis prevalence

Our data fitted with probability > $\chi 2$ = 0.0001 in the *logit* model, predicting the *Brucella* sero-positivity by ethnicity, poor, grazing practice, and animal brought-in (Table 3.6).

Muslim farmers (ETHNICITY_M) showed high probability ($p < 0.05$) of having brucellosis, showing seven times higher odds compared with others. The category of poor farmers who are *Samurdhi* beneficiaries (POOR) had higher chances (OR = 3.75, 95% CI = 1.43–10.0%) of having *Brucella* sero-positive herds compared with others (. Farms with free grazing practice (GRAZE PRACTICE) in which animals are co-mingle with other herds were highly susceptible ($p<0.10$) with higher odds (OR = 5.62, 95% CI = 1.7–18.61%) for getting the disease than for farms with restricted grazing practice (such as with zero grazing, tethered, or animals reared in a restricted area). Animal brought-in from outside farms (BROUGHT_IN) was significantly associated with the disease ($p < 0.10$) with odds of 3 (Table 3.6).

3.6. Results of logistic analysis on factors affecting brucellosis prevalence

Dependent variable, farm *BRUCELLA* positivity: Yes (1); No (0)

Variable	Coefficient	SE	P value	OR (95% CI)
Farmers' factors				
ETHNICITY_M	1.81	0.73	0.014**	7.25 (2.35-22.28)
POOR	1.45	0.69	0.035**	3.75 (1.43-10.00)
EDUCATION	0.53	1.02	0.607	3.44 (0.63-17.78)
Farming factors				
GRAZE_PRACTICE	1.39	0.73	0.055*	5.62 (1.72-18.61)
BROUGHT_IN	1.23	0.66	0.063*	3.06 (1.15-8.13)
BREEDING	-0.18	0.74	0.806	2.44 (0.83-7.18)
ABORT_HISTORY	0.65	0.71	0.358	2.79 (0.81-7.18)
Constant	-5.07	0.86	0	

Note: OR (95% CI) = Odds ratio with 95 % confident interval; SE =Standard error;

Factors are significant at *** $p < 0.05$, and * $p < 0.10$,*

Number of observations =153; log likelihood=-33.1449; pseudo R^2=0.3260.

Source: Field survey, 2016

3.3.6 Cattle brucellosis association with human brucellosis signs

Table 3.6 depicts that farm family members (one or more) of *Brucella* positive farms showed significantly high possibility (p<0.0001) of having human brucellosis related clinical signs such as undulant fever, joint pains, head ache or back pain. The association was very high with 3.78 odds ratio (Table 3.6).

Table 3.7 Human brucellosis clinical signs association with farm cattle brucellosis

Factors	OR (95% CI)	p-value
Human signs[1]/Cattle brucellosis	3.78 (3.24-32.64)	0.041**

Note: 1. Human signs - At least two human brucellosis related clinical signs present

Association is significant at ** $p < 0.05$

Number of observation (n) =155

Source: Field survey, 2016

3.4. Discussion

This chapter explored the farmers' factors affecting on brucellosis epidemiology in the dry zone of Sri Lanka. The overall brucellosis prevalence among animals was 2.7% and, in herds (farms) was 9.6% in the studied area. Results agreed with the previous results that is 4.9% overall animal prevalence (Silva et al., 2000) and herd prevalence of 14% in Ampara district (Wickrmasuriya et al., 1983).

It was observed that surveyed animals were not vaccinated against brucellosis in the study area in spite of some animals with abortions. Abortions were found to be a significant risk factor for *Brucella* infection in Sri Lanka (Silva et al., 2000) and other countries (Makita et al., 2011b; Adugna et al., 2013); yet, it was not related to herd level brucellosis according to this study. Around 53% (8/15) of the sero-positive farms in the sample did not have abortions. The low level of abortions could be attributed to chronic brucellosis or to the fact that abortions are unnoticed by the farmer in the extensive free grazing system, which is discussed later. Additionally, farmers did not have reliable information on other clinical signs related to the disease. The finding highlights the ineffectiveness of the current *Brucella* surveillance method that is mainly performed through reported abortions in identifying positive herds for vaccination. In this context, it can be hypothesized that there can be a large number of positive herds un-vaccinated, likely to spread the disease. Therefore, surveillance could be switch in to bulk milk sample testing for screening that is recommended by OIE (2009).

Brucellosis prevalence varies significantly among three veterinary ranges, which could be related to farming practices and predominant ethnicities. Brucellosis was significantly associated with free grazing management practice. The highest number of free grazing herds (75%) was recorded in Kalmunai, followed by Navithanveli (47%), while the lowest was found in Mahaoya (18%). Grazing practice is connected to the rainy season and cropping pattern in the area. In Kalmunai, animals are kept in small herds (n = 9.5) in paddocks at the backyard of the farm at night and sent for grazing during the daytime to paddy fields or common lands in the dry season. At the beginning of the rainy season, farmers are fully engaged in cultivation, and thus animals are relocated outside the cropping area to minimize crop damage, and herded to common marginal areas (Gamage, 2013) where animals share common pasture lands and water sources, readily mingle, and breed naturally (Fernando, 1969). The calving season coincides with the rainy season (Abeygunawardana and Abeywansa, 1995), thus infected animals may have late abortions or calving expelling infected materials to the environment. The conditions of low temperature and high humidity in the rainy days may facilitate longer survival *Brucella* organism (4 months) in pasture, manure, or bedding, causing extensive contaminations (Matope et al., 2010; Zhang et al., 2014). The practice with high animal contacts may bring about high brucellosis prevalence in the area as noted by other researchers in other countries (Diaz-Aparicio, 2013; Boukary et al., 2013).

On the other hand, most of the animals in Mahaoya area are kept as large herds (47.8) in jungles in restricted areas (either tethered or freely moving), causing less intermingling with other herds. The geographical variations such as large land sizes might cause low animal density result in low prevalence as discussed by Matope et al (2010). Moreover, large land areas may provide a natural biosecurity fence for *Brucella* infection in Mahaoya.

There were highest number of Muslim farmers in Kalmunai (65%) followed by Navithanveli (32%). Muslims are highly connected with animal husbandry as a part of the livelihood by tradition in Sri Lanka. It was noticed that livelihood dependency on livestock (income share to the total) was highest in Kalmunai and also among Muslim and Tamil ethnicities. The finding says, there is a high possibility of animal contacts in these two ethnicities. Also, Muslims communities mainly consist of their close relatives in the neighborhood; thus, tend to contact with animals of each other's. Similarly, Muslims predominate in the beef industry and animal trade in relation to their rituals in Hajj festivals (Azees, 2012), which could be associated with a high animal transaction in Muslim areas, increasing animal contacts. Additionally, goat farming mixed with cattle is a traditional practice in Muslim and Hindu communities (Wijethunga et al., 2015). Around 21% of the total goat population is concentrated in the eastern province of Sri Lanka (LSB, 2015). Goats in government goat breeding farm were positive for brucellosis in early stages (Kumaraswamy, 1971); thus, disease may exist in the goat population which could be a source of infection in cattle in this area. Matope et al (2010) recorded that mix management of cattle with sheep and goat is a risk factor for cattle brucellosis. However, there were no previous surveillance records on goats in the country. Data on mixed farming was not collected to support this hypothesis in this study; thus, further researches are recommended on this aspect. Hence, high brucellosis prevalence in Muslim ethnicity could be because of high inter-animal contact as noted by Dean et al (2013).

Animal brought in to the farm from outside source were found to be a significant risk factor as noted by Makita et al (2011b). Generally, animals were brought in to farms could be as purchases, subsidy programs, and inter-farm exchange programs (e.g. *Anda Govi* system), free issues from religious temples, etc. It was revealed that poor farmers (e.g., *Samurdhi* beneficiaries) had higher rates of brucellosis in their herds. Some (28 %) of the poor farmers were without a formal education. Poor farmers' annual family income (SLR 201,000; $1340) was significantly ($p<0.05$) lower to that of non-poor farmers (SLR 387,000; US$ 2580). Income dependency on livestock was significantly high among poor (76.9%) ($p<0.01$) compared to non-poor (45.9%), indicating higher possibility animal contacts. Hence, low knowledge, high animal contacts and non-affordability for quality hygiene facilities in farms may have contributed in high *Brucella* prevalence among poor farmers. Herffernan (2004) explained that animals of poor farmers are highly vulnerable for diseases due to high cost. Also, brucellosis is termed as a disease of marginalized people namely 'neglected zoonosis' (WHO, 2015).

It was clear that none of the factors of farmer training, farming experience (in years), and informal knowledge acquired from farming parents were counted in decrease the disease prevalence in their farms. The results indicate the extent of knowledge gap existing on brucellosis risk among the farmer population. Mussallam et al (2015b) highlighted that knowledge gaps causes high frequency of brucellosis, due to high-risk practices. Also, Matope et al (2010) highlighted that farmers' knowledge is highly associated with sero-positivity of the farm. Farmers and/or their family members possibly infect with brucellosis due to poor knowledge. Therefore, farmers' knowledge, attitudes and practices on brucellosis should be well studied to set an efficient control strategy.

3.5. Conclusion

The study disclosed that brucellosis is highly prevalent in the dry zone of Sri Lanka. Certain communities (Muslims) are highly vulnerable for brucellosis compared with others. Farmers' social factors such as ethnicity and being poor, and farming practice such as free grazing shows high probability of brucellosis, thus need high attention. These factors could be used as social indicators to identify the vulnerable communities and high-risk areas, could subsequently be considered for intensive control interventions. *Brucella* surveillance strategy (on abortions) must be changed to get wider screening to enhance the effectiveness of control.

Farmers' knowledge on brucellosis seems to be extremely poor. Hence, a proper understanding of knowledge, attitudes and practices is essential prior to set an appropriate strategy.

The study uncovered that "farmer" is an important factor in veterinary epidemiology; therefore, it should be well considered in animal disease control policy planning. It was tried to address the limitation of considering farmers' socio-economic factors in animal disease control, through this chapter.

CHAPTER 4

Knowledge, Attitudes, and Practices（KAP） related to brucellosis

4.1 Background

Knowledge seems to be a barrier in animal husbandry (Vithanage et al., 2013), particularly in animal disease control in most of the rural areas. Wide spread of major infectious diseases that shared between wildlife, livestock and humans are mainly because of a huge knowledge gap (Wiethoelter et al., 2015). Since most (60%) of the infectious pathogens can cause diseases in human beings (Taylor et al., 2001), the threat becomes severe.

Risky farming behavior due to poor knowledge and attitudes of dairy farmers has been identified as one of the main reasons for the transmission of brucellosis in many developing countries (Hegazy et al., 2016; Musallam et al., 2015b; Lindahl et al., 2015). Farmers' behavior is strongly affected by their knowledge and attitudes (Dernberg et al., 2007). Small scale farmers have low knowledge and their participation in animal disease control programs is crucial (Grace et al., 2008). Farmers' awareness and concern about risk from unseen threats is little compared to obvious ones (Garforth et al., 2013).

Attitudes are defined as organization of beliefs, feelings and behavioral tendencies towards objects, events, individuals or groups (Hogg and Vaughan, 2005). The function of attitudes is to provide evaluative information, and it can be positive, negative or uncertain towards an action (Mankad, 2016). Most of the UK farmers believe that on-farm biosecurity (e.g cleaning shed, disinfecting, restrictions to visitors, etc.) is more cost-effective and more time efficient than treating animals when get sick (Brennan and Christley, 2013). Farmers' attitudes towards possibility of successful brucellosis control by disposing placentas and aborted fetuses were appropriately uncertain probably because of poor knowledge (Hegazy et al., 2016).

High-risk brucellosis related practices such as assisting in animal parturition, disposing aborted fetuses without protective gloves, or masks, and not boiling milk before preparation of dairy products were identified due to knowledge gaps (Musallam et al., 2015b). Lack of knowledge about disease transmission causes brucellosis prevalent in Egypt (Hegazy et al., 2016). Poor knowledge leads to risky farming practices that could be answered by animal health education (Lindahl et al., 2015). A study in Ghana revealed that formal training on milk handling was effective in improving milk quality (Addo et al., 2011). A brucellosis-related educational program was very effective in developing positive attitudes and good practices among students in Iran (Mahmoodabad et al., 2008). It is very advantageous of understanding and working with farmers' beliefs and attitudes for herd health professionals to develop appropriate communication system to make biosecurity recommendations (Brennan et al., 2013). Nevertheless, there are very little studies done related to farmers attitudes towards production diseases, thus huge evidence gap exists (Clark et al., 2016).

Despite long establishment for seven decades, there is no evidence on farmers' knowledge and attitudes about brucellosis in Sri Lanka. There are very few numbers of annual brucellosis confirm cases (n=75) in spite of 4.6 % prevalence (Silva et al., 2000), probably due to low abortion reporting by farmers, that could be because of lack of knowledge (Chapter two). Further, the government contribution in information dissemination and farmer trainings related to animal diseases is insufficient (Chapter two). Only 18 % of the farmers have heard about brucellosis or contagious abortions (KNOW_BRUCELLA) (Chapter 3). Even though some (18%) have heard about brucellosis (KNOW_BRUCELLA), they could not control brucellosis in their farms effectively ($p>0.25$) (Chapter 3). Farmer training (TRAINING), years in farming (FARM_EXPERIENCE) and informal knowledge acquired from parents (PARENT_FARMER) have no significant ($p>0.25$) effect on brucellosis control in their farms. On this account it was hypothesized that farmers' knowledge, attitudes and practices related to brucellosis is extremely poor in Sri Lanka, which could be a valid reason for high and long-standing disease prevalence.

Knowledge, Attitude and Practices (KAP) are method of surveying to reveal misconceptions or misunderstandings that may represent difficulties to rule out desired activities that likely to be implemented to change the behavior (USAID, 2011). Therefore, it was tried to explore the gaps in KAP on brucellosis and attempted to uncover the underlying factors affecting knowledge sharing on animal diseases, with the intention of providing valuable inputs for a brucellosis control policy in Sri Lanka. There were three specific objectives of this chapter,

1) to discuss the knowledge gaps in disease identification and transmission and KAP related to brucellosis,

2) to identify potential farmer characteristics related to knowledge sharing, and

3) to elucidate the efficiency of the existing animal health extension system.

The study will specifically focus on awareness gaps on brucellosis, which is a "hidden" or asymptomatic (no specific signs) disease of high public health and economic importance, in comparison to Foot and Mouth Disease (FMD), which is symptomatic.

4.2 Materials and methods

4.2.1 Study design, sampling and data collection

This study corresponds with previous chapter results, therefore same farmers were selected (Thrusfield, 2005). The total sample was 155 farmers (Chapter 3). They were directly interviewed in either Sinhala or Tamil for the survey. The survey was conducted in August and September 2016. A pre-survey was conducted with four farmers (two of each in Sinhala and Tamil language).

The survey questions were related to farmers' characteristics, disease knowledge, attitudes, and practices. The farmer characteristics related to social attributes such as ethnicity, main occupation, age, sex, etc. were used in this analysis. Farmers' mother language (e.g Sinhala or Tamil) was noted as one variable. Additionally, farmers' social relationships were examined. It was considered the number of faithful persons from which one could request a loan or help (other than one's own family members) as an indicator of high social relationships. Further, relationships with veterinary authorities, such as the number of animal husbandry training sessions attended, contact with government veterinary surgeons or staff members when animals are sick, and the mode of communication with veterinarians or office assistants in an emergency were also recorded. To collect information on farmers' knowledge of brucellosis, seven dichotomous (yes or no) questions on symptoms (clinical signs) and two on disease transmission (Table 4.1) were prepared. Also, some questions were asked related to FMD for comparison's sake (a total of five questions, see Table 4.1). Farmers' attitudes towards buying and selling of unhealthy animals were recorded using two questions (Table 4.3). Further, we collected information on hygienic practices in farming and milk consumption related to the spread of brucellosis (Table 4.3).

4.2.2 Statistical analysis

(1) KAP of brucellosis

Descriptive statistics were used to understand the KAP related to brucellosis, farmers' social characteristics, and the farmer-veterinary authority relationship. *Kruskal Wallies* test which is for non-parametric data was used to compare KAP among different veterinary ranges.

To analyze farmers' knowledge of animal diseases, previous studies mostly used dichotomous (yes or no) question (Addo et al., 2011). To measure the farmer's knowledge in broad aspect, it was developed a score using knowledge-related questions (KNOW_SCORE; range from 0–1) for each farmer (Equation 4.1).

$$KNOW\_SCORE_{k\,i} = \frac{CA_{k\,i}}{QE_{k\,i}} \quad (4.1)$$

$QE_{k\,i}$ is the number of questions against farmer *i*, which are symptoms, disease transmission, and overall for brucellosis and FMD (*k*). $CA_{k\,i}$ is the number of correct answers for individual farmer *i*. The $KNOW_SCORE$s for brucellosis and FMD were not found to be normally distributed; therefore, the difference in knowledge of the two diseases was tested using a non-parametric test (sign test). The knowledge index was computed using $KNOW\_SCORE_{bru\,i}$ and $KNOW\_SCORE_{fmd\,i}$ for individual respondents' scores on brucellosis and FMD to study common disease knowledge of the farmers (Equation 4.2), which will be further discussed in the next part. Microsoft Excel was used for the score computations and STATA 12 was used for statistical analysis.

$$KNOW\_INDEX_{k\,i} = \frac{KNOW\_SCORE_{bru\,i} + KNOW\_SCORE_{fmd\,i}}{2} \quad (4.2)$$

(2) Factors affecting knowledge sharing

One's knowledge-acquiring capacity relates to personal factors, social factors, and institutional factors (Yiu and Law, 2012). Accordingly, it was hypothesized that the animal health knowledge of a farmer is the end result of the farmer's socio-economic characteristics and social relationships, and the extension methods of veterinary authorities as depicted in Figure 4.1.

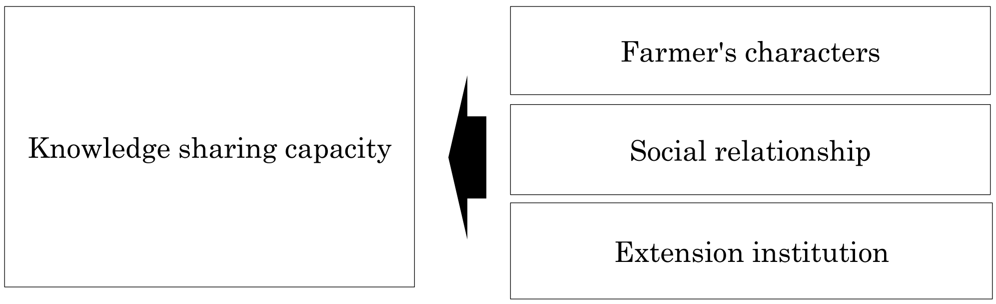


Figure 4.1. Diagram on factors affecting farmers' knowledge sharing capacity
Source: Adapted from Yiu and Law (2012)

The *tobit* model, which was described by Tobin (1958) initially, is used to study latent variables with a limited range. In previous studies, *tobit* model were used to analyze factors affecting technology adoption, in which the dependent variable was a latent variable as presented in Equation 4.3 (Adesina and Baidu-Forson, 1995; Chukwuji and Ogisi, 2006).

$$y_i *= x_i\beta + \mu_i \qquad (4.3)$$

where β is a vector of unknown coefficients, x is a vector of i^{th} independent variable, and μ is an error term that is assumed to be normally distributed with zero (0) mean and variance of σ_i^2. The dependent variable y_i* is a latent variable that is unobservable (KNOW_INDEX; 0-1).

In the model, independent variables were in three categories such as (1) farmer factors, (2) social relation factors, and (3) extension institutional factors (Figure 4.1). Correlation analysis was applied to study the collinearity between independent variables. Variable was considered to be collinear if the absolute value of correlation coefficient $|\rho|$ was >0.6.

4.3 Results

4.3.1 Knowledge, Attitudes, and Practices (KAP)

On average, 22.8% and 11.6% of farmers have heard the terms “contagious abortions” and “brucellosis,” respectively, whilst 95.5% knew the term “FMD.” On average, over 90% of farmers did not know about main symptom for brucellosis that is abortions (Table 4.1).

In contrast, the majority of farmers correctly answered the questions about FMD symptoms, such as mouth lesions (96.6%), low milk production (84.9%), and no blindness (69.7%). Around 93% of the farmers did not know that brucellosis causes huge milk loss (Table 4.1).

Results highlighted that many farmers did not know about infectious nature of brucellosis. Around 90% farmers did not know that brucellosis could be spread from one animal to another. Around 97 % of the farmers did not know the zoonotic risk of the disease. None of the farmers in Navithanveli (0) knew that brucellosis is zoonotic (Table 4.1).

Table 4.1 Farmers' knowledge on brucellosis and FMD in three VS ranges

Variable	Kalmunai (n=40)	Navithanveli (n=42)	Mahaoya (n=73)	p value	Total (n=155)
<u>Brucellosis</u>					
Symptom					
Heard about contagious abortions (Yes)	22.5	23.8	22.3		22.8
Heard about brucellosis (Yes)	10.0	16.7	9.6		11.6
Brucellosis causes abortions (Yes)	7.5	9.5	8.1		8.3
Brucellosis causes low milk production (Yes)	7.5	4.8	8.2		7.1
Brucellosis causes joint swelling (Yes)	0.0	2.8	4.8	*	3.0
Brucellosis causes mouth blisters (No)	2.5	6.7	8.2		6.3
Brucellosis causes blindness (No)	10.1	11.9	1.4	*	6.5
Transmission					
Brucellosis may spread from animal to animal (Yes)	10.0	11.9	9.6		10.3
Brucellosis may spread from animal to human (Yes)	2.5	0.0	4.2	*	2.6
<u>FMD</u>					
Symptom					
Heard about FMD (Yes)	97.5	95.2	94.5		95.5
FMD causes mouth lesions (Yes)	97.5	92.9	98.5		96.6
FMD reduces milk (Yes)	92.5	78.6	84.3		84.9
FMD causes blindness (No)	77.5	85.7	56.2		69.7
Transmission					
FMD spreads through air (Yes)	52.5	76.2	38.4	*	52.3

Note: Figures presented as percentages; * figure is significantly different *at* $p<0.10$ (*Kruskal-Wallis* test).

Source: Field survey, 2016.

The knowledge (*KNOW_SCORE*) of brucellosis transmission was extremely poor compared FMD. The majority (143/155) of the farmers' knowledge on transmission of brucellosis was zero (0) in contrary to FMD (Figure 4.2). More than half (83/155) of the farmers had knowledge in-between 50%-100% about FMD transmission (Figure 4.3).

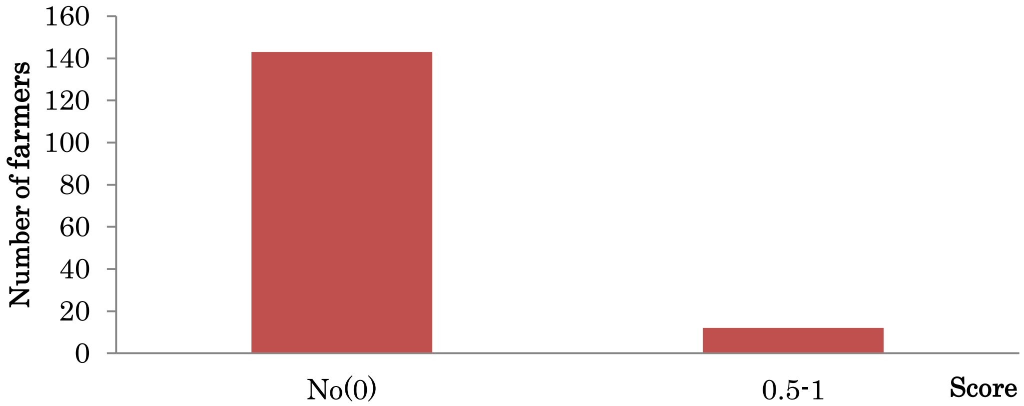


Figure 4.2 Knowledge score on brucellosis transmission

Source: Field survey (2016)

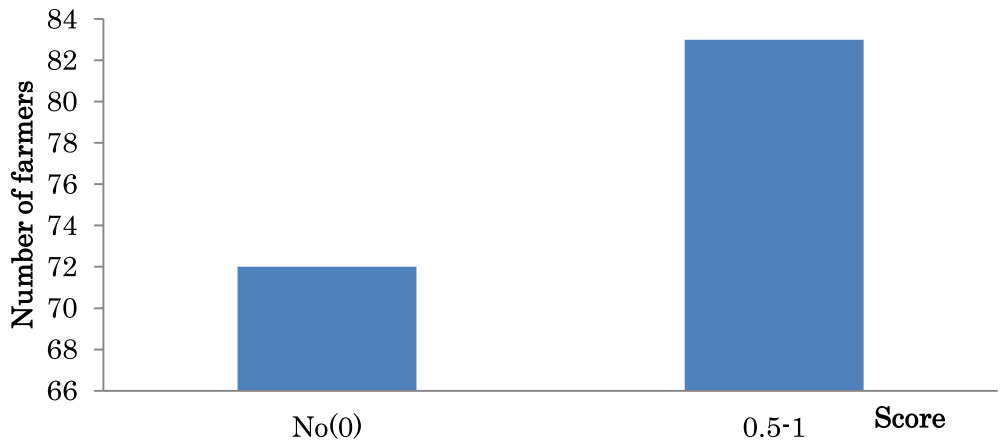


Figure 4.3 Knowledge score on FMD transmission

Source: Field survey (2016)

The knowledge of symptoms ($KNOW\_SCORE_{symptoms}$) of two diseases were more or less similar to transmission results (Figure 4.4 and 4.5).

Around 63 % (97/155) farmers knowledge was nil (score =0) about brucellosis symptoms (clinical signs) (Figure 4.4). There was only one farmer who knew all the brucellosis signs in the sample. Less than 1% (1/155) of the farmers had complete knowledge with score one (1) (Figure 4.4).

On the other hand, knowledge ($KNOW\_SCORE_{symptoms}$) about FMD symptoms was relatively good. Around 58% (90/155) of the farmers knew all the symptoms related to FMD (score = 1) (Figure 4.5). There were only six farmers (n=6) without any (score=0) knowledge related to FMD symptoms.

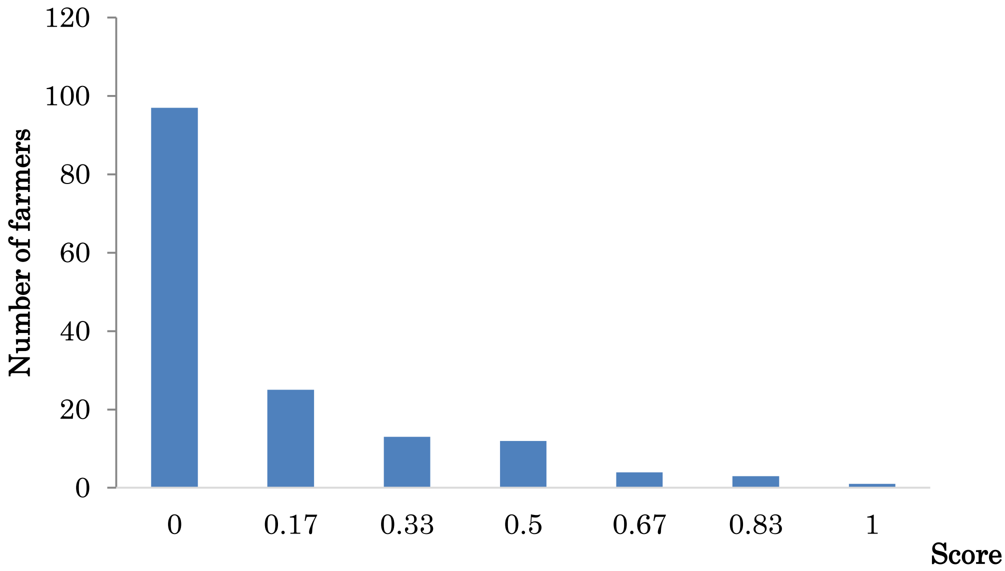


Figure 4.4 Knowledge score on brucellosis sympstoms

Source: Field survey (2016)

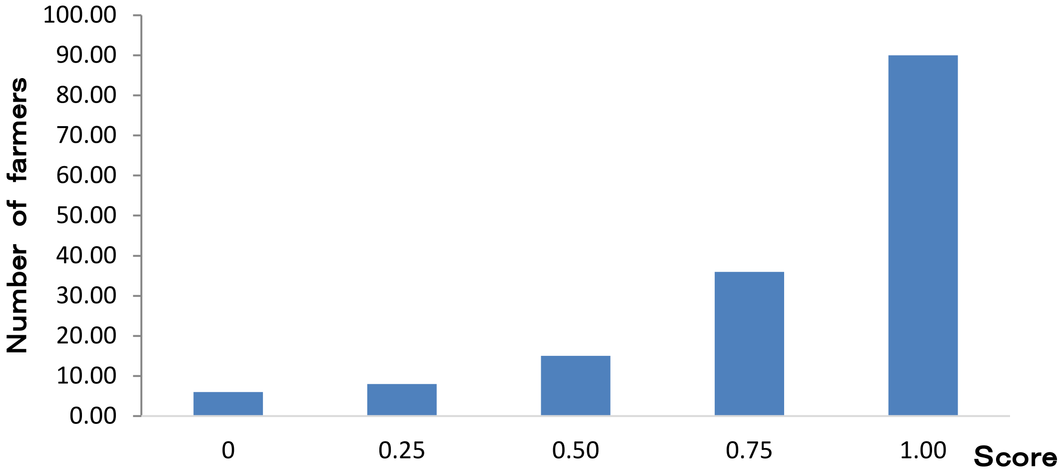


Figure 4.5 Knowledge score on FMD symptoms

Source: Field survey (2016)

The overall disease knowledge score ($KNOW_{SCORE_{overall}}$) of brucellosis and FMD are shown in Figure 4.6 and Figure 4.6 respectively. Around 60% (93/155) farmers did not give any correct answer (score = 0) to brucellosis related questions (Figure 4.6). None of the farmer had perfect brucellosis knowledge (score = 1) either (Figure 4.6). In opposite, there were no farmers with zero (0) knowledge score for FMD. Around 90 % (140/155) of the farmers had over 0.6 knowledge score about FMD and around 39% (61/155) of the farmers were well aware (score = 1) about FMD (Figure 4.7).

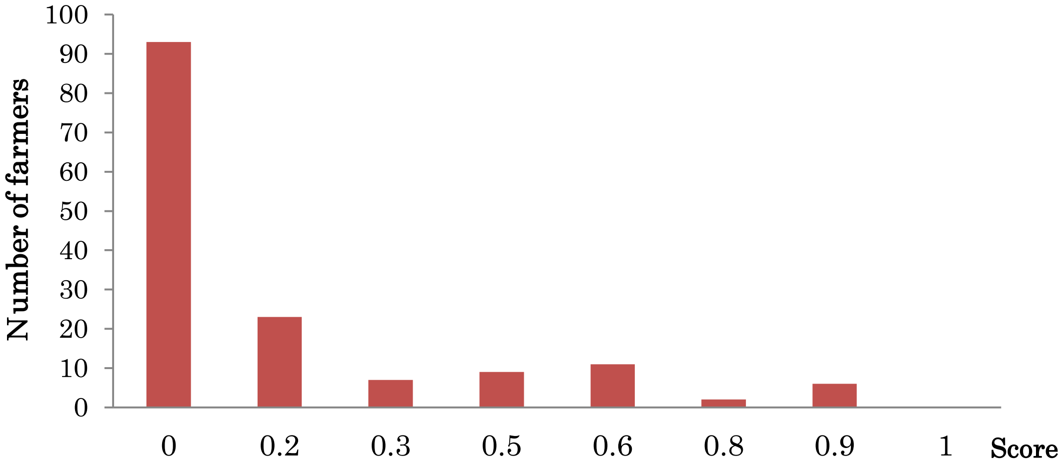


Figure 4.6 Farmers' overall knowledge on brucellosis

Source: Source: Field survey (2016)

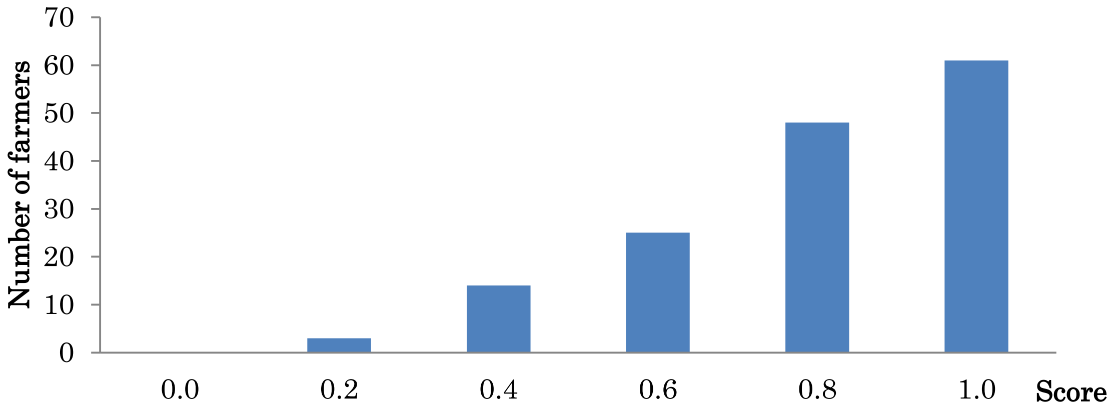


Figure 4.7 Farmers' overall knowledge on FMD

Source: Field survey (2016)

Table 4.2 shows the difference of the knowledge. The *KNOW_SCORE* of farmers of overall brucellosis was 0.12 and that of FMD was 0.80 (Table 4.2). Knowledge on symptoms ($KNOW\_SCORE_{symptoms}$) and transmission($KNOW\_SCARE_{transmission}$) of both brucellosis and FMD differed significantly (p<0.001) (Table 4.2).

On average, farmers' overall knowledge score on livestock diseases (KNOW_INDEX) was around 0.4 ranging from score of 0 to score of 0.5. None of the farmer had overall animal disease knowledge beyond 50% in this area.

Table 4.2 Median values of knowledge score for brucellosis and FMD

Category	Brucellosis	FMD	p value
$KNOW\_SCORE_{overall}$	0.12 (0.12)	0.80 (0.79)	0.000***:
$KNOW\_SCARE_{transmission}$	0.04 (0.04)	1.00 (0.66)	0.000***
$KNOW\_SCORE_{symptoms}$	0.13 (0.13)	1.00 (0.83)	0.000***

Note: Figures in the parentheses are mean values of the sample

*** indicate figures are different at p *<0.01* (*Sign test*)

Source: Field survey, 2016

Table 4.3 describes the farmers' attitudes on spreading *Brucella* by buying and selling diseased animals, and the hygienic practices of farm management. On average, around 17.2% of the farmers sold animals that had abortions to other farmers. They showed neutral attitude about selling of aborted animals to another farmer. Around 27.2% farmers in Navithanveli were selling aborted animals to another farmer. Selling of aborted animals to other farmers was 18.7% and 11.3 % in Kalmunai and Mahaoya respectively (Table 4.3). On average only 20.6% farmers paid attention to health certificates when purchasing female animals. Concern about health certificate when purchase male animals were extremely poor in all three ranges (Table 4.3).

Most of the farmers followed general hygienic practices such as using slippers when working and using detergents for personal cleaning after work. The practice among three veterinary ranges has no significant difference. Biosecurity practices related to within-herd transmission such as separation of diseased animals and animals that had abortions from healthy animals were 47.9% and 29.3%, respectively. Separation of disease and aborted animals were lowest among Mahaoya farmers while highest in Navithanveli farmers (Table 4.3).

Placenta disposal varied across ranges. Most (61.1%) of the farmers in the study area did burry. Some of the farmers (11.9%) allowed the animal to eat it or hung it on a tree (17%) due to a traditional belief. There was a belief that animal will produce more milk when it eats the placenta. This practice seems to be highly existed among Navithanveli famers (34.2%) who are predominantly Tamils, followed by Mahaoya (21.0%) predominantly Buddhists. While 15.3 % of Kalmunai farmers allow animals to eat retaining the placenta in farm shed.

Farmers did not have negative impression on selling and consuming of milk from aborted animals. Milk sales and consumption of animals that had abortions were 88.5% and 86.2 %, respectively in the study area. However, almost all farmers boiled milk before consuming it or processing it into value-added products such as yoghurt or curd.

Table 4.3 Farmers' attitudes and practices related to brucellosis

Variable	Kalmunai (n=40)	Navithanveli (n=42)	Mahaoya (n=73)	p value	Study area (n=155)
Attitudes					
Purchasing animals with health certificate					
Females	20.1	7.5	29.2	**	20.6
Male	1.8	2.1	2.8		2.6
Sell aborted animals other farmers	18.7	27.2	11.3	**	17.2
Practices					
Use slippers	97.5	80.2	92.3		90.3
Use detergents	92.6	87.5	91.7		91.6
Remove placenta with bare hands	15.2	14.8	16.1		15.5
Separate diseased animals	42.5	67.5	33.8		47.9
Separate aborted animals	27.5	64.8	15.8		29.3
Disposal of placenta					
Burry	79.1	53.1	63.2		61.1
Allow animal to eat	15.3	12.7	11.8		11.9
Hang on a tree/other	5.6	34.2	21.0	**	17.0
Sell milk from animals who had abortions	82.3	90.4	84.6		88.5
Consume milk from animals who had abortions	85.3	87.3	88.2		86.2
Boil milk before drinking	100	100	100		100

Note: Figures are presented in percentages; **** indicate *figures are different at p<0.05* (*Kruskal Wallis* test)

Source: Field survey, 2016

4.3.2 Socio-economics of the study area

The majority of farmers (52.6%) in the study area spoke Tamil, and 29.4% received a living subsidy from the government (poor) (Table 4.4).

Table 4.4 Descriptive statistics of the sample

Variable	Description	Mean ± STD [4]
Farmers' factor		
MAIN_LANGUAGE_S	Sinhala (1); Tamil (0)	0.48 ±0.50
POOR [1]	Receive *Samurdhi,* Yes (1); No (0)	0.29 ±0.46
EDUCATION	No formal education (1); Had (0)	0.06 ±0.24
PARENT_FARMER	Farmers' parent(s) are dairy farmers, Yes (1); No (0)	0.64 ±0.48
FARM_EXPERIENCE	Farming experience >10 years (1); <10 years (0)	0.34 ±0.47
SEX	Head farmer's sex, Male (1); Female (0)	0.82 ±0.38
MAIN_JOB	Farming (crop/livestock) (1); Off farm (0)	0.73 ±0.44
AGE	Head farmer's Age (years)	46.63±10.73
FAMILY_MEMBERS	Number of members in the family	4.22±1.29
Social relationships		
FAITHFUL_ PERSONS[2]	Number of faithful persons	0.87±1.38
Institutional factors		
TRAINING	Trained on animal husbandry (1); No (0)	0.25±0.43
VET_ASSISTANCE [3]	Veterinary assistance (1); No (0)	0.96±0.21
COM_METHOD_PHONE	Communication via phone (1); Other (0)	0.31±0.46

Notes: 1). Farmer receives a living subsidy for poor from the government.

2). Number of faithful persons from which the farmer can request a loan/ help.

3). Farmer asks for assistance/advice from government veterinary office.

4) STD: Standard Deviation

Source: Field survey, 2016

The majority (82.1%) of farmers were male, and only 6.3% lacked a formal education. On average, farmers of the area had good social relationships (0.87±1.38) with at least one faithful person (friend or neighbor) from whom loans or credits could be obtained in an emergency. Although only 24.9% of the farmers had some training on farming practices, animal management or in a livestock-related field, almost all (98%) had very good relationships with respective veterinary office staff.

4.3.3 Factors affecting knowledge sharing

Our data fitted with $p<0.0000$ in the *tobit* model, explaining farmers' knowledge sharing (KNOW_INDEX) by farmers' education (EDUCATION), spoken language (MAIN_LANGUAGE_S), age (AGE), and social relationships (FAITHFUL_PERSONS) (Table 4.5).

Lack of formal school education negatively influenced knowledge acquiring capacity. Sinhala speaking farmers were negatively associated ($p<0.05$) with animal disease knowledge. Young farmers were better at acquiring knowledge ($p<0.05$). Factors of farming experience (FARM_EXPERIENCE), receive living subsidy from the government (POOR), informal knowledge from farmer parents (PARENT_FARMER), and main job as a farmer (MAIN_JOB) did not influence the acquisition of knowledge.

The effect of social relationships (FAITHFUL_PERSONS) on knowledge sharing was significantly positive ($p<0.001$). Selected institutional factors such as farmer training (TRAINING), communication via phone (COM_METHOD_PHONE), and ask veterinary assistance frequently (VET_ASSISTANCE) did not contributed in increasing of farmers' knowledge significantly (Table 4.5).

Table 4.5 Results of *tobit* analysis of factors affecting animal disease knowledge

Dependent variable, KNOW_INDEX (0 to 1)

Variable	Coefficient	SE	p value
Farmers' factors			
ETHNICITY_M	0.02	0.03	0.615
MAIN_LANGUAGE_S	-0.08	0.03	0.016*
POOR	-0.04	0.03	0.591
EDUCATION	-0.19	0.05	0.001**
PARENT_FARMER	-0.02	0.03	0.348
FARM_EXPERIENCE	0.01	0.03	0.772
SEX	0.02	0.03	0.491
MAIN_JOB	-0.01	0.03	0.853
AGE	-0.00	0.00	0.017**
FAMILY_MEMBERS	0.014	0.01	0.273
Social relationships			
FAITHFUL_ PERSONS	0.025	0.01	0.005***
Institutional factors			
TRAINING	0.004	0.03	0.89
VET_ASSISTANCE	-0.082	0.09	0.347
COM_METHOD_P	0.036	0.03	0.271
Constant	0.638	0.117	0

Note: *, ** and *** indicate *$p<0.1$, $p<0.05$, and $p<0.01$* respectively,

Number of observations=153; log likelihood=84.8078; pseudo R^2=-0.3655;

SE-Standard error

Source: Field survey, 2016

4.4 Discussion

It was found that many farmers (88%) have not heard of brucellosis, as noted by many other researchers in other countries (Lindahl et al. 2015; Arif et al, 2017), and were not aware of symptoms or transmission mode (Arif et al, 2017). Knowledge about both aspects of identification (clinical signs) and transmission were poor among farmers in all three studied areas. Significantly, farmers' knowledge of the method of infection (transmission) was poor compared to symptoms, signifying that more attention should pay to that aspect in the training modules of *Brucella* control programs.

Most of the farmers did not know about the zoonotic danger of the disease as observed by Addo et al (2011), so farmer infections are likely; therefore human surveillance is needed (Roth et al., 2003). Mangalgi et al (2017) have discussed about poor KAP of veterinary staff assistants who are likely to expose to infected animals frequently. Therefore, knowledge improvement among veterinary staff including veterinarians, could give utter impact in minimizing the zoonotic threat of the disease (Govindaraj et al., 2016).

The study clearly showed that knowledge of "asymptomatic" or "hidden" brucellosis was significantly lower than that of symptomatic disease or with clear symptoms such as FMD. There was a huge outbreak in FMD covering all most all the districts in the dry zone in year 2014. Most of the areas were declared as infected zones (Animal Disease Act 59, 1992) imposing movement restrictions with bans on milk selling, animal selling, artificial insemination, etc. Farmers would have acquired knowledge through experience from that recent incident; that could be a reason for high competency on FMD. However, farmer awareness and concern on unseen risks such as brucellosis are low compared to obvious ones as observed by Garforth et al (2013).

In this study, farmers' attitudes towards the spread of brucellosis via buying and selling of infected animals were extremely neutral. Highest number of farmers who sold aborted animals to another farmer was in Navithanveli (27.2%) where the Hindus are predominant (83%). Hindu farmers are not probable to sell their infected animals (e.g aborted) to slaughter house due to religious commitment; thus, may try to sell to another farmer as discussed by Silva et al (2000). The same situation was noticed in other countries like Jordan tending high spread of brucellosis by selling of infected animals in the absence of compensation for culling (Musallam et al., 2015a). This farmer behavior may influence over relatively high brucellosis records in Navithanveli farms (11.9 %) as discussed in chapter 3. Therefore, strategic change of farmers' behavior could be well-thought-out in brucellosis control intervention.

Even though general hygienic practices were satisfactory among farmers, brucellosis-transmission-related practices such as separation of diseased animals or animals that have abortions were not satisfactory. Abortions are strongly associated with *Brucella* sero-prevalence (Silva et al., 2000; Ahasan et al., 2017), indicating the importance of farm sanitary practices (Bakallah et al., 2017) to reduce the disease risk. The separation of aborted or disease animals may be challenging in extensive management system in this area. Hence, pre-immunization of susceptible animals using mass vaccination would be appropriate in such situations.

Farmers with no formal (school) education showed poor knowledge sharing capacity indicating more training programs for such farmer groups. Older farmers tend to have difficulty in acquiring knowledge of animal diseases, so they should be targeted in training programs. Our findings are in line with Frossling and Nöremark (2016) who said that factors of gender, education level and age influence on knowledge of animal disease occurrence and prevention.

Those who speak Sinhala language had low knowledge; thus, request for high awareness, may be though more printed materials in Sinhala. Also, training classes can be conducted in both languages in this area.

It was found that existing institutional setup had not efficiently contributed in developing farmers' knowledge related to animal diseases. Garforth et al (2013) highlighted that risk communication through the veterinary authorities is indispensable to encourage farmers to recognize hidden threats from the disease. It was noticed that communication facilities such as the use of a phone to contact a veterinary office have not counted in improving disease knowledge. But, previous studies discussed the importance of communication variables to the adoption of dairy farming technologies efficiently (Beck and Gong 1994). Inadequacy of veterinary extension officers and related infrastructure (e.g mobile facility) in the dry zone of Sri Lanka may limit their service to disease diagnosis and treatment which catch the higher demand. However, it could be due to the lack of attention to animal health aspects in extension policies as noted by Rezvanfar (2007).

Findings clearly showed that farmers with high levels of social relationship acquired better knowledge, which is in accordance with earlier finding (Lindahl et al., 2015), that farmers who talked about animal health with family members and friends were less likely to experience brucellosis in their herds than those who talked to a veterinarian (p=0.03). Farmers may collect information from friends and neighbors, or at the milk collecting centers, or at any other associations. Heffernan et al (2008) noticed that farmers' attitudes towards bio-security practices were not influenced by sources of information in particular.

This result indicates the possibility of sharing knowledge through informal channels effectively. Also, farmers' social relationships could be efficiently used to change the attitudes of their community. Heffernan et al (2008) emphasized the usefulness of support group formation in recognizing perceptions and attitudes among communities to explore bio-security collective action. Correspondingly, farmer to farmer extensions (community extensions) have proved to be practical, cost effective (Wellard et al., 2012), and successful in many African countries (Wolmer and Scoones, 2005); could be tried in the dry zone of Sri Lanka to control endemic diseases.

4.5 Conclusion

Poor knowledge leads to negative attitudes, which lead to unsatisfactory practices that may result in endemic diseases in the dry zone. Farmers' neutral attitudes and behavior towards selling of aborted animals to another farmer could be due to religious forbids or poor knowledge, should be carefully considered in control intervention. Lack of farmers' concern about veterinary health certificate, when buy animals and, poor bio-security practices such as non-separation of aborted and diseased animals from others would have resulted in high tendency of disease spread in the area. Knowledge improvement strategies by the extension authorities on animal diseases are not efficient at present; hence it should be severely addressed in brucellosis control program.

Farmers with high levels of social relationship could be utilized as 'lead farmers' in informal knowledge dissemination to control animal diseases and improve public health. Study the likelihood of farmer attitudinal and behavioral change through motivation strategy would be useful in controlling and eradication.

CHAPTER 5

Effects of incentives on information asymmetry and farmers' behavior towards brucellosis control

5.1 Background

Farmers' behavior on disease control depends on underlying attitudes to biosecurity risk, vulnerability to a biosecurity threats, influence of social incentives or social norms, and motivational drivers (Mankad, 2016). Many biosecurity decisions might get economic externalities because the decision-maker does not face their full consequences (Hennessy and Wolf, 2015).

As discussed in chapter 2, dry zone farmers' practice of reporting abortions to the veterinary authorities is not satisfactorily; thus, most of the aborted animals are less likely to be included in brucellosis surveillance (Chapter 2). Priyantha (2011) noted that most of the herds with abortion history (61.11%) are positive for brucellosis; thus, infected animals could exist in herds. Also, most of the farmers (70.7%) do not separate aborted animals from healthy ones (Chapter 4). Therefore, in the extensive management system, farmers may send infected animals for grazing with healthy animals, neglecting or hiding their disease information. Disease free farmers do not know about their neighbors' aborted animals, thus send their susceptible animals to co-mingle with diseased ones. This may result in brucellosis outbreaks. Moreover, farmers might sell aborted (*Brucella* infected) animals to another farmer hiding the disease status (hidden action), due to prevailing socio-religious taboos for animal slaughter (Silva et al., 2000). The veterinary authorities can't monitor the situation due to information gap between farmers and the government authorities. In information economics, "hidden action" or "adverse selection" that arises when the people in the informed side select an option that is harmful to the other side of people that are uninformed (Tumay, 2009). Therefore, information asymmetry between farmers and the veterinary authorities (government) as well as among farmers is likely to occur (Laffont and Martimort, 2001), and it was assumed to be one of the main reasons for brucellosis existence for decades in the dry zone of Sri Lanka.

Economic incentives are often used to avoid information asymmetry by motivating people to change their behavior (Laffont and Martimort, 2001). Private-public economic incentives were found to be effective in controlling anthrax in North Dakota in USA (Mongoh et al., 2008). On this background, it was hypothesized that economic incentives can change farmers' behavior towards bio-security information and practices; thereby control brucellosis in Sri Lanka effectively.

Brucellosis was successfully controlled and eradicated by test and slaughter with farmer compensations in UK (DAERA, 2004). It was not attempted in Sri Lanka due to social restrictions and financial limitations. Therefore, it was assumed that strong government intervention with incentives may succeed in culling of infected animals.

As Brucella is a milk born pathogen (Ning et al., 2013), and can be tested using MRT simply and cost effectively (OIE, 2009; Godfroid et al., 2010), milk testing and payment system was proposed as an incentive to motivate farmers

The objective of this chapter was to study farmers' behavior towards milk incentive-based cattle culling policy to eradicate brucellosis in Sri Lanka. There were two specific objectives of the chapter,

1. to elicit farmers' willingness to accept (WTA) the milk incentive system, and
2. to study the factors affecting WTA of the incentives.

5.2 Materials and methods

Brucellosis persistency in the dry zone is due to poor knowledge, attitudes and risky practices (Chapter 4). Yambo (2016) noted that knowledge, attitudes and practices (behavior) can be changed through training and awareness. Also, economic incentives can change farmers' behavior towards risk avoidance (Gilbert and Ruston, 2016). Therefore, it was hypothesized that risky behaviors such as non-separation of disease animals from healthy animals, selling of aborted animals to other farmers, selling of milk from infected animals can be changed with incentives and famer awareness (Figure 5.2).

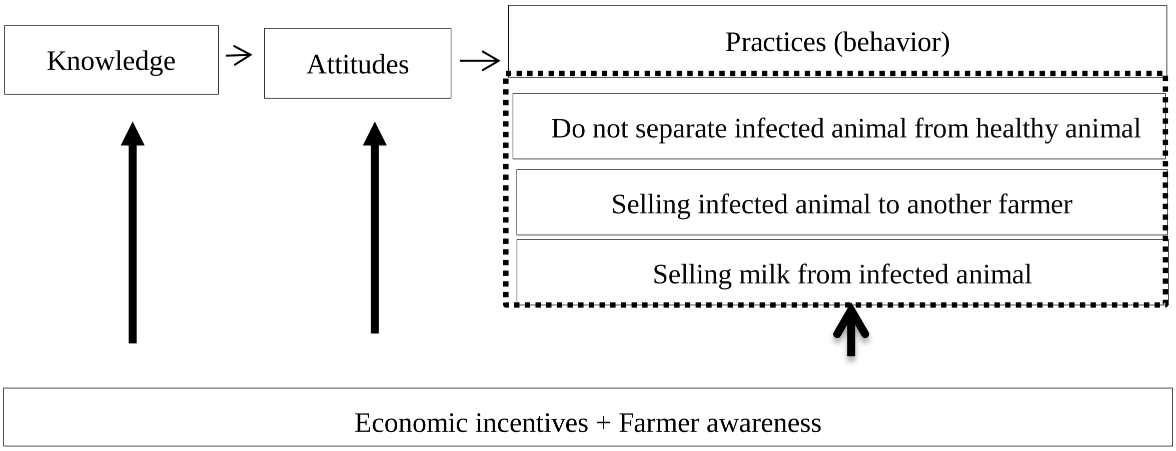


Figure 5.1 Hypothetical diagram of impact of intervention on farmers' behavior

Farmers' behavior for hypothetical market place is often studied using contingent valuation method (CVM) (Hector, 1992; FAO, n.d c). Accordingly, this chapter studied the feasibility of hypothetical economic incentives on maintaining farm bio-security using CVM.

5.2.1. Study design, sampling and data collection

(1) Study area and sampling

As in other chapters, Ampara district of the eastern province (dry zone) was the area of study. Additionally, Kandy district (Central province) was included in the survey (Figure 5.2) for the comparison sake as socio-economics and farming practices in Kandy differ from the dry zone. Kandy is one of the three administrative districts (Kandy, Matele, NuwaraEliya) in the central province of Sri Lanka. It predominates with semi-intensive and intensive cattle farming practices and categorized as a milk shed area in the country (Ibrahim et al., 1999). The area is highly diversified in socio-economics with different ethnicities such as Sinhalese (74%), Sri Lankan Muslims (13.27%), Indian Tamil (8.09%), Sri Lanka Tamil (4.06%), Sri Lanka Malay (0.21), Burgher (0.17%) and others (0.2%).

Total sample size comprised of 110 numbers of farmers who supply milk to the formal milk collecting network. Simple random sampling was used to select farmers from the milk collecting network. MILCO which is the largest milk collecting organization in all over Sri Lanka, was selected for this study.

It was purposively selected milk collecting areas such as Samanthurai and Mahaoya in Ampara district, and Teldeniya and Kundasala in Kandy district for the study (Figure 5.2).

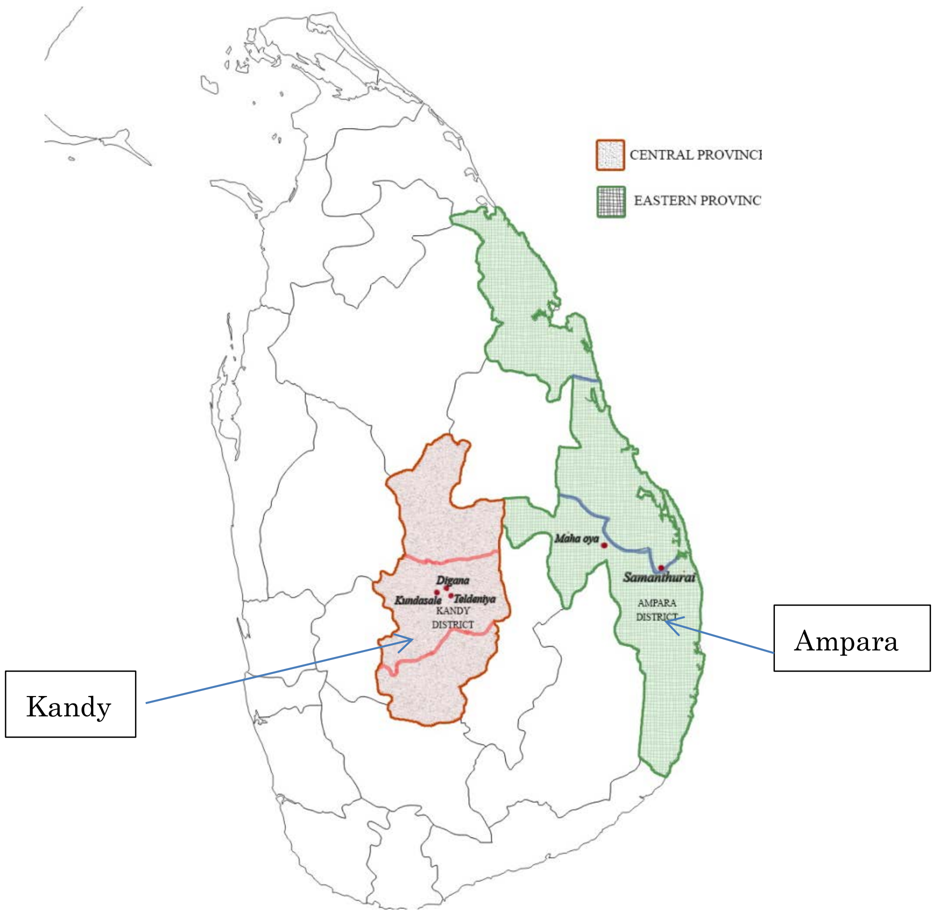


Figure 5.2 Map of the study area

Milk collecting centres were visited in the early morning to meet farmers who bring milk to the centre. Farmers were directly questioned using Contingent Valuation (CV) survey method.

(2) Contingent valuation method (CVM)

Willingness of a person for particular good or service can be estimated using CVM which is a survey-based method frequently used for placing monetary values on goods and services that is not bought and sold in the marketplace (Carson, 2000). CVM has been increasingly used in health economics (Donaldson, et al., 2006; Olsen and Smith, 2001) where hypothetical market place is created. Research were carried out using CVM to elicit the demand for water in rural areas by the World Bank (WB,1993), for sanitation services in Ghana (Whittington et al.,1993), recreational value of wildlife viewing in Kenya (Navrud,1994) and to study the costs/benefits of restricting land use to reduce tropical deforestation in developing countries (Shyamsundar,1996).

A questionnaire was prepared and pre-tested by visiting milk collecting centres in Teldeniya and Kundasala initially with 10 farmers (five from each). There were three main parts in the questionnaire as follows.

1. First, questions about socio-demographics of farmers were asked. These included the respondent's name, age, ethnicity, household income, sex, number of family members, educational attainment, whether receive government living support namely S*amurdhi,* as explained in Chapter 3, and farming information such as herd size, milk production, free moving practice, etc. Further, it was asked questions related to brucellosis knowledge which may likely influence the willingness to accept the control policy.
2. Second part opened with general ("warm-up") statements related to animal diseases followed by a comprehensive description of brucellosis, losses (milk loss, calf loss, abortions, retained placenta, etc.), and its transmission mode by infected animals who are life-long carriers, and possible control measures to convince the farmer about importance of control.
3. Third, hypothetical scenario depicting a plan for culling, compensations and milk testing system through milk collecting network was described. Then farmers were asked about willingness to accept (WTA) of culling policy and compensation to elicit their behavior. They are discussed in detail in the next two parts.

(4) Economic incentives for voluntary culling

The proposed economic incentive system consists of voluntary culling with compensation linked to milk premium-penalty system through collecting network. Price premium for high quality products induced individuals to maintain a reputation for quality production (Kranton, 2003). Quality penalties were found to be more effective in motivating farmers than quality premiums (Valeeva et al., 2007). Even though milk premiums and penalties in regulating quality was frequently used by developed countries, it is very rarely practiced in developing countries, could be due the poor infrastructure facilities and less coverage of formal milk collecting network. However, formal milk collecting network is being developed in Sri Lanka; thus, assumed that milk premium-penalty system (Figure 5.3) for *Brucella* free milk will work in future.

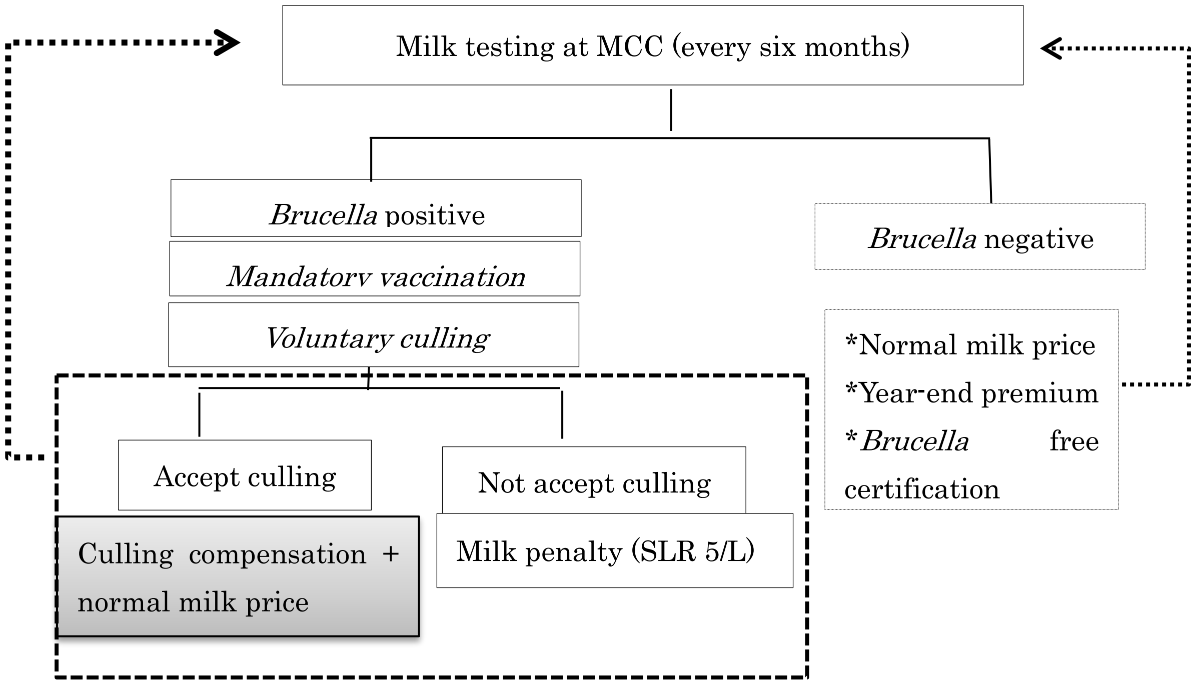


Fig. 5.3 Proposed economic incentive (premium-penalty) system to control brucellosis

Note: MCC- Milk Chilling Centre

In the proposed system bulk milk is tested every six months for brucellosis as recommended by OIE (2009) at milk chilling centres (MCC) in the formal milk collecting network[3]. When a farm (herd) is found to be positive for brucellosis, whole farm (individual animals) could be tested (e.g RBT) and confirmed (e.g i-ELISA or CFT) for *Brucella* infection at farm premises. The positive farms are requested to vaccinate (mandatory) all the animals if the farm has not been vaccinated, and to cull (voluntary) the infected animals (Figure 5.3).

Farmers are motivated to cull positives by providing compensation (indemnity payment) based on animal's market value which is less than the market value of the animal. If the farmers accept culling, he/she will be paid the normal farm gate milk price. Milk of infected animals will not be rejected unless the bacterial count exceeds the standards with alcohol test as discussed in chapter 2. The farmers those who do not accept culling are expected to de-motivate by milk penalty of deducting SLR 5/litre. Farmers those who maintain bio- security well, to be free from brucellosis in their farms would be motivated by year-end milk premium and certification as "*Brucella* free farm". The milk testing will be repeated bi-annually, thus result and payments are valid for 6 months. Government will be responsible of culling of infected heifer/ cows and payments, but does not pay a compensation for male animals. Milk collecting network will arrange farmer awareness campaigns on brucellosis, its impact and control measures, via simple leaflets, books and training programs.

3.Formal milk collecting network is described in detail in chapter 2

(5) Elicitation of farmers WTA on economic incentives

After the description of hypothetical incentive system, farmers' willingness to accept the policy was questioned using dichotomous choice 'yes' or 'no' (Figure 5.4). In the case of 'yes' respondents, preferred bid value was questioned using double bound system with 70%, 80% and 90% (as percentage to the market value of animal) initially. Since all the respondents agreed on the bid presented at first bound showing insensitivity to the bid value in the pretest, farmers with 'yes' preference were directly questioned to elicit preferred minimum bid for culling compensation as a percentage to the animals' market value (Figure 5.4).

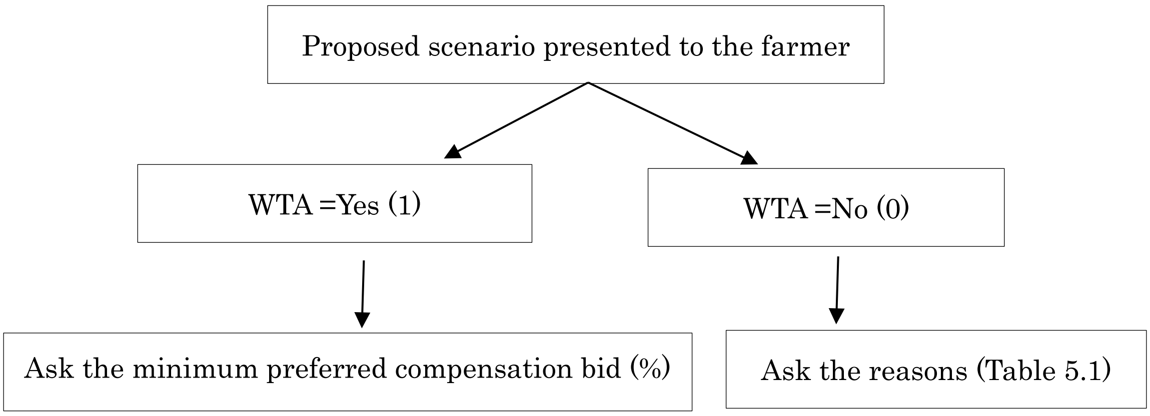


Figure 5.4 Process of eliciting WTA of culling through CVM

Table 5.1 shows the questions used to elicit reasons for not accepting culling. Also, farmers were questioned about preventive vaccination of animals for brucellosis as depicted in the Table 5.1.

Table 5.1 Questions presented to farmers to elicit reasons for not accepting vaccination or culling

Eliciting questions and reasons for rejection	
1. Do you accept voluntary culling of infective and compensation? Yes/No	
If not reasons for rejection of culling of infected cows	1.I do not like to kill my animals because of the religion 2. I want to sell positive animal at normal price. 3. Other (……………………………)
2. Do you accept preventive *Brucella* vaccination of your animals? Yes/ No	
If not reasons for rejection of preventive vaccination	1.I have to spend a lot of labour to take the vaccine 2. I can't sell vaccinated animals on normal price. 3. Other (…………………………..)

5.2.2 Statistical analysis

Descriptive statistics were used to study the characteristics of the study area and study populations.

WTA could be defined as the amount of money that must be received by a farmer for experiencing losses due to cattle culling, while keeping his utility constant given in Equation 5.1 (FAO, n.d).

$$V(WTA, p_1, q_1;\ Z) = V(y, p_0, q_0;\ Z) \qquad (5.1)$$

Where V denotes the indirect utility function, y and WTA are family income of the farmers and willingness to accept bid respectively, p_0 and p_1 are vector of prices faced by the farmer, q_0, and q_1 are the alternative levels of quality indexes ($q_1 > q_0$, indicating q_1 refers improved biosecurity status of the farm when infected cows have been culled).

Z is the vector of other characteristics of the farmer.

In this equation utility is allowed to depend on a vector of individual characteristics influencing trade-off that farmer is preferred to make between income from selling infected cow or selling the milk from infected cow, and improved health status of the farm by removing infection from the farm. Therefore, WTA should depend upon (1) initial and final level of status in question (q_0 *and* q_1), (2) respondent's family income (3) all prices faced by the respondent and (4) respondent's social characteristics.

As described earlier, it was assumed that farmers' willingness of to accept/reject is related to the bid (%), family income and socio-economic characteristics of the farmer (Equation 5.2).

$$Y_i = \alpha + \rho C_i + \beta Z_i + \varepsilon_i \quad (5.2)$$

Where Y_i *is* an unobservable dependent variable that is *i* th farmer's willingness of to accept/reject (dummy variable, 1/0) for culling of *Brucella* infected cattle. C_i is compensation bid (%) offered by the farmer and Z_i *is* vector of observable farmer's and farming characteristics (Table 5.2), and ρ and β are respective coefficient vectors.

Except the farmers bid (%), it was considered farmer characteristics such as area, ethnicity, family income, poor (receive *Samurdhi*), and farming characteristics of herd size, milking cow number, milk production, abortion history, grazing in free area, knowledge and training as independent variables (Table 5.2). Variables were tested for multicollinearity. *Probit* model was used in STATA 12 using the *command probit* (StataCorp, 2011). Since the coefficients do not indicate the marginal value change in *probit* model, marginal effect was calculated using command *mfx* in STATA.

The compensation amount (WTA) received by each farmer according to his/her accepted bid, was calculated using Equation 5.3

$$WTA_i = C_i V \quad (5.3)$$

Where WTA_i is the amount of willing to accept as culling compensation by i^th farmer, and C_i is accepted compensation bid by i th farmer, which is a proportion (%) to the total animal value. V is the market value of animal in the area.

The mean value for compensation bids for an area can be estimated by Equation 5.4.

$$MWTA = \frac{1}{n}\sum_{i=1}^{n} y_i \quad (5.4)$$

Where *MWTA* is the mean compensation amount that is willing to accept in an area (e,g district) by *n* number of farmers.

Additionally, it was computed the rate of acceptance of culling policy (C_r) by using Equation (5.5).

$$C_r = \frac{number\ of\ farmers\ accepted\ culling\ policy}{total\ number\ of\ farmers\ qustioned} \quad (5.5)$$

5.2.3 Principal-Agent (PA) theory in effect of incentives on farmers' behavior

The application of incentives by the government (principal) to change the farmers' (agent's) attitude towards accepting culling of the infected animals is studied using PA theory, which was initially described by Olson (1965). PA theory is used in the presence of information asymmetry, which means the agent has more information than the principal.

There are some assumptions in application of PA model in studying principal and agent relationship (Laffont and Martimort, 2001), such as

1) The principal and the agent both adopt an optimizing behavior and maximize their individual utility. In other words, they are both are fully rational individualistic agents.

2) The principal does not know the agent's private information, but the probability distribution of this information is common knowledge.

3) The principal is a Bayesian expected utility maximizer. He moves firm as a leader under asymmetric information anticipating the agent's subsequent behavior.

In the case of brucellosis eradication policy, farmers only have the information about their animals/farms health status. The government needs to disclose that information by testing animals and farmers have to exert efforts to accept culling. Therefore, the government has to create incentive for the farmers to ensure their cooperation.

Accordingly, the PA model is given in the following Equation (5.6) (5.7) and (5.8) (Starbird, 2005).

$$\text{Max E}[V(w,e)] \tag{5.6}$$

subject to

$$\text{E}[U(w,e)] > \underline{U} \tag{5.7}$$

$$U(w,e) \geq U(y,e_0) \tag{5.8}$$

Where w is the compensation paid by the principal to the agent; e is the effort exerted by the agent, which is accepting culling and e_0 indicates absence of effort to accept culling; $V(w,e)$ and $U(w,e)$ are the principal's and the agent's utility functions respectively.

Equation (5.6) is called the objective function. The participation constraint in

Equation (5.7) shows that the farmers' utility from his effort to accept the compensation is higher or equal to a certain level $\underline{U}$. Equation (5.8) is the incentive compatibility constraint that says that farmers' utility from exerting e have to be greater than the utility of not making the effort.

5.3 Results

5.3.1 Characteristics of the study area

The sample comprised of farmers who supply milk to Samanthurai milk collecting centre from Kalmunai (18%), Navithanveli (11%), Ninthavur (16%) and from Mahaoya (23%) in Ampara district, and farmers from Kundasala (11%) and Teldeniya (22%) from Kandy district. The majority of farmers (67%) were from Ampara district.

Table 5.2 shows the characteristics of the study area. The majority of the farmers in the sample were Sinhala (54%) followed by Tamils (24%) and Muslims (22%). There were few (5%) farmers were without formal education (Table 5.2), while the other were with school education.

Most of the farmers (60%) have exposed to training on livestock. Around 39 % of the framers have undergone a training (TRAINING) on brucellosis 6 months before the survey (Table 5.2). There were 42 % of the farmers who have heard about brucellosis or contagious abortions before (KNOW_BRUCELLA). Around 26% of the farmers have had abortions (ABORT_HISTORY) in their farms (Table 5. 2)

Despite the high poor farmer head count ratio (37%), average monthly family income was satisfactory with SLR 41,762 (US$ 278) as shown in Table 5.2.

Table 5.2 Descriptive statistics of the sample

Characteristic	Description	Mean±STD
BID	Farmer's bid (%) for compensation	68.60 ±16.12
Farmer factors		
AREA	Ampara (1); Kandy (0)	0.67 ±0.47
ETHNICITY_M	Muslims (1); Sinhala and Tamil (0)	0.22 ±0.41
ETHNICITY_S	Sinhala (1); Tamil and Muslims (0)	0.54 ±0.50
ETHNICITY_T	Tamil (1); Sinhala and Muslims (0)	0.24 ±0.43
AGE	Head farmers' age (years)	47.63 ±12.51
POOR	Receive *Samurdhi,* Yes (1); No (0)	0.37 ±0.49
FAMILY_INCOME	Total family income (000 SLR) per month	41.76 ±34.6
TRAINING	Trained on animal husbandry and diseases (1); No (0)	0.60 ±0.49
Farming factors		
MILK_PROUCTION	Milk production per farm per day in litres	14.5 ±15.8
ABORT_HISTORY	Had abortions in 2016/2017, Yes (1); No (0)	0.26 ±0.44
GRAZING_PRACTICE	Free moving for grazing (1); Restricted grazing (0)	0.64 ±0.48
KNOW_BRUCELLA	Farmer know term "brucellosis" or "contagious abortions", Yes (1); No (0)	0.42 ±0.49
HERD_SIZE	Number of animals per farm	12.59 ±23.68
MILK_ANIMAL	Number of milking animals per farm	5.61 ±10.29

Note: STD= Standard deviation

Source: Field survey, 2017

Ampara district had high monthly average income per family (SLR 46,921; US$ 313) compared to Kandy (SLR 30,858; US$ 206) (Figure 5.5). Farming (crop and livestock) was the main income generating source of the study area (Figure 5.5).

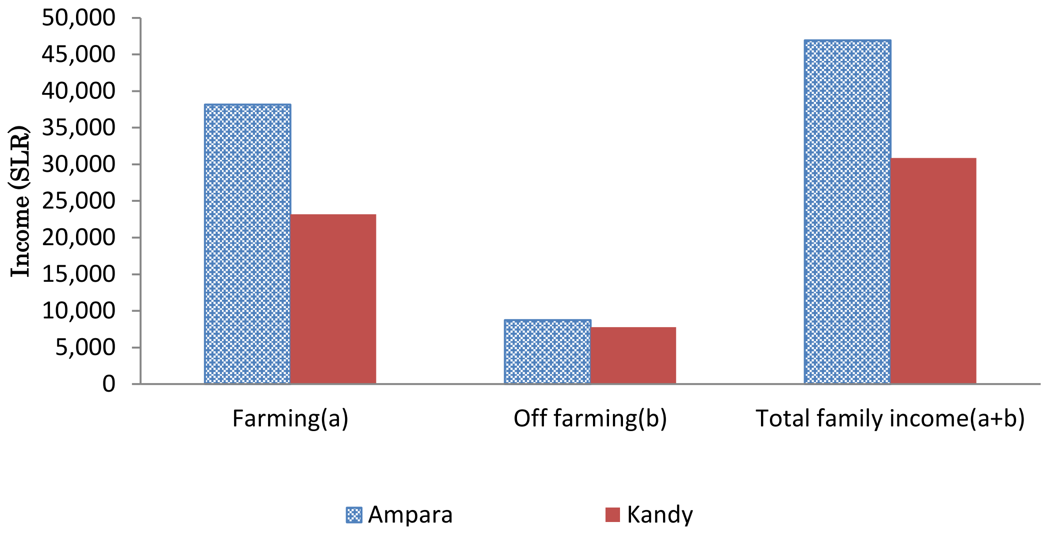


Figure 5.5 Farming, off-farm and total family income in Ampara and Kandy

Source: Field survey, 2017

Dairying was the major farming activity in both Ampara and Kandy (Figure 5.6). Average dairy income of the area was 24,300 SLR (US$ 162). Particularly, average farming income in Ampara district was higher (SLR 38,171; US$ 255) compared to Kandy (SLR 23,186, US$ 155) (Figure 5.6).

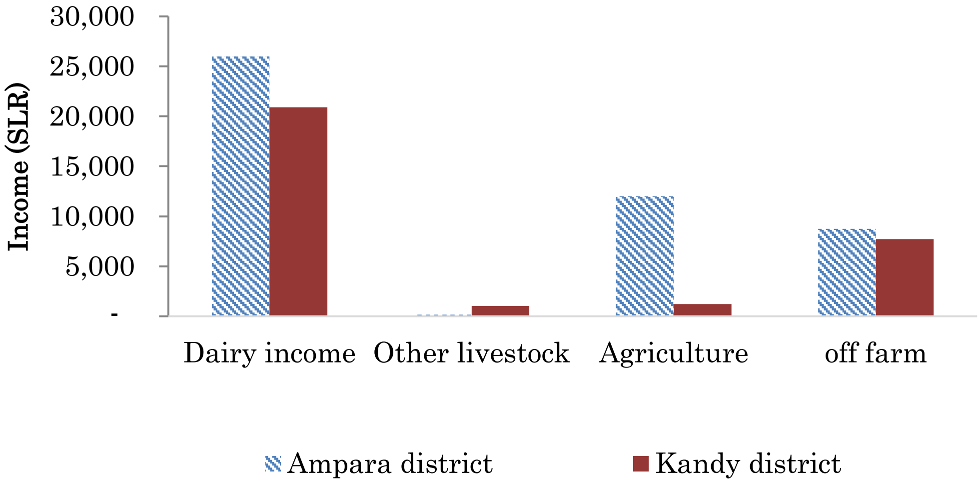


Figure 5.6 Family incomes from different sources in Ampara and Kandy

Source: Field survey, 2017

Table 5.3 Differences of dairy farming practices in Ampara and Kandy

Variable	Ampara district		Kandy district	
	Mean	Median	Mean	Median
Herd size**	14.9	6	8.02	5
Milking cows	6.1	3	4.1	3
Milk production(L/day) *	16.1	10	11.3	10
Milk productivity(L/day)	3.4	3.1	5.5	3.5

Note: * and ** indicate $p<0.10$ and $p<0.05$ (t test) respectively

Source: Field survey, 2017

There were significant differences of herd size and milk production/farm between two districts. Despite large herd size in Ampara district, milk production per animal was higher in Kandy district (Table 5.3).

5.3.2 Farmers' behavior on economic incentives and willingness to accept (WTA) cattle culling

The rate of acceptance of the culling policy as a brucellosis control measure was approximated to 90% (97/110). The accepted bid varied from 50% to 100 % of the animals' market value (Table 5.4). The mean WTA was SLR 61,920 (US$ 413) which is 68.6% of the market value of SLR 90,000 (US$ 600) of a cow at present.

Table 5.4 Distribution of compensation bid values (%) among culling accepted farmers

Category	Value						
Accepted bid (%)	50	60	70	75	80	90	100
No.of farmers in Ampara	23	7	12	7	7	3	5
No.of farmers in Kandy	2	9	5	7	5	3	2
No.of farmers* in total area	25	16	17	14	12	6	7

Note:No.of farmers those who accepted culling policy in both the districts (n=97)

Source: Field survervy, 2017

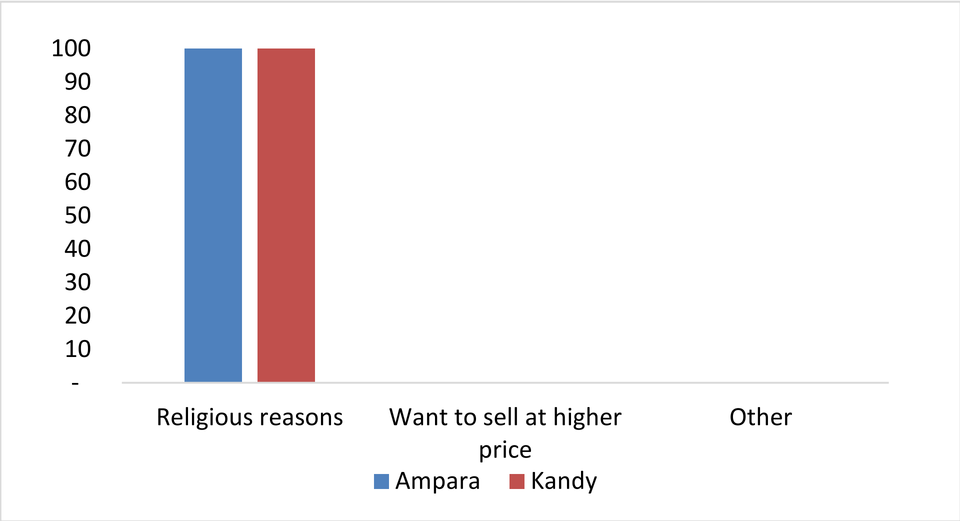


Figure 5.7 Reasons for not accepting culling and compensations

Source: Field survey, 2017

The reasons given for not accepting culling was purely religious and sentimental in both distrcits (Figure 5.7). Additionally, almost all (100%) the farmers prefer to have vaccination as a preventive measures for brucellosis (Figure 5.8).

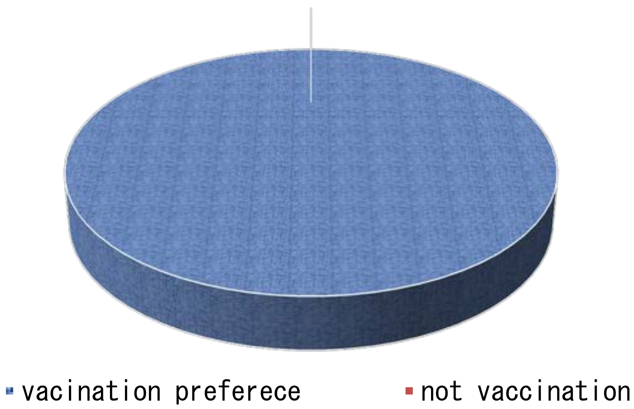


Figure 5.8 Farmers' preference for prevention vaccination

Source: Field survey, 2017

5.3.3 Factors affecting willingness to accept (WTA) cattle culling

Multicollinearity analysis shows that ETHNICITY_S (Sinhalese) was correlated with AREA (r^2 > 0.60) and also with ETHNICITY_M (Muslims) (r^2 > 0.60), therefore, ETHNICITY_S was dropped from the *probit* analysis. Further, family income (FAMILY_INCOME), total herd size (HERD_SIZE) and number of milking animals (MILK_ANIMAL) were highly correlated (r^2 > 0.60) to milk production (MILK_PRODUCTION), the latter was only considered in the *probit* analysis.

In the *probit* model farmers' WTA for cattle culling and compensation was well explained (Prob> chi^2 =0.0000) by factors of BID, ETHNICITY_T, KNOW_BRUCELLA, TRAINING and ABORT_HISTORY (Table 5.6). On the other hand, AREA, AGE, ETHNICITY_M, POOR, MILK_PRODUCTION and GRAZING_PRACTICE were not significantly associated with WTA of culling policy.

Compensation amount (BID) was positively related ($p<0.05$) to the acceptance of the culling and incentive scheme (Table 5.6). Also, farmer training (TRAINING) ($p<0.05$), knowledge about brucellosis (KNOW_BRUCELLA) ($p<0.10$) and farm history with abortions (ABORTION_HISTORY) showed high probability of accepting culling.

Marginal effect (ME) of bid value on WTA shows positive sign (Table.5.6) saying that there is a probability of increasing WTA by 0.0006 by increasing compensation bid by 1 %. Moreover, marginal effect of training on WTA of culling policy was significant and high (Table 5.6).

In opposite, Tamil ethnicity shows negative influence ($p<0.10$) on WTA of culling with very high marginal effect (100%). The interaction of bid value and Tamil ethnicity (BID x ETHNICITY_T) shows positive but non-significant influence on WTA.

Table 5.5 Results of *probit* analysis on factors affecting WTA culling policy

Dependent variable, WTA: Yes (1); No: (0)

Variable	Estimate			Marginal effect	
	Coefficient	SE	p value	dy/dx	SE
BID	0.05	0.01	0.027**	0.00	0.00
AREA	1.59	1.09	0.146	0.05	0.08
AGE	0.00	0.03	0.795	0.00	0.00
ETHNICITY_T	-10.62	6.25	0.089*	-0.10	0.00
ETHNICITY_M	0.633	1.06	0.553	0.01	0.00
POOR	-0.53	0.67	0.430	-0.01	0.01
KNOW_BRUCELLA	1.23	0.76	0.100*	0.01	0.02
TRAINING	2.12	0.92	0.021**	0.08	0.08
MILK_PRODUCTION	-0.02	0.02	0.319	-0.00	0.00
ABORT_HISTORY	1.99	1.18	0.090*	0.02	0.02
GRAZING_PRACTICE	3.00	2.23	0.178	0.22	0.41
BID x GRAZING_PRACTICE	-0.04	0.03	0.230	-0.00	0.00
BID x ETHNICITY_T	0.17	0.11	0.136	0.00	0.00
Constant	-4.27	2.38	0.072		

Note: * and ** indicate *p<0.10 and p<0.05* respectively; SE = standard error

Number of observations= 110; Log likelihood -17.91; Pseudo R^2 =0.5518

Source: Field survey, 2017

The analysis of farmers' behavior on milk payment system linked to cattle culling and economic incentives in the presence of asymmetrical information with regard to brucellosis using PA theory is discussed in the next part.

5.4 Discussion

This study examined that how brucellosis control policy works in the presence of information asymmetry. The government of Sri Lanka wants to control brucellosis with an intervention, aiming social benefits of public health (Zinnstag et al, 2005), and food security. Brucellosis could be spread due to selling of animals with abortions (possibly *Brucella* infected) to disease free farmers and free areas (Chapter 4). The government (principal) can't monitor the farmers' behavior of selling of infected animals to another farmer hiding correct information. Therefore, government will start milk testing to detect *Brucella* infected farms through national milk collecting network. Milk testing will uncover the disease status of animals; thus, information gap is intended to decrease. In the proposed intervention, farmers are paid on milk testing results with a compensation (certain percentage of market value of cow) for voluntary culling of infected animals. With this intervention, information availability would be increase; therefore, farmers would be uncertain about selling of infected animals at full market value as practiced before.

It was assumed that dairy farmers in Sri Lanka prefer to be risk averse; therefore, they prefer to minimize risk by accepting culling. Their expected utility upon cow value can be given in equation 5.9 (Campbell, 2006). The expected utility theory which is discussed by Bernoulli in 1738, explains people's preferences with regard to choices that have uncertain outcomes (Equation 5.9).

$$EU = \alpha U(X) + (1 - \alpha)U(Y) \tag{5.9}$$

Where EU is expected utility of the income function, X is the price of *Brucella* infected and confirmed animal (lowest) and Y is the price of healthy cow (highest). *U(X)* and *U(Y)* are utility of selling of *Brucella* tested (confirmed) and un-detected (un-tested) animal with α *and* $1-\alpha$ probabilities respectively.

Before the intervention, farmers do not report abortions to the authorities, thus *Brucella* testing is not very extensive; therefore probability of detecting *Brucella* infected animal is relatively low (α) and probability of not detecting is very high (1-α) (Figure 5.9). In this situation farmers are capable of selling their un-detected (could be infected) animals at normal market price (Y) because of the information unavailability with the utility U(Y). The tested and confirmed animals are few in number with lower market price (X) with utility of U(X) (Figure 5.9). In this situation there is no compensation (C) existing; thus U(C) may be zero which is lower to the expected utility (EU) of selling infected animal; therefore, farmers tend to sell infected animals (Figure 5.9).

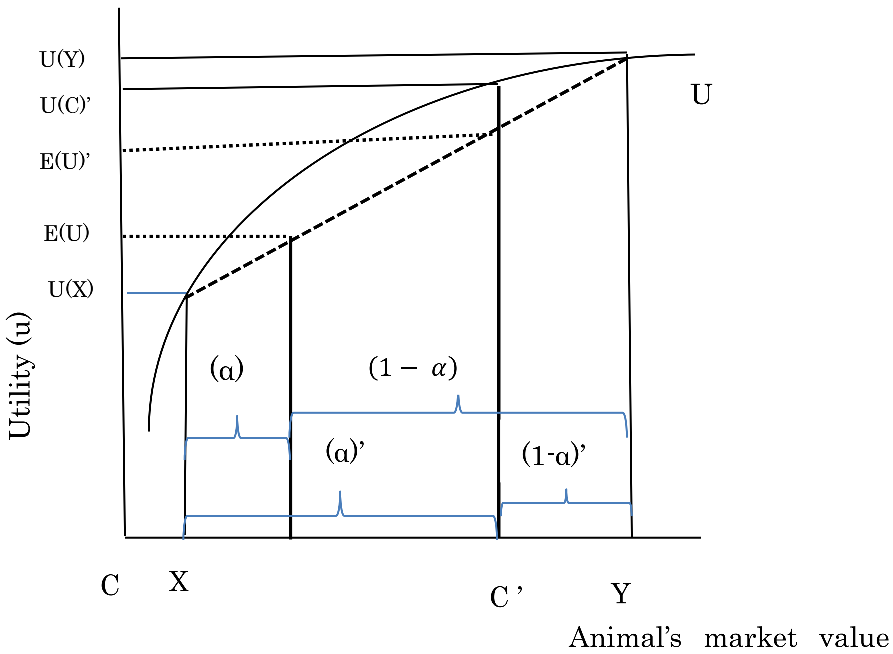


Figure 5.9 Animal's market value, utility and expected utility

With the new intervention milk testing will be increased extensively, the majority of infected animals will be detected and notified as *Brucella* infected. Farmers are offered to cull infected animals voluntarily for compensation. Therefore, the number of *Brucella* detected animals will be increased from (α) to $(\alpha)'$ and un-detected will be decreased from (α -1) to (α -1)' (Figure 5.9). The infected farmers have a choice of accepting culling and to be free from brucellosis.

Because of the milk testing and information availability about detected animals, the majority of the farmers will not be able (uncertain) to sell their infected animal at full market value. The testing is linked to voluntary cattle culling policy with compensation amount C' of which expected utility (E(U)') is lower to the utility of compensation (U(C)'); thus, farmers tend to accept compensation to cull infected animals. The two scenarios are given in following equations

Before the intervention (UC= 0) < EU (5.10)

After the intervention (E (U)') < (U(C)') (5.11)

It was explored that the rate of culling policy acceptance was around 90% and they accept 68.6% of the market value of animal as culling compensation. This could be explained by PA model that says farmers accept 68.6 % of the value as culling compensation, because the expected utility of keeping an infected animal is lower to the compensation value as shown in equation 5.11. Farmers highlighted that the bid amount should be at least sufficient to buy a new heifer for milking herd; which could be their expected utility of keeping an animal even with the disease.

In contrary, previous literature says only 49% farmers accepted culling and compensation for FMD infected animals (Gunaratne, 2015). The high acceptance rate in this study could be explained by possible extensive information availability in proposed system through milk collecting network. If farmers accept the voluntary culling, his/her milk income will be normal (normal farm gate price) for 6 months, after that they can be enter in *Brucella* free category if biosecurity maintained well. If the farmers do not accept culling of infected animals he/she will be punished by a fine of SLR 5/L; thus, reduces milk income. Also, *Brucella* free farmers are benefited by a milk premium at the end of the year. In line with this study, previous study stressed that milk premium-penalty payments were found to be very effective in providing incentives for increasing milk quality (Nightingale, et al., 2008). Also, it was shown that people response highly to ordinary penalties than very high penalties with regard to illegal behavior (Bar-Ilan, 2000). The study revealed that all farmers (e.g all ethnic groups) do not behave alike, such that understanding of farmer behavior is very important in livestock diseases control as noted by Hennessy and Wolf (2015).

Tamil farmers do not likely to accept culling, perhaps their religious commitment with cattle, despite the information availability and compensation. Tamil (Hindu) farmers may not be responsive to compensation and increasing income as discussed by Augenblick et al (n.d) that people with extreme and sincere religious beliefs are unresponsive to price manipulations. Fraser (2015) noted that compensation induces farmers' behavior which is influenced by farmers' decision-making environment. Farmers insisted that there should be essential government involvement in animal slaughtering and disposing of carcasses preventing them enter in to the beef market. Therefore, the government must consider these social aspects in order to increase farmers' psychological satisfaction (utility) (Caplin and Leahy, 2001), thereby motivating for culling acceptance other than compensation. Additionally, Tamil areas can be essentially categorized as high-risk areas for mass vaccination to decrease the prevalence to very low level since they resist on culling.

It was observed that there was no significant influence of per farm milk production or area of the farm on WTA of culling. Family income and the herd size was correlated to milk production indicating that culling policy acceptance was not sensitive to farmer' income or herd size. Also, it was evident that family income, herd size and milk production were significantly varying among two districts. The area of the farm had no influence on WTA, justifying above finding.

Brucellosis is a zoonotic disease that is possibly infecting human beings with raw milk consumption. People who are used to drink udder milk are at high risk which is possible to minimize with pasteurization very effectively (CIDRAP, 2017). In Sri Lanka, almost all people consume fresh milk after boiling (Chapter 4). Also, the process of milk processing is subjected to high heat treatment; thus, less likely to get milk born infection.

However, milk incentives would encourage farmers to produce *Brucella* free milk (minimize milk contamination) by infected animal culling (Ning et al., 2013). Sri Lanka is in the process of popularizing fresh milk among consumers (MLRCD, 2011) to increase local milk consumption. Milk borne pathogens are one of the limiting factors for that; it can be successfully addressed through this proposed incentive system.

Stimulatingly, it was observed that training and experience with abortions has significant impact over acceptance of culling and milk incentive policy. The farmers those who have undergone training on brucellosis, were well convinced about the proposed intervention, thereby accept culling policy. Knowledge gain through training create positive attitudes and behavior as noted by Mahmoodabad et al (2008) in accepting culling to be free from brucellosis, signifying the high likelihood of brucellosis control with awareness and training.

Agricultural research and extension are important to agricultural innovation, so markets, government systems; social norms could create the incentives for a farmer to decide the way in which he or she works (Berdegue and Escobar, 2001). It is planned to have wider coverage of awareness and training through milk collection network under proposed incentive scheme. Chapter 4 argued that farmers prefer to share knowledge through informal channels. Hence, it was expected that the proposed milk payment plan will be an incentive for farmers to share knowledge about brucellosis at milk collecting points informally, apart from formal farmer training and awareness programs.

Most of the milk incentive programs are based on total bacterial count (TBC), somatic cell count (SCC) and milk composition such as fat (%), protein (%) and solids non-fat (%) (Draaiyer et al., 2009; Dekkers et al., 1996), and mostly practiced in developed countries. Nevertheless, milk payments linked to disease control is still at infant stage in developing countries could be because of poor infrastructure development in milk collecting network. In Sri Lanka, milk collecting network is being rapidly developed even in rural areas; therefore, it is likely to use the milk collecting network for information sharing and disease control. This study shows the likelihood of such an intervention in developing counties, provided that there is high coverage of formal milk collecting network.

According to approximation based on current prevalence at 2.9% (Chapter 3), there will be around 21,000 infected cows to be culled in entire Sri Lanka with this proposed intervention, will be a huge cost. Therefore, economic evaluation is essential to get the information for cost effectiveness of this plan.

5.5 Conclusion

Brucellosis control and eradication would be a feasible attempt with incentive based voluntary culling policy in Sri Lanka. Compensation amount is important to incentivize in increasing farmers' utility to accept the cattle culling policy. Culling compensation linked to milk payment system (premium-penalty) through formal milk collecting network would be an extension system other than economic incentives. Farmer training and knowledge improvement are equally or more important in convincing farmers for intervention.

Farmers' behavior on voluntary cattle culling is significantly varied among different ethnicities. Tamil farmers are less likely to prefer culling policy. Therefore, understanding of farmers' behavior is crucial in implementing the project. Before starting the culling policy, mass vaccination of animals in high risk areas and vulnerable ethnic communities, could be very effective in decreasing the number of infective to very low level, to minimize the cost as well as social turbulence.

The culling-based milk incentive policy could be amalgamated with other zoonotic diseases such as Tuberculosis for cost-effectiveness and high social benefits.

CHAPTER 6

Efficiency of economics-epidemiology integrated control strategy

6.1 Background

Successful implementation of *Brucella* control and eradication programs shows remarkable efforts and costs. In USA, brucellosis eradication involved tremendous culling (test-and-slaughter) of infective cattle (Ebel et al., 2008). Compulsory cattle vaccination for nearly 20 years has been practiced by New Zealand before introduce test and slaughter (Sabirovic, 1997). Mass vaccination of adult animals and heifers followed by replacement stock vaccination combined with test and slaughter was practiced in Azores in Portugal to lead the program for eradication (Martins et al., 2009). Test and slaughter strategy over 30 years (from 1979 -2016) contributed in reducing the prevalence, but not in eradication in Malaysia due to infected animal introduction in to disease free areas from infected areas (Zamri-Saad and Kamarudin, 2016). However, the disease is likely to be well establishing in some countries like India, since the cattle slaughter ban due to socio-religious reasons (Renukaradhya et al., 2002). Simulation modelling with high level of vaccination coverage (over 80%) was shown the possibility of reducing the prevalence rate to near eradication level in settings like India where the test and slaughter is in-applicable (Kang et al., 2014). Therefore, it is obvious that brucellosis control and eradication are time consuming and resource intensive workings that need careful planning with high technical, economic and social concerns.

Brucellosis control looks neglected or given low priority by the Sri Lankan government, thus control appears inefficient (Chapter 2). Presence of information asymmetry of non-reporting of abortions and selling of infective to another farmer contribute to disease spread. However, it was observed that most of the farmers (90%) can be motivated by implementing economic incentive system for voluntary culling (Chapter 5). Still, Tamil farmers are less likely to accept voluntary culling, could be due to their strong religious commitment (Chapter 5). Tamils are around 12 % of total population in Sri Lanka, but they are the majority in the Northern (93.29%) and Eastern (39.29%) provinces of dry zone (DCS, 2012) where the brucellosis is endemic (EB, 2015). Farmers those who are not willing to cull cattle, would continue to sell infected animals to other farmers (Silva et al., 2000; Musallam et al., 2015b) to keep away from the milk penalty of proposed incentives scheme. Condition could lead to movement of infected animals to disease free areas aggravating the situation. Therefore, it was assumed that mass vaccination of high risk areas prior to implement incentives system would be appropriate according to the socio-economic background of the dry zone. It was expected to use simulation modeling to study epidemiology (Rich, 2007) and cost benefit analysis to study the economic efficiency (Carpenter, 2013) of the control strategy.

Economic analysis is a valuable technique in planning and management of animal health control strategies at the national policy level, as well as individual producer level (Morris, 1999). Economics and epidemiology integrated approaches to capture the farmers' behavioral aspects of animal disease control are of critical importance (Rich, 2007). Literature of integrated plans with disease epidemiology and socio-economics are harshly lacked in animal disease control strategies (Rich and Perry, 2011). Such approaches will increase the diversity of information available to policy makers incorporating spatial, dynamic, social and economic aspects, and allowed for a greater fitting to meet the demand of diverse stakeholders (Rich et al., 2006).

Therefore, it was assumed that brucellosis could be efficiently eliminated from Sri Lanka with an 'epidemiology-economics' integrated approach by combining farmers' behavior. To yield more information of integration, several possible alternative scenarios were analyzed and compared. The Objective of this chapter was to study epidemiological feasibility and economic efficiency of control approaches to select the most efficient strategy.

There were two specific objectives in the chapter,

1. to investigate brucellosis epidemiology and transmission of integrated approaches to predict the prevalence.
2. to revel the cost effectiveness of approaches to select the best option.

6.2 Materials and methods

6.2.1 Study area, data and analytical framework

Kalmunai veterinary range recorded the highest brucellosis prevalence of 10.9% (95% CI: 6.0-15.5) in the Chapter 3 analysis. Also, it is located in the dry zone which is endemic for brucellosis (EB, 2015). Therefore, it was selected as a representative area in endemic settings with high risk, needs intensive control. Hence, Kalmunai was the study area for epidemiological and economic analysis for suitable control intervention.

Data on total cattle population, breedable female population and number of farms in Kalmunai veterinary range (LSB, 2015) was used in the analysis. Additionally, epidemiological and economic parameters sourced from previous literature were also used in the analysis. Respective data and parameters are presented in due course.

As per the objectives, this section comprises of two main parts such as

1. Prediction of brucellosis prevalence of alternative control interventions using system dynamics (Figure 6.1).

2. Economic analysis based on predicted prevalence using benefit-cost analysis to reach the best option (Figure 6.1).

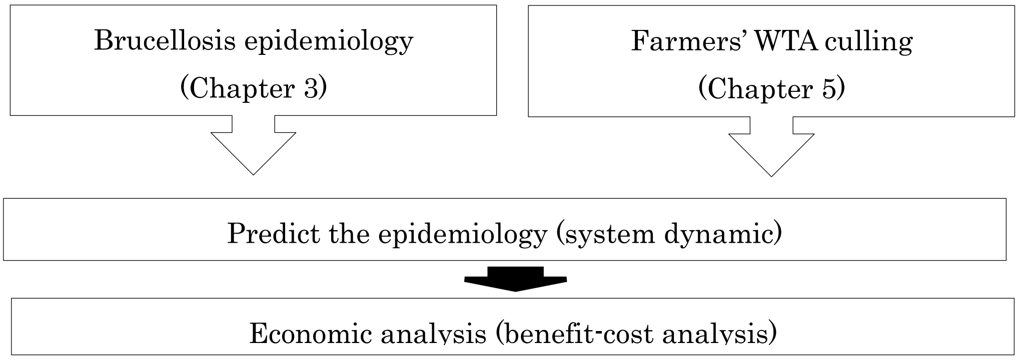


Figure 6.1 Analytical framework of 'epidemiology- economic' analysis

6.2.2. Epidemiological analysis

(1) Epidemiological model in system dynamics

Brucellosis transmission was studied using different epidemiological models such as SEIV (Susceptible- Exposed- Infectious- Environment), considering indirect environmental transmissions (Zhang et al., 2014) and SEIRS (Susceptible- Exposed- Infectious- Recovered-Susceptible) considering recovered compartment (Beauvais et al., 2016) in previous literature. Since brucellosis spread through latent carriers, I selected SEI (Susceptible, Exposed-Infectious) model (McCluskey, 2012) to study the brucellosis transmission in high risk area in Sri Lanka (Figure 6.2). Transmission dynamics were studied using differential equations given in equation 6.1 to 6.4. Additional compartment for vaccinated animals (V) is added to the model as SEIV. Effects of farmers' behavior on cattle culling was incorporated in this model (Figure 6.3); that is noted as a lacking aspect in most of the epidemiological models (Rich and Perry, 2011).

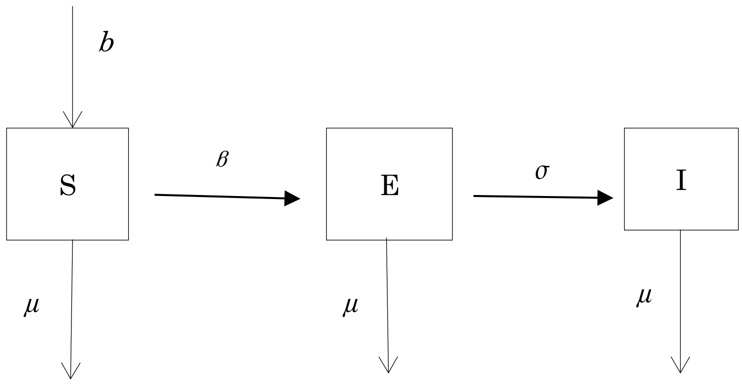


Figure 6.2 Basic Susceptible-Exposed-Infectious (SEI) model structure

Note: S-Susceptible; E-Exposed; I-Infectious; $\beta -$ transmission rate; $\sigma -$ infectious rate; b-birth rate; μ-death rate

Source: McCluskey, 2012

$$dS/dt = b(N) - \beta \frac{SI}{N} - \mu S \quad (6.1)$$

$$dE/dt = \beta \frac{SI}{N} - (\mu + \sigma)E \quad (6.2)$$

$$dI/dt = \sigma E - (\mu)I \quad (6.3)$$

$$N = S+E+I \quad (6.4)$$

Where beta *(β)* is the transmission rate or effective contact rate, the sigma *(σ)* is the rate at which an exposed animal becomes infective; *b* is birth rate and mu *(μ)* the natural death rate (this is unrelated to disease). The total population *(N)* consist of initial susceptible *(S)* which the number of susceptible animal at the beginning of the model run, initial exposed *(E)* which is the number of exposed at the beginning and initial infected *(I)* which is the number of infected individuals at the beginning.

(2) Modelling control interventions with alternative scenarios

Control interventions can change the brucellosis transmission by various ways as depicted in the figure 6.3. Strategy of vaccination *(V)* with a rate of *v* reduces the number of susceptible, thereby reduces the number of animals enter in to *E* compartment (Equation 6.2). Similarly culling of positives (infected) at rate *c* reduces the number of animals in *E* and *I* compartments (Equation 6.2 and 6.3). On that basis, a model was developed using in STELLA professional software (ISEESYSTEMS, n.d).

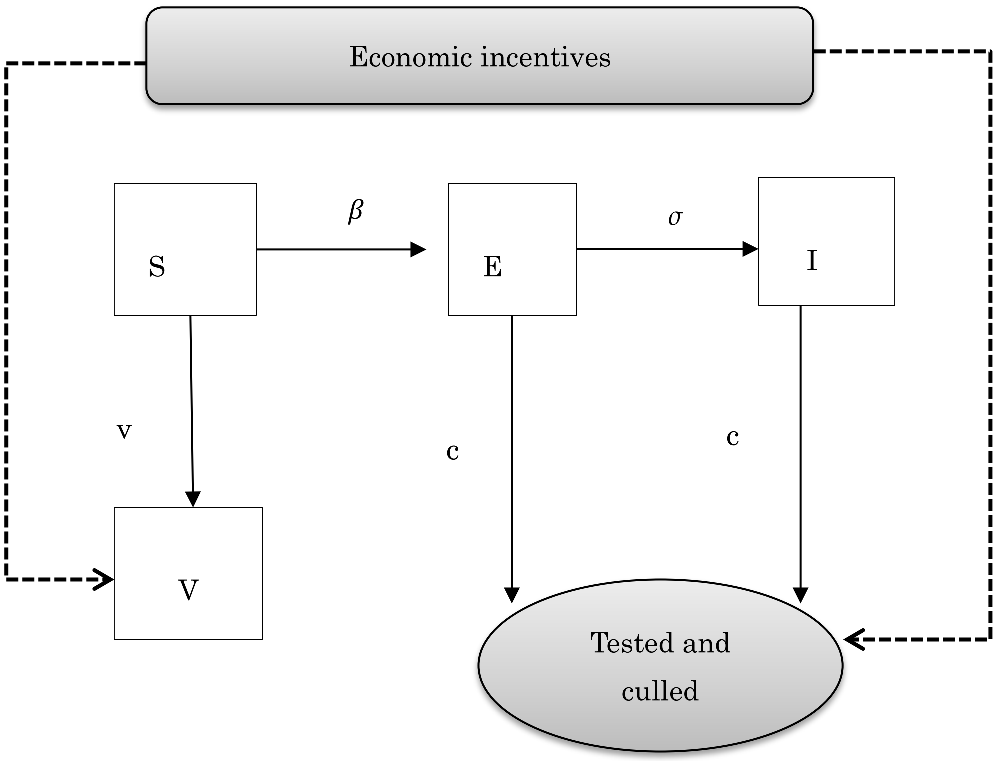


Figure 6.3 Diagrammatic presentations of the brucellosis control interventions (SEIV)

Note: S-Susceptible; E-Exposed; I-Infectious; V – Vaccinated; β – transmission rate ; σ – infectious rate; v - vaccination rate; c -cull rate

Table 6.1 Model structure and assumptions

Category	Description
Population	Dairy cattle in Kalmunai area
Structure	Age structure model (Reason: Brucellosis is an age specific disease of which animals show clinical signs and infectiousness only at calving). It was used three age structures (Beauvais et al., 2016) such as 1. calves (< 9 months) 2. heifers (09 -18 months) when the animals can be exposed but not be infectious 3. adults (above 18 months) when the animals can get late abortions or calving at which they can be infectious
Assumptions	1. Animals will be homogeneously mixed in the area (Reason: Most of the farms practice extensive management and tend to graze in common areas in the rainy season in which calving /late abortions happen as noted by Abegunawrdana and Abeywansa (1995) 2. Replacement animals are only from the same area 3. Population remains constant with no imports and the birth rate is equal to death rate.

Source: McCluskey, 2012; Beauvais et al., 2016

The model parameters are given in the Table 6.2. The detailed model depicting brucellosis transmission from one compartment to the other is given in Appendix 6.1. The differential equations used in the model are shown in the Appendix 6.2.

Table 6.2 Parameters used in epidemiological model

Parameter/ category	Description	Value	Unit	Source
	Prevalence rate (Kalmunai)	6.0-15.5	%	Chapter 3
	Calves (< 9 months)	13	%	LSB,2015
	Heifers (9 -18 months)	24	%	LSB,2015
N_3	Cows (milking and dry)	63	%	LSB,2015
m_1	Maturation rate 1(calf to heifer)	0.75	year	Beauvals et al., 2016
m_2	Maturation rate 2 (calf to cow)	1.5	year	Calculated 1)*
r_{pi}	PI rate (from exposed adults)	0.1	%	Adone and Pasquali, 2013
b	Birth rate	0.2	year	LSB, 2015
μ_1	Death rate (calf)	0.05	year	Jayaweerea et al.,2007
μ_3	Death rate (adults)	0.19	year	Calculated (6 years/animal
β	Transmission rate			Estimated (by model)
σ	Infectious rate (pregnancy rate)	66	%	Abeygunawardana and Abeywansa, 1995
c	Culling rate	< 90	%	CVM (Chapter 5)
v	Vaccination rate	<100	%	CVM (Chapter 5)
v_e	Vaccine efficacy (S-19)	80	%	OIE,2009
θ	Test sensitivity 2) *	80	%	Godfroid et al.,2000; Zhang et al.,2014
	Time step in the model	1	year	Zhang et al.,2014
	Simulation period	100	year	Zhang et al.,2014

Note: * 1) Age at first conception is 18 months.

* 2) Test sensitivity = common sensitivity of MRT (88.5%) and i-ELISA (98.6%).

Brucellosis transmission was considered with eight alternative scenarios. Different 8 scenarios were set combining different levels of vaccination coverage (e.g 70%, 80%) at different time points (e.g 10, 20, 25 years) together with voluntary culling of infected animals (50%). The results of epidemiological analysis of all eight scenarios were used in social benefit-cost analysis to study the economic efficiency. Table 6.3 shows the selected eight scenarios with their description.

Table 6.3 Alternative scenarios used in the analysis

Scenario	Description (testing, vaccination and culling strategy)		
	Testing	Vaccination	Culling
S1	No	No	No
S2	Milk testing	Calf-hood (6- 9 months)	No
S3	Milk testing	Single mass vaccination with annual calf hood (70%) *	No
S4	Milk testing	Single mass vaccination with annual calf-hood (80%) *	No
S5	Milk testing	Single mass vaccination with annual calf hood (80%) *	50 %, after 25th year of vaccination
S6	Milk testing	Single mass vaccination with annual calf hood (80%) *	50 %, after 20th year of vaccination
S7	Milk testing	Single mass vaccination with annual calf hood (80%) *	50 %, after 10th year of vaccination
S8	Milk testing	No	50 % annually

Note: 1. Milk testing will be carried out in every 6 months

2.* Vaccination coverage

3. Cull rate was taken as < 90% which is the accepted cull rate in CVM (2017)

Sources: OIE, 2009; Dorneles et al., 2015; CVM, 2017

6.2.3 Economic analysis

(1) Social cost benefits analysis

The social cost includes externalities, market failures, information failures, and public goods, etc. that are often used as an argument for government intervention (Ramsey et al., 1999). Social benefits are benefits gain by the entire society (e.g private and externality benefits).

Animal disease control and eradication program contains many events and actions result in costs (Horst et al., 1999). Costs that are incurred on routine vaccination, stamping out (culling), emergency vaccination and other supportive measures such as movement control, public awareness, identification and recording system, biosecurity measures (Horst et al., 1999; Tisdell et al., 1999) and laboratory testing, administration are categorized as control expenditure (Bernues et al., 1997).

Animal disease losses are in two categories such as visible or direct (abortions, milk loss, veterinary cost) and invisible or indirect (loss of breeding value, change in populations, market prices, etc.) as discussed by Gilbert and Rushton (2016). It was considered only direct losses in this study.

Reduction of losses (e.g milk and calves) due to control measures are considered as benefits (Gajanayake et al., 2000).

Excel spread-sheet model was used in calculation of costs and benefits (Kivaria, 2006) using parameters given in the Table 6.4 and Equations 6.6 to 6.8.

Table 6.4 Parameters used in the social benefit-cost analysis

Parameter	Value	unit	Source
Abortion rate (first pregnancy)	50	%	Tasiame et al.,2016
Abortion rate (second pregnancy)	25	%	Pillai and Kumaraswamy,1971
Calving rate	66	%	Abeygunawardana and Abeywansa, 1995
Rate of retained placenta	27	%	Tasiame et al., 2016
Reduced milk production / animal	20	%	ILRI, 2012
Lactation length (dry zone)	233	days	Mahadevan, 1955
Milk production per animal (day)	3.1	L	CVM survey, 2017
Veterinary charges per animal	2,500	SLR	Assumption
Milk price per litre (average)	70	SLR	CVM,2017
Farmers compensation	61,620	SLR	CVM, 2017
Heifer price	60,000	SLR	CVM, 2017
Cull animal price (calf)	20,000	SLR	CVM, 2017
Milk testing cost per farm	20.00	SLR	Expert consultation
Vaccine cost / dose (animal)	2.00	SLR	Expert consultation
Vaccine administration cost per animal	2.47	SLR	AR, 2010
Discount rate (interest rate)	10-30	%	CB, 2018

Note: AR- Annual report (DAPH); SLR-Sri Lanka Rupee; CB-Central Bank of Sri Lanka

According to described scenarios (Table 6.4), government has to incur cost on, vaccination, culling compensation, milk testing and administration, etc. (Equation 6.6)

$$E_{control} = E_{vac} + E_{com} + E_{test} + E_{other} \tag{6.6}$$

Where $E_{control}$ is the total control expenditure, E_{vac} , E_{com}, E_{test} and E_{other} are cost incurred separately on vaccination (vaccines and vaccine administration), farmers compensation on culled animal's value, milk testing and other cost (salary, transport, etc..) respectively.

The expected losses consequential to milk loss, calf loss, replacement (breeding) animal loss and veterinary charges were calculated as losses (Equation 6.7).

$$L = L_{heifers} + L_{male\ calves} + L_{milk} + L_{vet} \tag{6.7}$$

Where L is to total loss due to the disease. Total losses were calculated in four category such as $L_{heifers}$, L_{males} , L_{milk} and L_{vet} which are losses on breedable heifers, male calves due to abortions, milk production and veterinary cost due to the disease respectively.

The benefits were calculated using number of animals saved (benefits) due to the intervention using predicated prevalence in each intervention scenario (Equation 6.8).

$$S_{number} = I_{without\ intervention} - I_{with\ intervetion} \tag{6.8}$$

Where S_{number} is the number of animals saved due to intervention. $I_{without\ intervention}$ is the number of animals infected without intervention $I_{with\ intervetion}$ is the number of infected animals with control intervention

Time period to reduce the prevalence to near eradication level varies with the scenario. Therefore, all scenarios were studied for 40-year period and values were discounted using discount rate (Ramsay et al., 1999) of annual 10% which is the average interest rate for last 5 years in Sri Lanka (Equation 6.9).

$$\text{NPV} = \sum_{t=0}^{t} \frac{(B^t) or\ (C^t)}{(1+r)^t} \quad (6.9)$$

Where B^t is the total benefits received at year t, C^t is the total costs incurred at year t and r is the discount rate.

Benefit cost ratio for 8 specified scenarios were computed (Equation 6.10) and compared.

$$\text{B/C} = \frac{B_t}{E_{c_t}} \quad (6.10)$$

Where B_t *is* total benefits (reduction of losses) at year t, and E_{c_t} is total cost due to control expenditure and disease loss at year t.

(2) Brucellosis control trade-off

A trade-off is a situational decision that involves diminishing or decreasing one aspect (quality, quantity or property) in return for gains in other aspect. McInerney et al (1992) discussed the trade-off of the reducing production losses of a disease by increasing investment on control measures at farm level.

The total cost of a disease can be separated into two forms such as (i) the losses due to the disease (L) that are calculated as monetary values of decrease in production outputs because of disease situation, and (ii) the expenditures (E) associated with treatments and preventive interventions that are directly measured as amounts of inputs allocated for prevention, control or eradication as given in the Equation 6.11(McInerney et al, 1992).

$$C = L + E \tag{6.11}$$

The relative importance of the 2 categories generally relates inversely (Figure 6.4). When there is no disease control activity, expenditure cost (E) is zero (0), but losses (e.g. milk loss, abortion, weak calves, etc) are at maximum at A (Figure 6.4). When the government starts a control program with x control expenditure, the losses will be decreased to point B where the losses are still higher (x') to control expenditure of x. If the government decides to increase control cost further (m) where losses (m') are equal to the control expenditure, it gets the disease control trade-off. When the government spends more on control losses may decrease. The highest control cost yield minimum losses leading to eradication (C) of the disease (Figure 6.4).

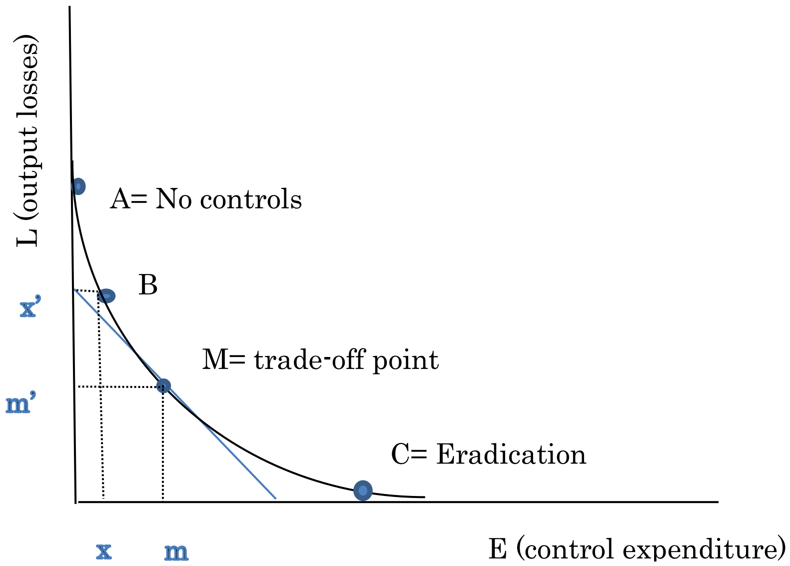


Figure 6.4 Relationship between output losses and control expenditure

Source: McInerney et al., 1992

The trade-off between output losses and intervention expenditure is important in decision making on disease control investment to optimize the value of it. Therefore, it was estimated the expected losses (L) and control expenditure (E) for each scenario and plotted to decide the trade-off point or scenario closer to trade-off, which can be considered as the most efficient strategy of investing money on brucellosis control.

(3) Internal rate of return (IRR) of control investment

Internal rate of return (IRR) is a metric use in capital budgeting to estimate the profitability of potential investments. It can be considered as the rate of growth of a project is expected to generate. In project planning, it often establishes a required rate of return (RRR) to determine the minimum acceptable return (%) for the investment to decide whether it is worthwhile.

Therefore, it was calculated the IRR of investment on brucellosis control to analyze profitability and growth rate of alternative scenarios (eight) using different discount rates such as 10% and 20 % and 30%.

6.3 Results

6.3.1 Brucellosis epidemiology under alternative scenarios

Result revealed that brucellosis transmission rate (β) in the area (e.g Kalmunai) was 0.39. It was observed that infection has introduced in to the area long ago; after that the disease has increasingly spread among cattle population until reach 7.8 % which is within the confidence limit of brucellosis prevalence in Kalmunai (95% CI 6.5-15.5) (Chapter 3). This prevalence was considered as the current (at zero time point) brucellosis prevalence in entire Kalmunai areas (Figure 6.5)

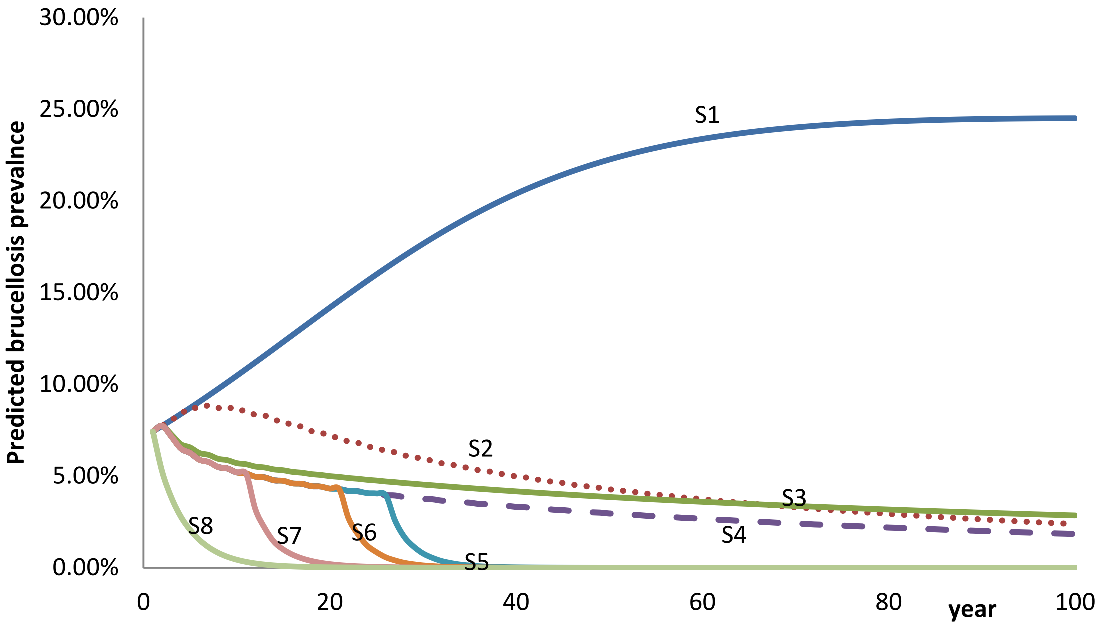


Figure 6.5 Brucellosis transmission and epidemiology in alternative scenarios

Source: Epidemiological model

If there is no control intervention as described in scenario 1 (S1), disease prevalence will be continued to reach 25 % in 80 years approximately (Figure 6.5). If there is an intervention with calf-hood vaccination as described in scenario 2 (S2), disease prevalence will start to decrease after few years reaching < 5% in 40 years (Figure 6.5). Scenario three (S3) and scenario four (S4) with single mass vaccination combining annual calf-hood vaccination at 70% and 80 % respectively, was very effective in decreasing the prevalence below 5 % within 10 years of interventions (Figure 6.5). If there is a culling policy at certain point together with vaccination strategy as described in S5, S6 and S7, prevalence drops near zero after some years depending on the scenario (Figure 6.5). On the other hand, strategy with only test and slaughter of infected animals (50% cull rate) would reduce the prevalence to near zero within 17 years (S8), will be discussed in the next part.

6.3.2. Social benefits and costs of brucellosis control

All selected senarios showed higher benefits than costs (B/C >1) showing the high impact of control. Calfhood- vaccination intervention (S2) which was the strategy with lowest cost, shows B/C ratio of 75.9 (Table 6.5). The most economical senarios were S3 and S4 with B/C of 103.9 and 107.82 respectively although they are not capable of eliminating the disease entirely. Both of them were only vaccination with single mass vaccination followed by annual calfhood vacination with 70 % and 80 % coverage respectively. Despit the high B/C of S3 and S4; they were left with 4.15% and 3.31% disease prevalnce at the end of 40 year period.

Table 6.5 Social benefits, costs, B/C and prevalence in alternative scenarioes

Scenario	Predicted prevalence				
	(%)	Time (years)	(B)	(C)	B/ C
S1	20.31	40	-	-	-
S2	4.97	40	15.18	0.2	75.9
S3	4.15	40	21.82	0.21	103.9
S4	3.31	40	23.72	0.22	107.8
S5	0.02	37	21.82	1.28	19.4
S6	0	33	64.61	2.91	22.2
S7	0	25	75.34	7.81	9.6
S8	0	17	100.66	18.67	5.4

Note: Values are summation of NPV of 40 years (discount rate 10%)

Source: Epidemiological model and cost benefit analysis

Scenarios of S5, S6 and S7 were combination of vaccination and, culling introduction after few years of vaccination shows B/C of 19.29, 22.2 and 9.57 respectively showing a capacity of reducing the prevalence to near zero in different time periods. The results show the effectiveness of integrating vaccination with test and slaughter in reducing losses as well as eliminating the disease entirely (Table 6.5). Only culling of infective (test and slaughter) without vaccination (S8) is the most expensive strategy, but can be free from brucellosis in 17 years with B/C ratio of over 5 (Table 6.5).

Overall B/C analysis results depicts that all scenarios are economical with high B/C ratio (>1) compared to baseline that is without any intervention. S3 and S4 are economical with very high B/C but not efficient enough in eradicating within 40 years. Therefore, it is likely to develop the disease again if control strategy is not continuing. S8 is capable enough of eradicating the disease but need high cost and longer time (17 years). In contrast, S6 and S7 are efficient of eradicating the disease with high B/C in 33 and 25 years respectively.

Brucellosis causes huge losses to the dairy industry in a high-risk area. It was SLR 85.45 million (US$ 0.55 million) in Kalmunai area for 40 years period if control strategy is not initiated as in S1 (Table 6.6). When the control intervention starts losses becomes lesser and lesser depending on the level of control and its expenditure (Table 6.6).

Table 6.6 Control expenditure and output losses in alternative scenarios

Scenario	Costs (C) in SLR mn	Losses (L) in SLR mn
S1	0	85.45
S2	0.2	31.84
S3	0.21	29.77
S4	0.22	22.51
S5	1.28	24.99
S6	2.91	20.76
S7	7.81	12.83
S8	18.67	7.99

Source: Social benefit cost analysis

Out of the brucellosis losses, milk loss was the highest (42%) followed by heifer calf loss (37%) and male calf loss (16%) (Figure 6.6). The losses indicate the externalities and social impacts on milk and beef markets (male calves) as well as impact on dairy industry by losing breeding stock (heifer claves) in the area. However, 95 % the losses were hidden or unseen as milk and abortions, while around 5 % of veterinary cost (treatment for retained placenta, abortions, etc.) which is the visible cost to the farmer (Figure 6.6).

The estimated average loss per animal in the area was estimated at SLR 2,222.74 (US$ 14.34). Therefore, intervention is essential to reduce these social impacts.

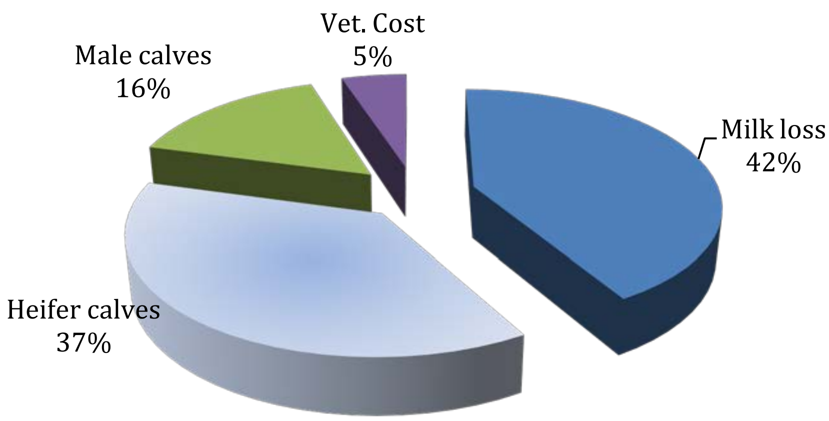


Figure 6.6 Losses due to brucellosis

Source: Social benefit cost analysis

6.3.3. Brucellosis control trade-off

The trade-off analysis showed that point M (Figure 6.7) is the trade-off point where the control expenditure (E) and disease losses (L) become equal. It is approximated to the control cost of SLR 10 million (US$ 0.07 mn) for the studied area (Figure 6.7). The resulted trade off point (M) was closer (higher) to the scenario seven (S 7).

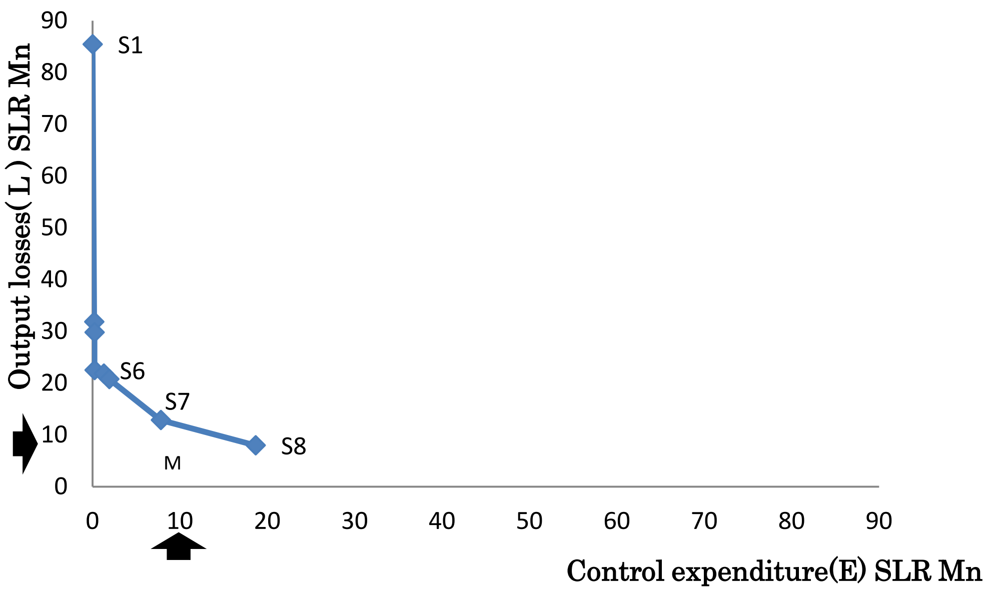


Figure 6.7 Trade-off analysis of brucellosis control

Source: Epidemiological model and social benefit cost analysis

Brucellosis control with S6 which was still below the trade off point and yield very high B/C with 22.2. It is single mass vaccination followed by annual calf-hood vaccination for 20 years, then start compensation and culling of infective at 50 % rate. Importantly, it was capable of reducing the brucellosis prevalence to near zero within 33 years (Table 6.5). The considered culling rate of 50% is far below the 90% that is WTA (chapter 5), the intervention seems socially acceptable. Considering all aspects such as B/C ratio, trade-off point, culling rate of 50 % and the near zero prevalence in 33 years, scenario 6 (S6) can be considered as the most efficient option to control brucellosis in high risk areas in the endemic settings in Sri Lanka.

6.3.4. Costs and returns of brucellosis control investment

Figure 6.8 shows the different cost components of brucellosis control per year. Cost on culling compensation was the highest with 95% of the total, while vaccination is only 1% of the total cost (Figure 6.8). Milk testing through milk collecting network with regular bulk milk testing (twice per year) followed by positive farm testing would incur around 4 % of the total control cost (Figure 6.8).

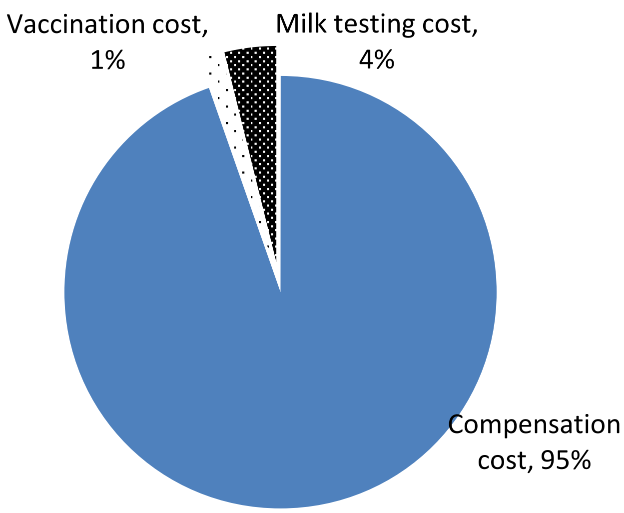


Figure 6.8 Different cost components of brucellosis control and eradication
Source: Social benefit cost analysis

Sensitivity analysis with different discount rates of 10%, 20% and 30% resulted positive net benefits in all cases (Table 6.7). The results indicate that intervention project on brucellosis control would generate return at the rate (IRR) of > 30%. Therefore, it can be ensured that the investment can makes more money than its actual cost.

Table 6.7 Results of sensitivity analysis and IRR of brucellosis control

Scenario	Net benefits with different discount rates		
	10%	20%	30%
S1	-	-	-
S2	14.97	3.55	1.25
S3	21.61	7.16	3.52
S4	23.49	7.91	3.93
S5	23.42	7.88	3.92
S6	62.04	17.72	7.92
S7	68.9	33.5	19.14
S8	81.53	24.8	10.12

Source: Epidemiological model and benefit cost analysis

6.4 Discussion

This study predicted the brucellosis prevalence under different control strategies, and they were analyzed economically to come up with the most efficient strategy under prevailing socio-cultural settings in Sri Lanka. The analysis used SEI (Susceptible-Exposed-Infectious) model that use to study infections by latent carriers (McCluskey, 2012) with different age structures. It was added a vaccination compartment (V) as intervention strategy to form SEIV model. The model was quite similar to the age structure model (SEIR) that used in studying brucellosis co-transmission among cattle and goats in Jordan (Beauvais et al., 2016). But, I did not use recovered and reinfection compartments as did by Beauvais et al (2016), since brucellosis can be spread through chronic carriers (USDA, 1986). A modified SI model with environment compartment (Susceptible-Infected-Environment) considering indirect transmission from environment was used to study brucellosis transmission among ovine by Aïnseba et al (2010) Also, SEI model together with environment compartment considering environmental persistence of *Brucella* bacteria has been used in a study in China (Zhang et al., 2014).

The study revealed that brucellosis control and eradication is feasible and economical with vaccination and, test and slaughter in high risk areas in Sri Lanka. Farmers' social consideration about cattle slaughter was integrated for high efficiency and social feasibility in the model. Single mass vaccination of 80% coverage together with annual calf-hood vaccination (S4) is economical in high risk areas to reduce the existing prevalence to acceptable level. The findings comply with findings in Brazil that vaccination of 90% of the replacement heifers offers the high economic performance (Alves et al., 2015). It was stressed that vaccination is very important in reducing prevalence in livestock and wildlife to prevent human risk worldwide (Olsen, 2013). Study in China recorded that combination of animal vaccination, disinfection of contaminated environment, and elimination of infected animals is necessary for economical control of brucellosis (Li et al., 2017). However, it is not feasible to disinfect of cattle moving environment in the dry zone of Sri Lanka since the extensive management is the practice. The study revealed that vaccination of only calves (4-9 months) was also highly economical with high benefits, indicates the importance of starting vaccination at least with calf population. Kang et al (2014) stated that one-time vaccination at very high coverage could lower the prevalence initially but increase with influx of new susceptible births, indicating the importance of continuation of calf hood vaccination.

Sri Lanka is producing S-19 (smooth) vaccine which is considered to be the vaccine of selection for brucellosis control (Godfroid et al., 2010; Dorneles et al., 2015). Despite the merits of S-19 in brucellosis control, its usage has limited with test and slaughter because of detecting false positives with vaccine antibodies (Dorneles et al., 2015). The limitation has solved by RB-51 (rough vaccine) which can be used with test and slaughter strategy together. However, OIE has recommended vaccinating calves through conjunctiva (eye drop) with S-19 vaccine to minimize the false positives (OIE, 2006), that can be tried in Sri Lanka. But, cost of eye drop vaccination may different from intramuscular vaccination; thus, economic analysis is suitable before making the decision.

Trade-off analysis, benefit cost analysis and epidemiological analysis shows that vaccination is essential in reducing prevalence; then integration of test and slaughter with 50 % cull rate after 20 th year of vaccination (S6) is economical with very high B/C ratio (22.2) as well as high returns (>30%). Complying with these findings, it was recorded that compulsory cattle vaccination for nearly 20 years and introduction of test and slaughter has been practiced in New Zealand for successful brucellosis control (Sabirovic, 1997). Olsen and Stoffregen (2005) also stated that test–and–slaughter policy, surveillance and hygiene measures are crucial besides vaccination in controlling brucellosis. It was found that only culling without vaccination is not economical neither not feasible according to the prevailing socio-economics setup in Sri Lanka. Therefore, brucellosis control using S6 scenario could be practiced in phased out program with two phases, such as control phase with vaccination and eradication phase with test and slaughter with an economic incentive for culling as a motivation. Brucellosis control and eradication strategy in Azores Portugal indicated that prevalence reduction approaching eradication was obtained only on the island of Terceira, where a high level of vaccine coverage was rapidly reached (Martins et al., 2009).

It was observed that some farmers (mostly Tamil) are not likely to accept compensation and culling due to their high religious commitment with cattle (Chapter 5). Given the high preference for preventive vaccination (Chapter 5), they can be motivated for mass vaccination in Tamil areas. However, brucellosis control with 50% culling rate would be socially feasible in these areas. Rivera et al (2002) stated the importance of collaborative participation of farmers and livestock markets in eradicating brucellosis in 10th region de Los Lagos in Chile. Moreover, farmer awareness about importance of veterinary health certificate in purchasing and selling of animals and strict implementation of respective regulations (Animals Act No.29 of 1958; Animal disease Act No.59 of 1992) are essential in minimizing illegal transportation and farmer motivation for acceptance of infective cattle culling.

It was observed that brucellosis causes highest losses to the dairy industry through milk loss and heifer calves. The average current losses per one animal due to milk, heifer calf, male calf and veterinary cost was estimated at US$ 14.34 in the high-risk area in Sri Lanka, that was higher to that in India (US$ 6.8) (Singh et al., 2015) and lower to that in Sudan (US$ 29.8) (Angara et al., 2016). This study confirms the previous findings those say bovine brucellosis control program with vaccination and slaughter was economically efficient in Spain (Bernues et al., 1997) and in Mongolia (Roth et al., 2003) with US$ 8.3 Million control cost with US$ 26.6 Million benefits.

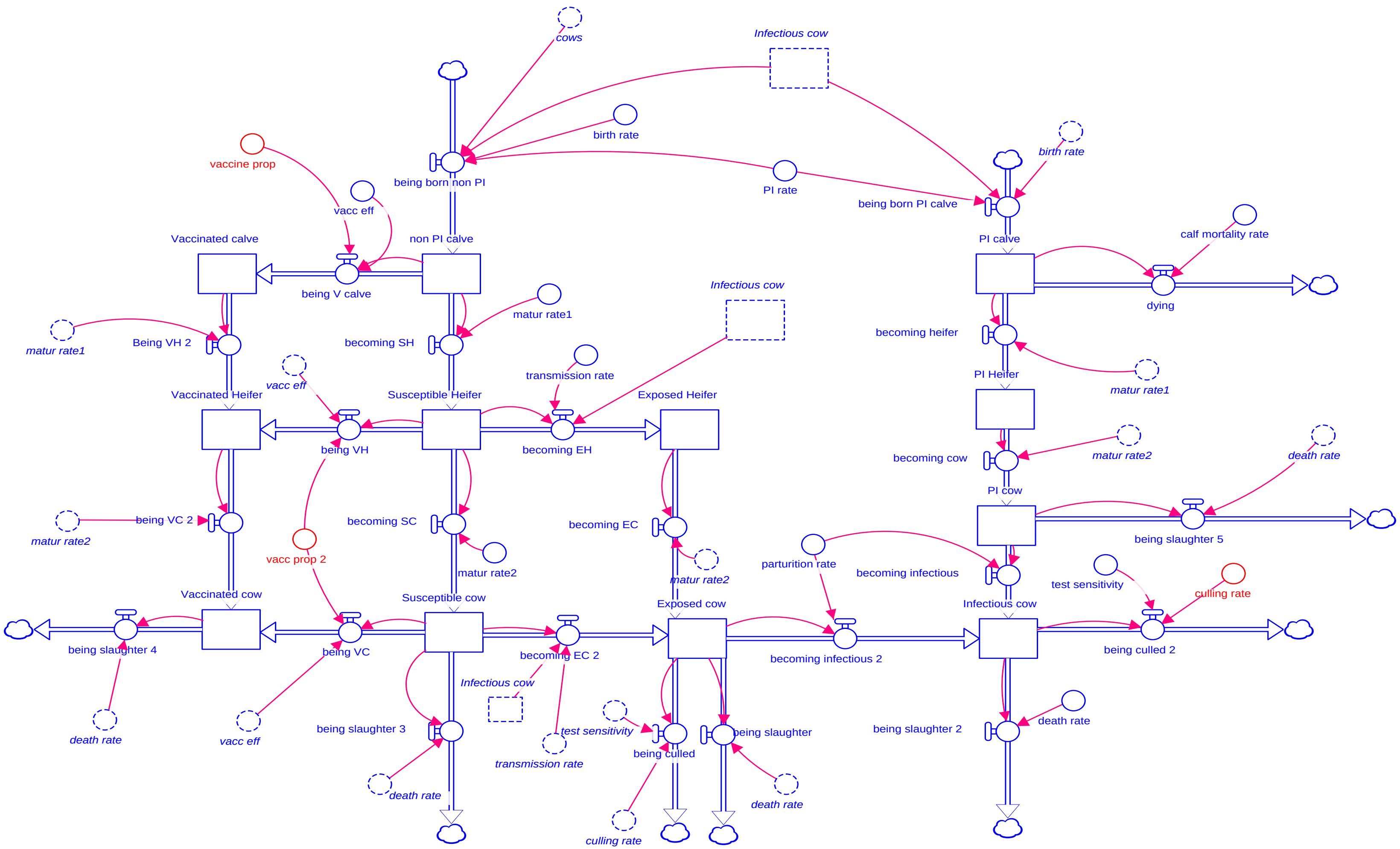
6.5 Conclusion

It can be concluded that brucellosis can be controlled to near zero prevalence successfully in the endemic areas in Sri Lanka with very high economic returns.

Control plan with two phases is suitable economically as well as socially. The first phase is recommended with bulk milk testing followed by single mass vaccination of animals in high risk areas together with annual replacement stock vaccination (calf hood) to reduce the prevalence. In the second phase, voluntary culling policy with 50 % culling rate, incentivized with compensation can be initiated at the 20 th year of vaccination, to be continued for 13 -15 years until the prevalence becomes near zero.

In nut-shell, brucellosis control is epidemiologically feasible and socially attainable investment with high benefits and very high return rate.

Appendix 6.1 System dynamic model (age structure) for brucellosis control



Appendix 6.2 Age structure model equations

Differential equations were used to study the animal movement between compartments

(A) Transmission in calves

Total calf population* =Non-PI (S_1)+ PI_1+ V_1+

$\frac{dS_1}{dt} = b(N_3 - I_3) + b(1 - r_{pi})I_3 - v_p v_e S_1 - m_1 S_1$ ....(1)

$\frac{dV_1}{dt} = v_p v_e S_1 - m_1 V_1$ ....(2)

$\frac{dPI_1}{dt} = br_{pi}I_3 - \mu_1 PI_1 - m_1 PI_1$...(3)

(B) Transmission in heifers

Total heifer population* = S_2+E_2+PI_2+V_2

$\frac{dS_2}{dt} = m_1 S_1 - v_{p\prime} v_e S_2 - \beta S_2 I_3 - m_2 S_2$ ....(4)

$\frac{dPI_2}{dt} = m_1 PI_1 - m_2 PI_2$ ....(5)

$\frac{dE_2}{dt} = \beta S_2 I_3 - m_2 E_2$ ....(6)

$\frac{dV_2}{dt} = m_1 V_1 + v_p v_e S_2 - m_2 V_2$ ....(7)

(C) Transmission in adult cows

Total adult cow population = S_3+E_3+PI_3+V_3

S+E+I+PI+V

$\frac{dS_3}{dt} = m_2 S_2 - v_p v_e S_3 - \beta S_3 I_3 - \mu_3 S_3$ ....(8)

$\frac{dE_3}{dt} = m_2 E_2 + \beta S_3 I_3 - pE_3 - \mu_3 E_3 - c\theta E_3$ ....(9)

$\frac{dI_3}{dt} = p\,(E_3 + PI_3) - \mu_3 I_3 - c\theta I_3$..(10)

$\frac{dPI_2}{dt} = m_2 PI_2 - (p + \mu_3)PI_3$ ....(11)

$\frac{dV_3}{dt} = v_p v_e S_3 + m_2 V_2 - \mu_3 V_3$ ....(12)

Note: S, E, I, V, and PI indicate Susceptible, Exposed, Infectious, and Vaccinated, and persistently infected respectively and N_3 is total cows(S+E+I+V+PI)

The subscripts 1, 2, and 3 indicate calf, heifer and cow respectively.

CHAPTER 7

General discussion

This study provides information for policy makers to lay down a complete brucellosis control and eradication plan for endemic areas in Sri Lanka. It was particularly tried to explore farmers' socio economics and biosecurity behavior in relation to brucellosis epidemiology which has been a severe gap in animal disease control policy recommendations (Rich and Perry, 2011). Also, it provides information about cost-effectiveness of epidemiologically feasible intervention that is noted as a limitation in controlling most of the trans-boundary animal diseases (Otte et al., 2004).

7.1. Farmers' behavior and economic incentives in animal disease control

It was revealed that long establishment of brucellosis in Sri Lanka is due to information asymmetry and poor biosecurity behavior of farmers; it can be successfully addressed by economic incentives as discussed in principal-agent theory. The proposed incentives are compensation for voluntary slaughter (cull) by the government linked to milk payment of premium-penalty mixed system. Hennessy (2007) discussed the role of punishments in strengthening the incentives for disease control. The use of penalties or failure costs in food safety regulations in the presence of imperfect information was discussed by Starbird (2005) using principal-agent theory. In line with findings of chapter 5, indemnity payments for biosecurity improvements for livestock disease control in the presence of moral hazard and adverse selection was discussed by Gramig et al (2009) using principal-agent theory. It was (chapter 5) uncovered that brucellosis causes huge social cost in affecting livelihood of poor people by reducing milk production and replacement stock. Also, it shows possibility of infecting humans as well. Therefore, public incentives are justifiable in brucellosis control as discussed by Wolf (2005) that economic incentives by the public sector can be justified by large social costs. It was studied that farmers will accept the voluntary culling of cattle when the compensation amount is equal/more to farmers' expected utility of keeping infected animals at the farm. Yet, Tamil farmers do not favor for voluntary culling even with compensation because of their strong religious beliefs. The government must try to increase farmers' psychological expectations (utility) [4] (Caplin and Leahy, 2001), thereby motivating for culling acceptance apart from compensations. The government can take necessary measurements such as maintaining animal welfare in slaughtering, prevent dead animals enter in to beef market to increase the psychological utility of non-willing farmers.

Controlling farmers' behavior using incentives was discussed (chapter 5) with the help of theory of planned behavior by Gilbert and Rushton (2016). Theory of planned behavior discuss the possibility of changing human behavior with information, knowledge, education, income, etc. (Ajzen, 1991). It was expected to create extensive social awareness and attitudinal change through incentives linked to milk premium-penalty payments through formal milk collecting network; thereby changing farmers' behavior towards brucellosis control, through proposed intervention. The same approach is discussed by another researcher that farmers' cognitive thinking and attitudes can change their bio-security behavior (Mankad, 2016).

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[4] Expected utility theory is further extended to situations in which agents experience feelings of anticipation prior to the resolution of uncertainty to form psychological expected utility theory.

In practice, UK is currently implementing a compensation policy on bovine brucellosis, bovine tuberculosis and bovine leucosis to stop re-emergence of those diseases in the country (DEFRA, 2016).

7.2 Application of research findings in developing countries

The study critically examined the factor "farmer" in animal disease transmission and its control decisions. Attempts to understand farmers' behavior on bio-security measures are still at infant stage in most of the developing countries. Most of the available literature related to human behavior in animal diseases is quite 'recent' and 'confined to developed countries' like UK (Heffernan et al., 2008; Garforth et al., 2013; Brennan et al., 2016), France (Mankad, 2016), Australia (Wright et al., 2016) and USA (Gramig et al., 2009), indicating importance of research focus on this aspect in developing countries. Given that most developing countries are diversified in ethno-cultural settings which could be related to different animal farming practices, that aspect is enormously pertinent.

The study explored that poor most people are highly vulnerable for cattle brucellosis as noted by ILRI (2012) that brucellosis incidence and global poverty maps are overlapped. Animals of poor people could be highly susceptible to diseases due to high cost and/ or absence of control sector (Seimens, 2014), poor hygienic practices (ILRI, 2012) or marginalization by most of the disease prevention projects (Heffernan, 2004); thus likely to have low income and impact on livelihood (Perry and Grace, 2009). It was noted that brucellosis control would secure the animal assets (e.g heifers), improve marketing opportunities for milk and meat animals, and thereby alleviate poverty.

Therefore, brucellosis control would have societal importance not only in livelihood development but also in human health benefits (Zinsstag et al., 2005) in low income areas.

The chapter 3 revealed that Muslim farmer community is highly vulnerable for brucellosis could be due to their traditional association with animals and, lifestyle in which extended families and nearby relatives are common, thus vulnerable to have high contacts with neighborhood animals. The findings are in line with previous findings that say the traditional lifestyle, beliefs and certain farming environments favor the animal to human disease transmission (Smits, 2013). Similarly, Dean et al (2013) noted that certain ethnic groups with high animal contacts (e.g Fulani)[5] showed high susceptibility for brucellosis. Therefore, farmers' socio-economic factors can be used to identify high risk areas and ethnicities in controlling animal diseases, particularly zoonotic.

Knowledge and attitude gaps were found to be one of the main factors affecting brucellosis spread in Sri Lanka as noted in most of the other developing countries such as Tanzania, Jordan, India and Pakistan (Swai et al., 2010; Musallam et al., 2015b; Govindaraj et al., 2016; Arif et al., 2017). Also, existing veterinary extension service was found to be not effective in disseminating animal disease knowledge and information particularly about 'hidden diseases' such as brucellosis. Therefore, farmer training, risk communication and veterinary extension could be tried with another strategy such as community-based approach that could be cost-effective in disease control in developing countries.

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[5] Fulani ethnicity is a pastoralist community who represent the most dispersed ethnic group in West Africa. The majority of cattle herds in northern Togo (in West Africa) are managed by Fulani people.

Milk payments for disease free milk is not common in developing countries, regardless of payments for low bacterial counts (Botaro et al., 2013). This study provides stimulation of disease control through milk payments particularly for milk borne diseases such as brucellosis, which could be a cost-effective extension strategy too. Also, milk collecting centers can be used as focal points for community-based animal health extension activities that would be efficient and effective in resource poor settings.

7.3 Study limitations and policy implications in Sri Lanka

This study is confined to brucellosis control in a high-risk area in the dry zone of Sri Lanka. Low country wet zone and mid country were not included in the analysis due to non-availability of epidemiological data, which is a limitation of this study. However, findings can be generalized to entire dry zone which is the endemic area for brucellosis; thus findings would significantly contribute in national brucellosis control strategy in Sri Lanka.

The estimated annual milk production increase due to brucellosis control is around 4% of the total annual milk collection in a high-risk area. Therefore, brucellosis control would be synergistic with the government policy of increasing local milk production to be self-sufficient in milk to curtail the huge foreign exchange.

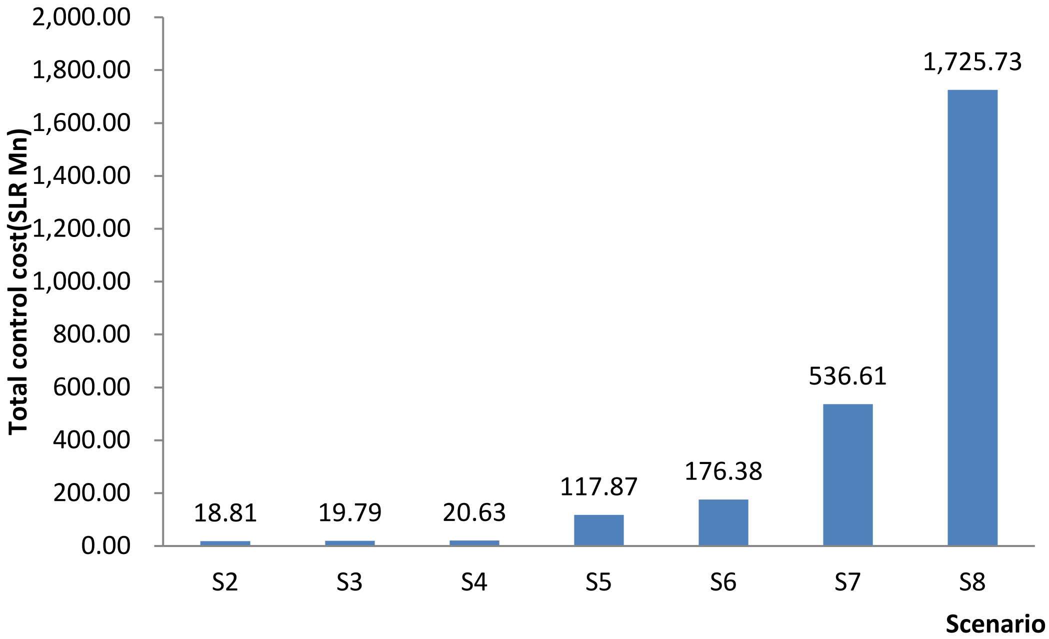

Figure 7.1 Estimated total brucellosis control cost for high risk areas (40 years)

Source: Calculation

The Figure 7.1 shows that the estimated total control cost for high risk areas (calculation based on NPV benefits and costs with an assumption of around 70% of the dry zone cattle and buffalo population is at high risk for brucellosis) varied from SLR 18.81 million for scenario 2 (S2) to SLR 1725 million for scenario 8 (S8). The total cost for the scenario 6 which was discussed as the best strategy, requires SLR 176.38 million (net present value). Also, annual fund requirement for S6 may vary from SLR 0.56 million to SLR 67.65 million depending on the activity e.g vaccination or vaccination and culling. The maximum cost is at 20^{th} -25^{th} year because of introduction of culling of infected animals (Figure 7.2).

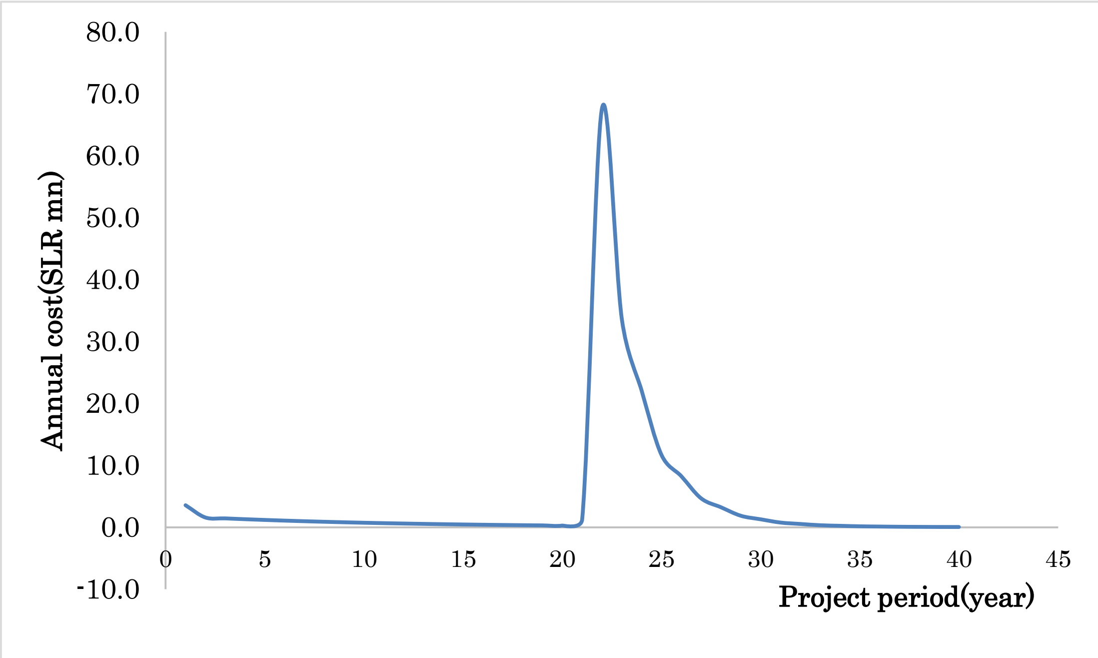

Figure 7.2 Change of estimated annual brucellosis control cost for high risk areas under scenario 6 (S6)

Source: Calculation

The livestock master plan in Sri Lanka says that financial allocation for brucellosis control and eradication from 2011-2016 ranged from SLR 20-SLR 60 million with a total of SLR 200 million (MLRCD, 2011). Additionally, government expenditure on annual milk imports of SLR 30 billion (LSB, 2015) is expected to decrease with brucellosis control intervention; therefore, it can be utilized for control interventions. Hence, it seems that funding would not be a limitation when there is a technically sound and economically feasible control plan. On this account, information generated from this economics-epidemiology integrated analysis can be used to prepare a holistic brucellosis control policy that could utilize available funds effectively and efficiently.

CHAPTER 8

Conclusion

The aim of this study was to make policy recommendations for cost effective bovine brucellosis control strategy for endemic areas in Sri Lanka. This study critically analyzed farmers' socio economics and biosecurity behavior in relation to brucellosis spread, and tried to fill the literature gap of human behavior in animal disease control policy framework.

It was revealed that certain ethnicities (e.g Muslims), poor farmers and free grazing farming behavior are significantly related to cattle brucellosis. The findings confirm the first hypothesis that cattle brucellosis epidemiology and farmers' socio-economic behavior is related. It was observed that farmers' knowledge and attitudes with regard to brucellosis was extremely poor and lead to risky farming behavior such as selling of infected animals and non-separating of infective; that may consequence information asymmetry result in high brucellosis prevalence in the area. These findings confirm my second hypothesis that poor knowledge, attitudes and practices causes brucellosis in the area.

Economic incentives linked to milk premium-penalty payment system can motivate farmers to accept voluntary cattle culling in the presence of information asymmetry that is due to poor knowledge and socio-religious forbids for cattle slaughter according to the prevailing conditions. These findings prove the third hypothesis that farmers' behavior can be changed towards high biosecurity practices with economic incentives in the presence of information asymmetry. Culled cows can be compensated with a compensation or indemnity payment with 68.8 % of the market value of a cow, which would yield higher utility to their expected utility of keeping the infected animal. However, Tamil farmers (mainly Hindus) do less likely to accept cattle culling, which could be due to their strong religious commitment with cattle. Therefore, government must decide in securing animal welfare in slaughtering and preventing culled carcasses enter in to the beef market to motivate such farmers psychologically.

Dynamic model integrating farmers' behavior indicates that single mass vaccination followed by annual calf hood vaccination would be epidemiologically feasible to reduce the prevalence in high risk areas. Test and slaughter of positives with 50 % cull rate would be economical and socially acceptable since it is far below the farmers' acceptance rate of 90%. The eradication level could be achieved around 33 years of initiation of the control intervention with high benefits and very high returns; thus, it would be profitable to invest on brucellosis control. These findings confirm the fourth hypothesis that integration of epidemiology and farmers' social behavior is cost-effective in controlling brucellosis.

Farmer awareness, training and education should be the prime responsibility of veterinary authorities throughout the control program to get farmers' cooperation in controlling animal brucellosis as well as minimize chances for human brucellosis. Brucellosis extension via milk payments through milk collecting network would be an efficient extension strategy too.

In conclusion, brucellosis control towards eradication is feasible and economical with economics-epidemiology integrated strategy. Farmers' knowledge and social behavior is crucial in animal diseases; therefore, it should be essentially considered in disease control policy planning. Compensations through milk payments are effective in changing farmers' behavior towards brucellosis control.

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要約

ブルセラ病は，世界で経済的に深刻な人獣共通感染症の一つと考えられている．それは，主に貧困層や限定的集団に影響を与えることに鑑み，「顧みられない人獣共通感染症」ともいわれている．ブルセラ病は，感染性疾患であり，主に牛の流産を伴う繁殖関連の問題を引き起こす．また，ヒトにインフルエンザのような症状を引き起こす．したがって，低所得国の動物やヒトに及ぼす経済的影響は多大なものになる．スリランカでは，ブルセラ病は，特にドライ・ゾーンの農村地域において 40 年間も見られている，いわゆる風土病である．包括的なサーベイランス，高いワクチン接種率，感染家畜の淘汰方針の欠如により，数十年にわたって国内に蔓延しているのである．さらに，農家にとって牛は，経済的，社会的，文化的に重要であるが，人口の 90%を占める仏教徒とヒンズー教徒にとって感染牛の淘汰は望ましいことではない．これにより，農家は淘汰を避けるために，感染した家畜を他の農家に販売する傾向にあり，感染が地域をまたいで広がる可能性が高い．たとえ，感染家畜の移動を家畜衛生規制（1958 年 : 家畜法第 29 号）によって予防できたとしても，様々な社会文化的背景や，知識と情報の乖離が違法な移送を可能にしてしまうのである．以上により，スリランカにおけるブルセラ病の長期的な動向には，社会経済学的研究や農家行動に基づく適正な技術計画が重要であると推察される．

既往研究では，家畜疾病管理とコントロールは社会的課題であると論じている．なぜなら，養牛は農家の社会経済的要因と密接に関係しており，それゆえに家畜への感染の暴露は，民族性や文化といった社会的要因によって潜在的に影響を受けるからである．また，農家，政府，消費者による知識の乖離や不確実性，情報に関連した非対称的なアクセスは，最適な疾病コントロールの政策的含意にとって課題となっている．以上を背景とした農家行動は，一般的に疾病への初期の対応であるため，それを理解することが予防およびコントロールに極めて重要である．これは，ブルセラ病においても同様である．ブルセラ病は，これまで，微生物学，疫学，サーベイランステクニック，ヒト-家畜-野生動物の間の統合的研究，伝播モデル，ワクチン開発，経済的影響など，さまざまな分野の観点から広範に研究されてきた．しかし，その伝播や疾病コントロールに関する農家の社会経済的行動については，限られた議論しかなされていない．その中では，適切な疾病コントロール戦略には，特に農家の社会文化的行動と疫学研究を統合すべきであることが強調されているが，学術的アプローチはまだ十分とはいえない．そこで，本論文の主目的は，ブルセラ病のバイオセキュリティに作用する農家行動を分析し，スリランカにおける包括的なブルセラ病コントロール戦略を解明することとした。

具体的には，１）ブルセラ病の疫学と農家の社会経済的要因との関連に関する研究，２）

ブルセラ病の知識・態度・行動の乖離と知識共有に影響を与える要因の研究，３）スリランカにおけるブルセラ病撲滅のための感染牛淘汰政策を基にした，生乳インセンティブに対する農家行動に関する研究，4）経済的実現可能性とコントロールアプローチの効率性に関する研究，の４つの課題から主目的に接近する．

ブルセラ病の罹患率が高く，多民族多文化地域であることから，ドライ・ゾーンの Ampara 地区が研究域として選択された．この中で，スリランカにおける主要な３つの民族であるムスリム，タミル，シンハラが居住している獣医支局（VS）を選出した（Kalmunai，Navithanveli，Mahaoya）．当該 VS において，155 件の牛農家を対象に横断面的調査が実施された．以上の対象農家から，2016 年に，疾病の罹患率を調べるために計 1,153 の血液サンプルを採取した．さらに，前２つの課題に対するデータとして，農家の社会経済的特性である養牛方法やブルセラ病に関する知識を，構造的調査法を用いて収集した．2017 年には，ブルセラに感染した家畜を淘汰する誘因として，生乳支払システムに関連した経済的インセンティブを想定し，その可能性を検討するために仮想評価法を用いた調査を実施した．当該調査においては，比較地域としてスリランカ中央部の Kandy 地区が選択されている．

１つ目の課題では，疫学的方法を用いて血液試料を分析し，牛のブルセラ病の有無（陽性/陰性）と社会的特性との関係を，プロビットモデルを用いて分析した．結果は，粗放的な飼養（$p<0.01$）や外部から家畜を導入している場合（$p<0.05$），疾病の罹患率に有意に関連していることが明らかとなった．さらに，貧困と民族性は，ブルセラ病の重要な決定要因である（$p<0.05$）．

２つ目の課題では，ブルセラ病に関する知識・態度・行動（KAP）を，記述統計を用いて分析した．特に知識に関しては，ブルセラ病と口蹄疫に関する質問によって知識指標を作成し，それらを t 検定で比較した．さらに，社会経済的要因に関連したブルセラ病の知識を，トービットモデルによって明らかにした．ブルセラ病に関する農家の知識・態度・行動は，非常に貧弱なものであった．ブルセラ病が牛の流産を引き起こすことを，8.5%の農家だけが認識していた．また，ブルセラ病が伝播することを知っていたのは 10%の農家だけであり，96%はそれが人獣共通感染症であることを知らなかった．家畜を外部から導入する際の獣医証明書には，約 80%の農家が中立的な態度を示し，感染家畜の分離や健康な家畜の流産などの群内伝播に関するリスク行動は，それぞれ 47.9%と 20.6%の農家でみられた．

３つ目の課題では，ブルセラに感染した牛の淘汰政策に対する受入補償額（WTA）を導き出すために，仮想評価法（CVM）を用いた．CVM の仮説シナリオとして，生乳集荷ネットワークを通じたブルセラ病検査を基にして，生乳ペナルティ-プレミアムの支払に反映することを提案した．具体的には，生乳検査によって発見された感染牛を自主淘汰するために，指定された補助金を受け入れる意志があるかどうか尋ねた．ただし，農家が自主淘汰を受け入れない場合，Rs.2/L の生乳ペナルティがかかるとしている．ブルセラ病のコントロールにおける農家行動に変化をもたらすよう設定された経済的インセンティブに関するこの政策は，プリンシパル・エージェント（PA）理論を用いて議論された．生乳検査という新し

い介入によって感染家畜に関する情報は入手が容易になるために，情報の非対称性が解消される．したがって，約 90%の農家が淘汰政策を受け入れる意志を示した．また，補助金が感染家畜の期待効用（牛の市場価値の 68.8%）と同等かそれ以上の場合，農家は自主淘汰を受け入れることが明らかとなった．上述した情報に基づいて，スリランカにおけるブルセラ病コントロールの新たな介入として，情報の非対称性を低減させ，農家の社会経済的行動を変えることが必要だと示唆された．

４つ目の課題では，上記３つの分析の結果を使用し，ドライ・ゾーンにおけるブルセラの代替的コントロール戦略を設定した．スリランカにとって最も望ましいあり方を検討するために，農家行動を統合した疫学経済シミュレーションモデルによって，各戦略の疫学動向，費用対効果を分析した．ブルセラ病のコントロールへの投資に関しては，第一段階で実施するワクチンの集団接種を段階的に廃止し，20 年後には第二段階である感染淘汰を年間 50%に引き上げることで，利益率 30%の高い B/C 比（>22）が達成されることが示された．また，農家のトレーニングと知識向上戦略とともに実施することによって，B/C 比はさらに高まると推察される．

以上より,ブルセラ病のコントロールと撲滅は，農家の社会的行動を十分に考慮すれば，疫学的には可能であり，経済的にも利益のある投資となることが明らかとなった．家畜疾病の伝播とそのコントロールに作用する「農家」または「農家行動」の要因は重要であり，家畜疾病コントロール政策の策定において十分に検討されなければならない．

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Dedication

I dedicate this work

To my husband - Dr. Hemal Kothalawala

For your immense support, encouragement and assistance for my studies and, love, endure, understanding and accepting all the hardships in my absence for three years.

To my son - Isuru Sachintha Kothalawala

For your love, understanding, patience, and absorbing all the difficulties in my absence.

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