An economic and epidemiological analysis of Foot and Mouth Disease (FMD) and its control in Sri Lanka

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

Abbreviation		Meaning
AE	-	Allocative Efficiency
AGA	-	Assistant Government Agent
AH&E	-	Animal Health and Extension
AI	-	Artificial Insemination
ARU	-	Attack Rate in the Unvaccinated Population
ARV	-	Attack Rate in the Vaccinated Population
BCA	-	Benefit Cost Analysis
BCR	-	Benefit Cost Ratio
CGE	-	Computable General Equilibrium
CSF	-	Classical Swine Fever
DAPH	-	Department of Animal Production and Health
DEA	-	Data Envelopment Analysis
DQ	-	Direct Questioning
FAO	-	Food and Agriculture Organization
FMD	-	Foot and Mouth Disease
FMDV	-	Foot and Mouth Disease Virus
GDP	-	Gross Domestic Product
MCLS	-	Mixed Crop Livestock System
MDG	-	Millennium Development Goal
MFC	-	Marginal Factor Cost
MVP	-	Marginal Value Product
MLDEI	-	Ministry of Livestock Development and Estate Infrastructure
MLDRI	-	Ministry of Livestock Development and Rural Infrastructure
MLRCD	-	Ministry of Livestock and Rural Community Development
NPV	-	Net Present Value
OIE	-	World Animal Health Organization
OLS	-	Ordinary Least Squares
ICT	-	Item Count Technique
ILRI	-	International Livestock Research Institute
LDI	-	Livestock Development Instructor
LDT	-	Livestock development Technicians
NLDB	-	National Livestock Development Board
PCP	-	Progressive Control Pathway
SIER	-	Susceptible-Exposed-Infected-Recovered
SPF	-	Stochastic Production Frontier
TAD	-	Transboundary Animal Disease
TE	-	Technical Efficiency
VE	-	Vaccine Efficacy
VIC	-	Veterinary Investigation Centers
VIF	-	Variance Inflation Factor
VIO	-	Veterinary Investigation Officers
VRI	-	Veterinary Research Institute

CHAPTER 1

Introduction

1.1 Background and challenges

The global livestock sector is growing faster than any other agricultural sub-sector and it constitutes more than 33 % to agricultural gross domestic product (GDP) in developing countries (World Bank, 2009). Majority (about 1.3 billion people) of the world's poorest people live in developing countries depend, directly or indirectly, on livestock for their livelihoods (World Bank, 2008 and FAO, 2009). These estimates highlight the important contribution of livestock to poverty eradication and sustainable development, especially in the developing communities.

Developing countries are undergoing a 'Livestock Revolution' characterized by increasing consumer demand for livestock and their products due to population growth, rising income, and urbanization (Delgao et al., 1999),which is likely to continue well into the future. This growth of the livestock sector creates both enormous opportunities and challenges. Further, it represents a potential pathway out of poverty for many smallholders in the developing world (Perry et al., 2002; Perry et al., 2003b; Perry et al., 2007; Perry and Grace, 2009).

Livestock play diverse roles in Sri Lankan agriculture, just like any other South Asian country. Mainly, they provide a crucial source of high quality protein by producing milk, eggs, and meat. Additionally, cattle and buffalo are a main source of renewable and low cost draft power for transport and a variety of agricultural operations and transport. Also, livestock serve as a 'living bank' for majority of smallholders, cushioning the risk of frequent crop failures (Perera and Jayasuriya, 2008). The total number of farmers involved in livestock production is estimated at 700,000, and between 30-60 % of gross farm income is generated from livestock activities (MLDEI, 1996).

Dairy is the single most important subsector in livestock in Sri Lanka and dairy farming has been a practice from pre historic era among the rural poor. This is mainly because of the impact it can make on rural economy. At the present moment, it is one of the major employments for poor people in rural areas (DAPH, 2012). Further, Milk is a 'cash crop' for smallholders, converting low value agricultural byproducts, crop residues, and cheap family labor into a value added market commodity (Taneja and Birthal, 2005). However, in the current global context, the dairy industry in Sri Lanka is far below expectations; the local production was only 33 % (2009) of the national demand. While imported milk powder has filled the gap between demand and domestic production (DAPH, 2010). Nevertheless, imports of milk primarily, milk powder continue to be significant feature of the Sri Lankan economy, if there is sufficient effort is not geared for the development of the sector. For these reasons government gives high priority to reach self-sufficiency in milk production. While recognizing the importance of active participation of the private sector in developing the dairy industry, the government has decided to play a leading role at the beginning and set the stage of rapid development (MLDRI, 1995).

The dairy sub-sector has been stagnant over the past two decades due to various factors such as uncertainty, lack of reputation, severe land fragmentation, industrialization, attitudes, and economic and political factors (Livestock statistics, 2004). In addition, lack of profitability is one of the main constraints in the milk production sector. Further, absence of proper technology, poor genetic merit of indigenous cattle and the unsatisfactory extension and the other supporting services, and the unavailability of proper and low cost input delivery system worsened the situation (Hitihamu et al., 2007).

Demographic and socio-economic factors have significant impact on decision-making and dairy management practices. These factors will therefore affect the productivity and profitability of dairy herds and without having a good understanding of these factors it would very difficult to be involved in dairy business. There are main three agro-ecological zones in Sri Lanka. Resource availability, the management of the dairy farming system, and constraints and opportunities are significantly differs on the climatic zones. Additionally, each dairy farm and agro-climatic zone has its own unique ability to make decisions to produce a certain output given a set of inputs and technology. Thus, understanding technical efficiency, its measurement and determining factors, is of crucial importance in dairy production economics. However, no study to date has examined the technical efficiency of dairy farms in different agro-climatic zones in Sri Lanka. Studying of the factors that determine milk production and farm efficiency in each agro-climatic zone are important from a farmer's, as well as, from a policy point of view. Policy makers can use this knowledge to identify and target public interventions to improve farm productivity and income, while farmers can use this information to improve their performance, which ultimately leads towards self-sufficiency in milk production.

Foot and mouth disease (FMD) is endemic in almost all developing countries and it is clearly the biggest threat to livestock industries, with major economic impacts on trade and food security due to ease of spread between countries compromising international trade in livestock and their products (Rweyemamu et al., 2008). FMD also has major social impacts in developing countries, particularly in southeastern Asia, with impacts at both village and national levels (Khounsy et al., 2008). At the village level, FMD has negative impacts by significantly reducing the value of large ruminants for sale, loss of draft power, and reduction of weight with lower local consumption of meat and significantly as a reduction in income security as large ruminants are a major store of wealth.

FMD has an ancient history in Sri Lanka and it is endemic in the country particularly in the eastern part of Northern and Eastern province. Therefore, FMD has been ranked as the highest priority disease for control and eradication. Nearly, 45 % of health management and disease control budget, 860 million rupees allocated for FMD control and eradication strategies (MLRCD, 2011). The economist views budgeting as a matter of allocating resources in terms of opportunity cost where allocating resources to one consumer takes resources away from another consumer (Robert et al, 2004). Therefore, management of highly contagious infections such as FMD is a complex and dynamic decision problem (Morris et al., 2002; Speers et al., 2004). Policy makers face tradeoffs between effectiveness and cost of different control strategies (Barnett et al., 2002; Morris et al., 2002; Bates et al., 2003a).

Previous work estimated the direct economic impact of an outbreak of FMD at the farm level in early 2009 at Polonnaruwa districts in the dry zone (FMD endemic zone) and in the wet zone at Kandy District (FMD non-endemic zone) during the same year (DAPH, 2012). However, this estimate excluded the cost of different FMD control options in the endemic and non-endemic zones. Thus, the current study was to estimate the cost-effectiveness of FMD control strategies based on integrated epidemiological-economic model.

Based on the above issues, the main purpose of this thesis is to economically and epidemiologically analyze the constraints and challenges of dairy farming, impact of FMD outbreak and cost-effectiveness of control policies as well as farmers' attitude towards FMD control, particularly early detection and reporting.

The specific objectives are:

1) To identify the major socio-economic factors affecting on milk production in three different agro-climatic zones.
2) To examine the resource-use efficiency in dairy productions systems in different agro-climatic zones
3) To evaluate the economic viability of current preventive vaccination program (or economic return for the government budget)
4) To analyze the farmers' knowledge level and behaviour towards FMD outbreak and its control
5) To suggest policy measure to improve the dairy production in Sri Lanka

1.2 Review of related literature and present challenges

1.2.1 Characteristics and constraints to livestock production in developing countries

South Asia's economy is one of the fastest growing (5-6 %) in the world, yet one thirds (571 million) of the world's poor live in South Asia (World Bank, 2010). Livestock play a significant role in rural livelihoods and the economies of developing countries, particularly in South Asian countries. It provides food security, income, employment and many other contributions to rural livelihood development. Moreover, livestock provides major additional contribution to agriculture through manure, draft power, fuel as a fertilizer, animal origin products such as milk, meat, eggs while milk provide daily cash income and much required nutrition to rural communities. But, Livestock production in the developing countries is faced with a number of constraints, which on the long run results in low productivity and low profitability.

The table below compares the characteristics of livestock production systems in developing and developed countries.

Table 1.1 Comparison of livestock systems in developing and developed countries

	Developing country	**Developed country**
Scale	Small/smallholder	large
Enterprise form	diverse	specialised
Objective	multiple	profits
Market destination	local, regional	global
Market form	informal	formal

Source: Baker, 2012

Smallholder livestock keepers represent 20 % of the world population and smallholder livestock farming is the dominant activity in most of developing countries, like Sri Lanka. Small-scale Mixed Crop Livestock System (MCLS), in which crop and livestock are integrated, is the common and the most dominant form of animal husbandry. MCLS covers around 2.5 billion hectares of all land worldwide. It produces 90 % of world milk production, all of buffalo meat, and nearly 70 % of small ruminant meat (Parthasarathy et al., year). Nevertheless, in developed countries, the livestock farms are large scale and highly specialized. Further, not like in developed countries, the livestock farming is not only source of income, yet also provides additional contribution to agriculture such as draft power and manure.

Generally, in developing countries, most livestock produced are marketed through informal channels to local consumers and processors. On the other hand, in the developed countries livestock products usually flow through formal market.

The informal market system is characterized by high variability in milk price, lack of bargaining power (Perera and Jayasuriya, 2008) low quality (Uddin et al., 2011), not adequately market oriented, and long marketing chains (Alemayehu, 2011). At the same time, the quality of the livestock product from the informal processing sector pose a serious public health concern. For example, majority of the milk produced and sold by the informal sector is raw (unpasteurized), which does not meet the minimum statutory requirements, and the milking practices and milk handling also do not comply with best practice compliance welfare standards (Agenbag, 2008).

Dairy sector is the most important of all livestock sub sectors. This is mainly because of the impact it can make on the rural economy, especially among the poorest people. There are numerous studies of livestock production and productivity from both developed and developing countries.

In India, Patil et al. (2009) the constraints faced by the dairy producers in Nagpur district. Low milk production from the local breeds (72. 4 %), shortage of green fodder (45.3 %), and high cost of concentrates (56.4 %) were constraints limiting dairy production in the study area. Moreover, as regards technical constraints, majority of the respondents stated their constraints as inadequate knowledge on disease prevention and control (68.0 %) and non-availability of veterinary services (56.9 %). Further, Duguma et al (2011) have also investigated constraints faced by the small-scale dairy farmers in Jimma town, Oromia Region, Ethiopia. Main constraints identified were: lack of land (50.0 %), shortage of feed (38.9 %), lack of improved animals (5.6 %), and lack of access to artificial insemination (3.7 %).

In addition, Seifu et al (2014) conducted a study in Dire Dawa, Eastern Ethiopia, to characterize the dairy value chain and to identify challenges and opportunities for dairy industry development. The results of this study clearly showed that value chain was no well-structured and organized and the roles and functions performed by actors in the value chain was not clear. Lack of quality control of milk, poor quality of milk supplied from rural areas, inappropriate milk handling and storage vessels, and milk spoilage because of lack of preservation and processing techniques were the main constraints in milk marketing.

The dairy technologies encompass the use of improved genotypes, improved feed and processing technologies, and promotion of integration of cross bred cattle in to smallholder sector (Mohomad et al., 2004). But in many South Asian countries like Indian, Sri Lanka, and Bangladesh, dairy farms constituted primarily from smallholder farming system being managed in conventional way. Therefore, understanding the factors influencing dairy farmers' adaptation of dairy technology is critical to success of development and implementation of policies and programmes in the development of dairy industry. Quddus (2012) has conducted a study to determine the causes of adoption and non-adoption of high yielding breed, the level of practices and constraints in adopting the improved technology. The study found that nearly one quarter of farmers use artificial insemination and two- fifth of the respondents belonged to high or medium level of technology adoption. Around 17.5 % of the farmers reared crossbred dairy cattle and they are reluctant to utilize new technologies. Interestingly, more educated dairy farmers (Secondary and higher) were 9.7 times more likely to adopting new technologies than illiterate.

In most developing countries, dairy production systems are constrained by socio-economic, technical and institutional factors (Fekadu, 1994; Chamboko et al. 2014). Demographic and socio-economic factors have significant impact on decision-making and dairy management practices. These factors will therefore affect the productivity and profitability of dairy herds and without having a good understanding of these factors it would very difficult to be involved in dairy business. Numerous studies have been conducted to identify the socio-economic, technical, and institutional factors effect on profitability of smallholder dairy farming (Somda et al., 2003; Alary et al., 2007; Cicek et al., 2007; Mumba et al., 2012;Kuma et al., 2013; Chamboko et al., 2014).

Mumba et al (2012) used multiple regression analysis to determine the effect of socio-economic factors on profitability of smallholder dairy farming in Zambia. Level of education, dairy cow herd size, and distance to the market were significantly affected the profitability of dairy production. In addition, the same method was employed by Cicek et al (2007) to determine the technical and socio-economic factors affecting the cost in dairy enterprises in Western Turkey. The study found that variables such as education of the farmer, scale of operation, feed procuring, feed consumption, and litter size had significant effects on the average milk costs. However, age of the farmer, main occupation, and the way of marketing milk (own or cooperative) were found to be statistically insignificant.   Also found similar results

Additionally, Kuma et al (2013) applied multinomial logit model to examine the factors affecting milk market outlet choices in Wolaita zone, Ethiopia. The results revealed that compared to accessing individual consumer milk market out let, the likelihood of accessing cooperative milk market outlet was lower among dairy producers who owned large herd size, who considered price offered by cooperative lower and those who wanted payment other than cash. On the other hand, large land holding size, cooperative membership, experience, and dairy extension have significant effect on the likelihood of accessing cooperative milk market outlet.

Though some studies (Navaratne and Buchenrieder, 2003; Hitihamu et al, 2007; Jayaweera et al, 2007) have been done to characterize the dairy production system in Sri Lanka, not much has been done to characterize and represent the dairy farming systems in different agro-climatic zones. There is need for appropriate characterization of smallholders and the identification of the constraints that they face. This is a crucial step for the design and the successful implementation of dairy development and marketing policies. Therefore, the present study identifies the characteristics, constraints, and opportunities for small-scale dairy farms in three different agro-climatic zones (namely Up-country, Mid-country, and Coconut Triangle) in Sri Lanka.

1.2.2 Resource use efficiency in livestock production

The first Millennium Development Goal (MDG1) is to eradicate extreme poverty and hunger, as set by 189 United Nations Member States in 2000 (reference). Reducing extreme poverty and hunger will require greater agricultural and rural development. The contribution of agriculture to the national gross domestic product (GDP) of Sri Lanka as a whole is estimated to be 10.7 %. The livestock sub-sector contributes around 7.4 % of agricultural GDP (Department of Census and Statistics, 2010).There are about 670,000 smallholders are engaged in the sector and between 30 to 40 % of their farm income is generated from livestock activities (MLRCD, 2011). Dairy sector is the most important of all livestock sub sectors. Since small holdings account for over 80 % (less than 1 hectares in extend) (Department of Census and Statistics, 2002) and are dominated by the small scale, mixed crop-livestock operation, this growth must be centered on the resource-poor famers. Due to this reasons, rather than advocating investments for the smallholder, which may already be beyond their capacity, it is prudent to inquire into the ways of using the existing resources to the maximum. Further, identifying and prioritizing factors effecting on dairy production are critical in policy making for dairy development in Sri Lanka.

Analysis of efficiency in the context of resource allocation has been a central concern of economic theory from ancient times, and is an essential element of modern microeconomic theory. Resource allocation and productivity is a major aspect of increased livestock production in most developing countries. It is also associated with the management of the dairy farmers, who employ these resources in production. One way of increasing production by the resource poor-poor farmers is to efficiency use all the resources available in the production process. The efficiency of a farm refers to its success in producing as large amount of output as possible given a set of inputs. M.J Farrel originated the current interest in efficiency measurement. Farrel (1957) proposed an approach that distinguishes between technical and allocative efficiency. "Technical efficiency" is the ability to produce a given level of output with a minimum quantity of inputs under a given technology. It means that natural resources are converted into good and services without waste. On the other hand, "allocative efficiency" (pricing efficiency) refers to the ability to choose optimal input levels for given factor prices. Economic efficiency is the product of technical and allocative efficiencies (See chapter 3 for more details).

Numerous studies (Ajewole and Folayan, 2008; Canbera et al, 2010; Khai and Yabe, 2011) have attempted to determine economic efficiencies of darmers in developing countries because determining the efficient status of farmers is important for policy purposes. Moreover, it is also important factor in productivity growth. In developing economies where resources are scare and the opportunities for new technology are lacking, inefficiency studies will be able to show that it is possible to raise productivity by improving efficiency without increasing the resource base or developing new technology. Estimates of the extent of inefficiency also help in deciding whether to improve efficiency or to develop new technologies to raise agricultural productivity.

M.JOlayide (1980) reported that the most productive and efficiently used resources are labor, seed, and farm equipment. Ajewole and Folayan (2008) examined the production efficiencies of farmers and factors influence on such efficiencies in dry season leaf vegetable production in Ekiti State, Nigeria by applying stochastic frontier approach (SFA). The farms operated on increasing return to scale. Furthermore, household size, level of education, credit accessibility and extension visits were found to contribute positively to technical efficiency while age, farming experience and off farm income reduces technical efficiency. Olarinde et al (2008) considered technical efficiencies of bee-keeping farms and their determinants, using SFA, in Oke-Ogun area of Northern Oyo State. Their results indicate that marital status and major occupation of the honey producers are most important factors of technical efficiency. Using the data from US dairy sector in Wisconsin Cabrera et al (2010) examined the effect of practices used by dairy farmers and the effect of intensification on the performance of the farm. The dairy farms operated on constant return to scale. In addition they found that farm efficiency was positively related to farm intensification, the level of contribution of family labor in the farm activities, the use of a total mixed ration feeding system and milking frequency.

Khai and Yabe (2011) applied SFA to measure the possibilities of technical gains from enhancing the efficiency of rice farms in Vietnam. The results demonstrated that intensive labor, irrigation and education are most important factors having positive impacts on technical efficiency, while agricultural policies reduces technical efficiency. Omonona et al (2010) studied resource-use and technical efficiency of cowpea production in Nigeria. Using a SFA, they concluded that farm size, seed, hired labor, family labor, fertilizer and pesticides are significant factors of production and using tobit regression model they found that cooperative membership and farming experience are important in technical efficiency. Their results indicate that farmers can obtain higher efficiencies through joining cooperative society, extension services and training. In addition marginal value products of all the resources used are less than their prices (MVP<MFC), indicating underutilization of resources.

Oniah et al (2008) used Ordinary Least Square (OLS) approach to study allocative efficiency of resources used in Obubra Local Government areas of Cross River State, Nigeria and found that farmers were inefficient in the allocation of all inputs in rice production. So the resources were under-utilized. A study by Kothalawala et al (2006) on resource use efficiency of small scale dairying in Bareilly districts of Uttar Pradesh in India conclude that in this area resource poor farmers over-utilized their cheap family labor, especially female labor in dairying, while underutilized other resources such as green fodder, dry fodder and concentrates. Alemdar and Yilmaz (2011) studied technical efficiencies of cooperative member dairy farmers in Cukurova region. Using a SFA they concluded that farming experience is one of the significant and positive factors of technical efficiency, while grazing reduces technical efficiency. Their results indicate that farmers would benefit from reductions in share of grazing whereas recommended to increase use of concentrate feed in order to obtain higher milk yields.

Very few studies have analyzed the productivity and technical efficiency of both agriculture and livestock sectors in Sri Lanka. For instance, Edirisinghe et al (year) found that, 52 % of average levels of efficiency compared to most efficient dairy farmers in the sample. However, no study to date has examined the resource use efficiency of dairy farms in different agro-climatic zones (specifically Up-country and Coconut triangle) in Sri Lanka.

1.2.3 Socio-economics of foot and mouth disease

Foot and mouth disease (FMD) is a World Animal Health Organization (OIE) – listed viral disease that is considered one of the most highly contagious diseases of cloven-footed livestock and wildlife (James et al. 2002). The disease is caused by a Foot-and-Mouth disease virus (FMDV) that belongs to the family Picornaviridae, a member of the genus *Aphthovirus* (Belsham, 2005). There are seven major immunologically distinct serotypes, that is, A, O, C, SAT1, SAT2, SAT3, and Asia1 (Belsham, 2005) that differ between distinct geographical regions. The disease is an eminent transboundary animal disease (TAD) that severely compromised livestock production and the international trade in animals and animal products (Belsham, 2005).

The global FMD distribution pattern largely reflects the development state of countries and regions (FAO/OIE, 2012). It is endemic in many areas of the world, especially parts of Asia, Africa and Middle East and only 59 countries are considered to be free from the disease by the Office International des Epizooties (OIE, 2007c). In FMD-endemic countries, usually developing countries, the disease threatens food security and the livelihoods of small holders and prevents animal husbandry sectors from developing their economic potential.

FMD causes huge production losses at the farm level and disease risks often preclude access to regional and international market (Parida, 2009). Although deaths usually occurs only in young animals (Kahn and Line, 2005), the frequency of outbreaks and the huge number of animals and species affected in each outbreak results in a high and on-going impact for FMD in endemic countries (Oxford Analytica, 2012). However, costly outbreaks can occur even in formerly FMD free countries. Striking examples are the recent outbreaks in the United Kingdom and the Netherlands. The outbreak in the United Kingdom in 2001 caused a crisis in both agriculture and tourism industry (Blake et al., 2002). Thompson et al (2002) estimated losses from FMD in the UK at £5.8 to £6.3 billion ($10.7 to $11.7 billion). Moreover, even though the United States has been free of FMD, it is predicted that

Although FMD is not a new disease, there are very few empirical studies assessing the economic impact of FMD on milk yield, due to lack of micro data on this aspect of the livestock life (Forman et al., 2009 and Zezza et al., 2011). Mathew et al (2008) studied the economic impact of FMD in Chazhoor Panchayath of Thrissur District, Kerala, India. The total economic loss was calculated as Rs. 313,900 (1 US$ = 61.68 Indian Rupee), out of which loss in milk production accounted for 80.7 %. In a sample of 62 Cambodian cattle producers, the average post-FMD infection cost differed from 216 to 370 USD per animal, including the average cost of treatment, the cost arising from lost draft power, and the animal death (Young et al., 2012). Moreover, Ferrari et al (2013) observed FMD-induced milk yield loss for 60 days following the onset of clinical signs in cattle and buffaloes as 202, and 210 litres respectively.

FMD is endemic in Sri Lanka since many centuries and has been ranked as the highest priority disease for control and eradication. To date very few studies have been conducted on socio-economic impact of FMD in the country. It is endemic in the country particularly in the eastern part of Northern and Eastern Provinces causing extensive outbreaks causing to major epidemics which often affect other areas too. A DAPH (2012) found that total cost (including cost on milk loss, calf death, weight gain reduction, disease control, labor cost, and breeding delay) was Rs. 31,044 (1 US$= 102 Sri Lanka Rupee) per farm per month in medium scale (<100 animals) operations and Rs. 78, 250 in large scale (>100 animals) dairy farms in extensive system. Whereas, the average post-infection cost for 35 days in wet zone was Rs. 29, 109. Therefore, above studies clearly highlighted the need to understand probable economic impacts of a highly contagious disease for effective public policy development.

Animal diseases are major constraints to animal production throughout the world, especially in the developing nations, therefore the need for animal health impact assessments have been increasing in recent years. Nevertheless, the economic impacts of animal diseases are difficult to understand and even more difficult to understand. There are many analytical (Paarlberg, 2013) tools for clarifying the socioeconomic impact of FMD. They include the following; (1) Cost-benefit analysis (Bates et al., 2003); (2) Partial budgeting (Elbakidze, 2009); (3) Input-output analysis (Ekboir, 1999); (4) Computable general equilibrium (CGE) models (Lin, 1998); and (5) Partial equilibrium models (McCauley, et al., 1979; Thompson, et al., 2002)

Investors (whether there are government or private) need to understand the possible outcomes of a particular disease control strategy in monetary terms. Cost-benefit analysis is a well-known static technique commonly used in project evaluation and also one of the best methods of deciding which control strategy performs best of average. This technique is best used on a limited scale, since it is frequently applied assuming no changes in market prices or costs. Bates et al (2003) employed this method to evaluate the relative cost and benefits of vaccination and pre-emptive herd slaughter for an FMD event in California. The range of benefit cost estimates for vaccination and slaughter programs were 5.0 to 10.1 (economically efficient) and 0.05 to 0.8 (economically inefficient), respectively.

Moreover, Bartholomew et al (1992) used a cost benefit approach to quantify the economic impact of economic impact of reduced FMD incidence in northern Thailand. Potential net annual benefit of 23.6 million Baht (1 US$ = 32.36 Thai Bath), a benefit cost ratio of 11.8:1, and net present values (NPVs) of between 179 and 245 million Bath were reported. Further, Perry et al (1999) used integrated epidemiological and economic models to evaluate the economic viability of FMD control in Thailand. Without exports and with additional exports the predicted benefit cost ratios of 3.73 and 15.1 were reported, respectively. Further, in a study in Laos, Vietnam, and Cambodia, FAO found that average return to FMD control per head ranged from US$0.2 to US$ 0.5 depending on FMD incidence.

1.2.4 Integrated epidemiological-economic model

There is a need for animal health managers, investors, and policy makers to examine and evaluate alternative approaches to disease control that deal with these concerns, including emergency animal vaccination as a strategy to reduce the numbers of animals destroyed. Evaluate the possible consequences of these outbreaks and modelling various control strategies in advance could help to prevent transmission of such infectious diseases.

Epidemic modelling has been used for more than 100years to better understand the epidemiology of a disease, including its potential spread and the value of alternative controls strategies. The approach has become increasingly significant and useful during last decade in infectious disease control, especially when it comes to planning for potential FMD incursions (Carpenter, 2013). Generally, epidemiological models do not generate the information required by an economic model, due to they are used for various things. Thus, economists have to convert epidemiological output into a form that makes sense for economic modelling (Paarlberg, 2013). Several epidemic simulation models have been applied to investigate and forecast the spread and control of FMD in the field of animal health.

The economic model converts the epidemiological parameters into cost estimates to individual sector of the economy, regions of the country and country as a whole. Initially, the primary focus in animal disease modelling was demographic, behavioural, and epidemiological rather than economic in nature. However, in more recent times, though, several models have been employed to evaluate the economic viability of alternative prevention and control strategies. For example, Perry et al (1999) developed integrated epidemiological and economic models to evaluate the economic viability of FMD control programmes in the countries and region of South-East Asia. In addition, Conrad (2004) developed a system dynamics model of livestock and feed production to analyse a hypothetical FMD outbreak in the United States. Unlike Conrad (2004), however, Rick (2007) explicitly models the evolution of animal disease through the use of simple Susceptible-Infected-Removed (or S-I-R) model (See chapter 4 for more details).

As mentioned above (section of background and challenges), to date no studies have investigated the cost-effectiveness of alternative control policies in Sri Lanka. Therefore, current study estimate the epidemic and economic impact of FMD associated with different control options in Sri Lanka using integrated epidemiological and economic model.

1.2.5 Policy instruments for eradicating foot and mouth disease

FMD remains one of the most significant widespread epizootic diseases of the world, given its highly contagious nature, its broad economic effect on animal welfare and productivity, as well as, its implications for successful access to local and export markets for livestock and products. The impact of the disease varies from country to country and also within a country. These differences in impact shape some markedly heterogeneous incentives for FMD control and eradication, which become of particular importance when setting priorities for poverty reduction goal in developing countries (Perry and Rich, 2007).

Today more than 100 countries are still not recognized as free from FMD by the OIE (OIE, 2013). The consequences of FMD in developing countries are often underestimated. In countries where FMD is still endemic, the disease has a significant negative impact on livestock production. This is usually caused high mortality in newborn and young animals, significantly reduced milk yield, and the absence of weight gain in animals. In addition, FMD reduced both draft power and traction. These factors lead to decreased agricultural productivity and thus threaten household food security in developing countries. Moreover, in the recent decades the world beef market has divided into several segments (endemic, free-with-vaccination, and free-without-vaccination) on the basis of FMD status. In such markets, the highest prices are provided to producers from regions that have been designed as FMD-free by the World Organization for Animal Health/Office International des Epizooties (OIE) (Lovell et al, 2008). On the other hand, FMD endemic countries are excluded from lucrative export markets and the disease has a negative effect on regional and local market in local and regional trade in products of animal origin (OIE, 2012).

FMD control policies are considered to be a global public good, because it benefit all people worldwide and future generations. The Global Strategy developed by FAO and the OIE is designed to help countries control FMD outbreaks more effectively

and take the necessary measures to prevent the disease spreading to other farms, communities and across borders to neighboring countries (Bangkok, 2012). FMD can spread very rapidly, early warning is therefore essential to detect an incursion and to prevent further infection. Also, early detection of FMD had the largest impact on minimizing the overall cost of the outbreak and the burden on the taxpayer and public.
FMD outbreak can be effectively controlled by repeated mass vaccination of cattle, by animal movement restrictions and by slaughtering affected animals (stamping out). Stamping out policy is successful, if an outbreak can be accurately detected early while still reasonably localized and contained by quarantine and animal movement controls (Geering and Lubroth, 2000). A stamping-out policy will probably be most appropriate for countries with highly developed livestock industries, particularly for those with a substantial actual or potential export trade in livestock and livestock products to protect. A combination of repeated mass vaccination of cattle and animal movement restrictions had been the strategy used by many developing countries.

Economically efficient FMD control policies would be those balancing the marginal cost and benefit of disease control measures. Many studies have also investigated economic effectiveness of various strategies for infectious animal disease management. Vaccination and slaughter have been the most commonly studied responses. Ferguson et al. (2001) called for cost-benefit analysis of mass vaccination options versus slaughter based control of infrequent outbreaks. Also, Garner and Lack (1995) investigated the effectiveness of four control strategies (stamping-out, dangerous contact slaughter and early or ring vaccination) in three different regions of Australia. They found that if FMD is likely to spread rapidly then slaughter of dangerous contacts as well as infected herds reduced the economic impact of the FMD outbreak. Early ring vaccination turned out to reduce the size and duration of an outbreak, but it was uneconomical than stamping-out alone. Furthermore, Schoenbaum and Disney (2003) found that slaughtering in 3 Km rings around contagious herds was more costly than other slaughter strategies. Ring vaccination was more costly than controlling with slaughter alone. However, early ring vaccination decreased the duration of outbreaks. Other studies have suggested that mitigation efforts required to be coordinated across the regions of the country associated with adverse events like infectious disease outbreaks. For example, since some regions would gain more from vaccination than from stamping out, compensation mechanisms may be needed to make culling, which they found to be a preferred strategy in the long run, acceptable across the entire multiregional zone. For example, Rich and Winter-Nelson (2007) argue that since some regions would gain more from vaccination than from stamping out policy, compensation mechanisms may be required to make culling, which they found to be the most preferred policy in the long run, acceptable across the entire multiregional zone.

The most common way the virus is spread is by animal movements that bring health animals into contact with animals infected with FMD. All secretions of sick animals are extremely infectious and effective movement control play a significant role in stopping the spread of FMD (Gerald, 2011). In the meantime, many studies have been conducted to assess the spread of FMD through animal movements (Green et al 2006). In addition, despite the animal movement restriction, animal products such as fresh meat, embryos, semen, milk, milk products, wool, hides and skins from susceptible species should not be moved into or out of or within the restricted zone. Furthermore, in developing countries, inability to access to veterinary services, poor awareness and knowledge of animal diseases, lack of incentives at national level, lack of incentives at producer level to purchase vaccine and poorly organized vaccination services are main obstacles for FMD control and eradication (OIE, 2012). For example, Mohan and Rajkamal (2010) investigated the dairy farmers' general awareness of FMD on prevention and control of FMD in Thrissur District, Kerala, India. They found that majority of farmers aware of the common symptoms of FMD like fever, profuse salivation, stamping of feet, frequent smacking of lips, protrusion of tongue, and the chances of abortion. Therefore, the awareness of such typical symptoms is surely of immense importance as the farmers themselves could easily identify FMD and also enabling them to report the fact to their local Divisional Veterinary Office. Hopp et al (2007) found that 34 % to 69 % of the Norwegian farmers' were vigilant in reporting scrapie associated symptoms in sheep.

Early detection and prompt reporting of suspicion of FMD is critically important to limit the risk of any further spread of disease before control measures are applied, thereby limiting the size and duration of the outbreak. Further, it protects and improves a country's reputation and gives it the assurance of a reliable trading partner. McLaws (2009) study conducted an analysis to determine the factors associated with the early detection of clinical FMD during the 2001 outbreak in the United Kingdom. The study suggests that reporting by farmers and initiatives that increase farmer education and awareness should be encouraged.

Additionally, biosecurity measures (to reduce the likelihood of an FMD outbreak) resourcing of surveillance (to allow early detection) and emergency response (to allow rapid eradication) are necessary to prevent the spread of FMD to multiple regions or provinces and reduce the possibility of economic and social impacts of an outbreak escalating (Buetre, 2013).

Nevertheless, improving the farmer's knowledge on distinguishing FMD from other diseases (early detection), prompt reporting of any suspicion of FMD (limit the extent to which disease can spread), as well as, restrict of all movements of animals or animal products are critical activities for an effective FMD response effort.

Dairy is the main income source for the poor rural farmers, especially in the dry zone of Sri Lanka. Therefore, this study hypothesized that farmers have poor knowledge to identify FMD infected animals, farmers are reluctant to report a suspicion of FMD to the veterinary authorities, and farmers sell raw milk from FMD-infected cows in the market. This study contributes to the existing literature by investigating the farmers' attitudes and behaviours towards FMD outbreak and its control.

1.3. Objectives and structure of the dissertation

This thesis mainly focused on two issues that are essentially important for the development of dairy sector in Sri Lanka from decision-making point of view.

Firstly, it will identify the major socio-economic characteristics and constraints that affect dairy production in different agro-climatic zones in Sri Lanka. Further, it will measure the technical efficiencies of dairy farms using a Cobb-Douglas stochastic production frontier. Also, it will identify the critical factors affecting on milk production. The accurate analysis of the determinants of technical efficiency is critical to the dairy producers as well as to policy makers. From the policy makers' point of view, knowing the distribution of technical efficiency level across dairy producers will help to draft specific and well defined dairy policies. On the other hand, from the dairy producers' point of view, understanding how different factors affecting their technical efficiency are a helpful tool for improving the productivity and profitability of their production. In addition, this study examines the feed resource-use efficiency in dairy production in two different agro-climatic zones in Sri Lanka (Chapter 2 and Chapter 3).

Secondly**,** this study will address the issues related to the outbreak of FMD in 2014. The study will report the magnitude of outbreak (number of infected cases and deaths) under different vaccination and cost-effectiveness of vaccination under different vaccination rates. Most importantly, study will describe the farmers' attitudes and behaviours towards FMD outbreak (Chapter 4 and Chapter 5).

The main purpose of this thesis is to economically and epidemiologically analyze the constraints and challenges of dairy farming, impact of FMD outbreak and cost-effectiveness of control policies as well as farmers' attitude towards FMD control, particularly early detection and reporting.

The specific objectives are:

1) To identify the major socio-economic factors affecting on milk production in three different agro-climatic zones.
2) To examine the resource-use efficiency in dairy productions systems in different agro-climatic zones
3) To evaluate the economic viability of current preventive vaccination program (or economic return for the government budget)
4) To analyze the farmers' knowledge level and behaviour towards FMD outbreak and its control
5) To suggest policy measure to improve the dairy production in Sri Lanka

The thesis comprises of six (6) chapters.

Chapter 1 explains the socio-economic characteristics and resource-use efficiency in the livestock production, and socio-economic impact of foot and mouth disease. Further, it reviews the aspects of epidemiology of FMD and epidemiological simulation modelling with the focus on FMD in terms of disease control. In addition, a review of both theoretical and the empirical literature pertinent to the topic of this thesis is presented.

Chapter 2 describes the livestock production and infectious diseases in the developing countries, especially in Sri Lanka. More specifically, this identifies the factors affect on milk production systems in different agro-climatic zones in Sri Lanka. Further, it examines the constraints and opportunities for increased milk production, especially focusing on the market channel.

Chapter 3 examines the resource use efficiency of dairy farmers in different agro-climatic zones in Sri Lanka, particularly considering the available feed resources and market prices in the regions.

Chapter 4 explains the integrated epidemiological and economic model used for the analysis. The transmission parameters were estimated from reviews and statistical analysis. Moreover, it examines the practical plan in place of FMD control and eradication.

Chapter 5 examines farmers' knowledge and behaviours towards FMD control.

Chapter 6 concludes the important findings of this research. The overall conclusion summarizes the results from the previous chapters.

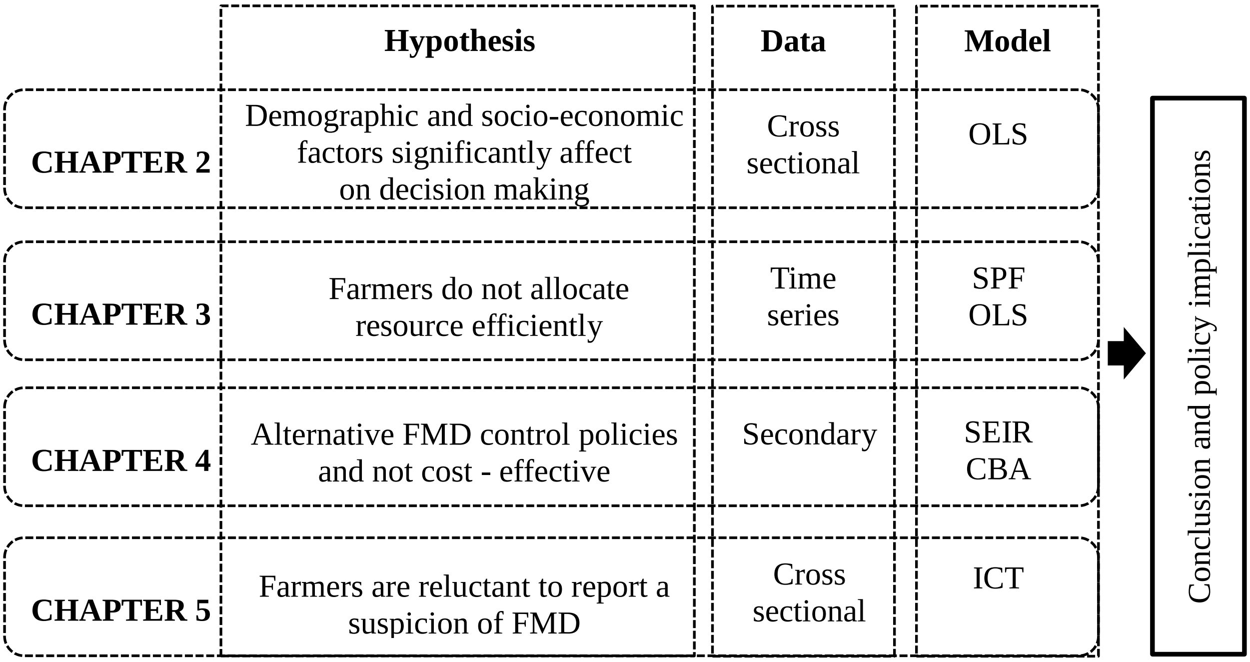

Figure 1.1 Framework for Analysis

CHAPTER 2

Livestock production and infectious diseases in Sri Lanka

2.1 Livestock production in developing countries

2.1.1 Income growth and changes in food consumption patterns

Livestock sector plays an integral role in improving food security, rural livelihoods and the economies of developing countries. At present, the world faces enormous challenges over food security (Millennium Ecosystems Assessment, 2005). According to World Bank estimates, at least a billion people will still live below the $1.25 a day line in 2015, including a third of the world's extreme poor in Africa (Chen and Martin, 2008). Livestock contributes 40 % of agricultural gross domestic product (GDP) and comprise nearly 30 % of the agricultural GDP in the developing world (Herrero et al., 2010). The International Livestock Research Institute (ILRI) has indicated that nearly 35 % of poor livestock keepers live in South Asia, about 30 % in Sub-Saharan Africa, about 15 % in East and South East Asia and the remainder is distributed across West Asia, Latin America, Europe, North Africa and Central Asia. These estimates highlight the importance of livestock sector in sustainable livelihood security.

Livestock sector is undergoing a rapid transformation, and developing countries are fueling a massive global increase in demand for high-value animal protein. Population growth, economic growth and urbanization are the three main driving forces behind the 'livestock revolution' (Delgado et al,. 1999). First, the current world's population will reach 9.1 billion by 2050, which is 34 % higher than today (FAO, 2009). Also, FAO's (Food and Agricultural Organization) latest projection indicate that global consumption of meat and dairy products will increase by 102 % and 82 % between 2000 and 2050. While the projected consumption growth rates are faster for the developing countries as a whole, being 164 % and 172 % respectively.

Economic growth is the second driver behind increased consumption of animal products. There is a strong positive correlation between the per capita gross domestic product and per capita meat consumption (Schroeder et al,. 1995). Also, Gehlhar and Coyle (2001) indicated that changes in consumption pattern are driven mainly by per capita income growth.

Developing countries, particularly in the East Asian and Pacific region, have experienced very strong economic growth, with an annual rate of 9.2 % over the decades between 2000 and 2012. South Asia and Sub-Saharan Africa follow, with gross domestic product growth rate (GDP) of 7.3 % and 5.3 % over the same period, respectively (Figure 2.1).

The third is urbanization; by 2050, about 70% of the world's population is expected to live urban areas. Urbanization affects the livestock sector on both supply and demand. The major factors influencing the demand for livestock products include household income growth, relative prices of foods and changes in consumption pattern due to change in purchasing power (Scott and Okali, 1993).On the contrary, supply side, the livestock concentration in the peri-urban areas leads to intensification of animal production systems especially landless systems such as chicken, dairy cow and pig farming.

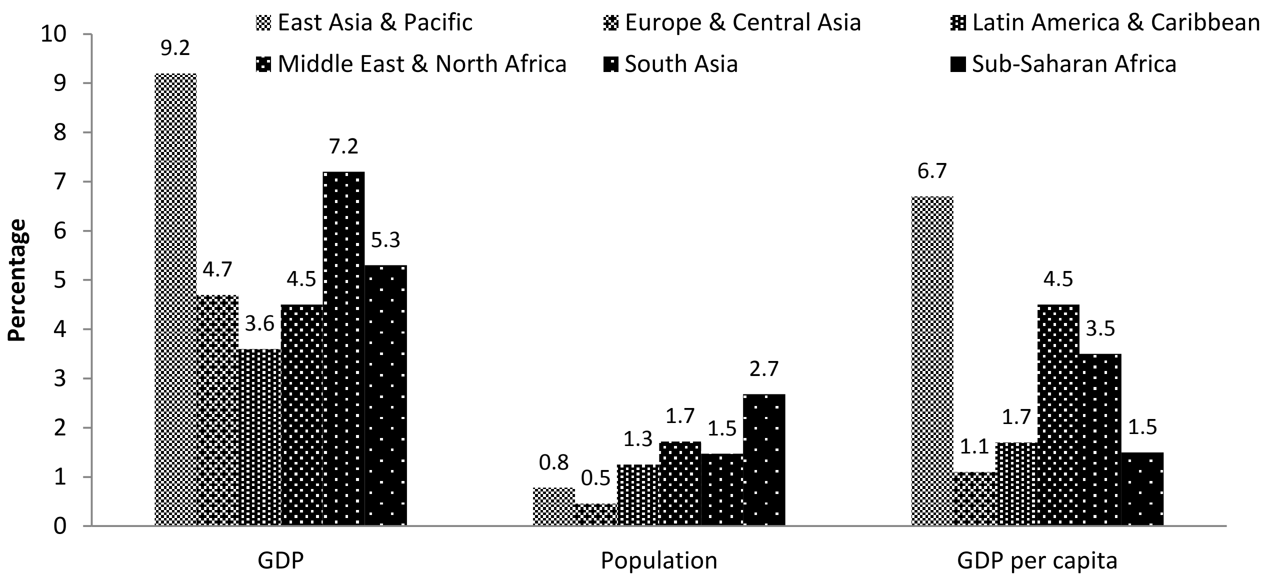

Figure 2.1 Average annual growth rates of GDP, population, and GDP per capita, 2000-2012 in developing region
Source: The World Bank, 2012

Figure 2.2 clearly shows that global demand for livestock consumption has increased substantially since the 1960s. The per capita total milk consumption shows an increase by about 2.0 % a year between 1961 and 2011. Moreover, the global demand for eggs, poultry meat, pig meat, mutton and goat meat, and bovine meat are 3.0 %, 5.0 %, 1.6 %, and 1.6 %, respectively.

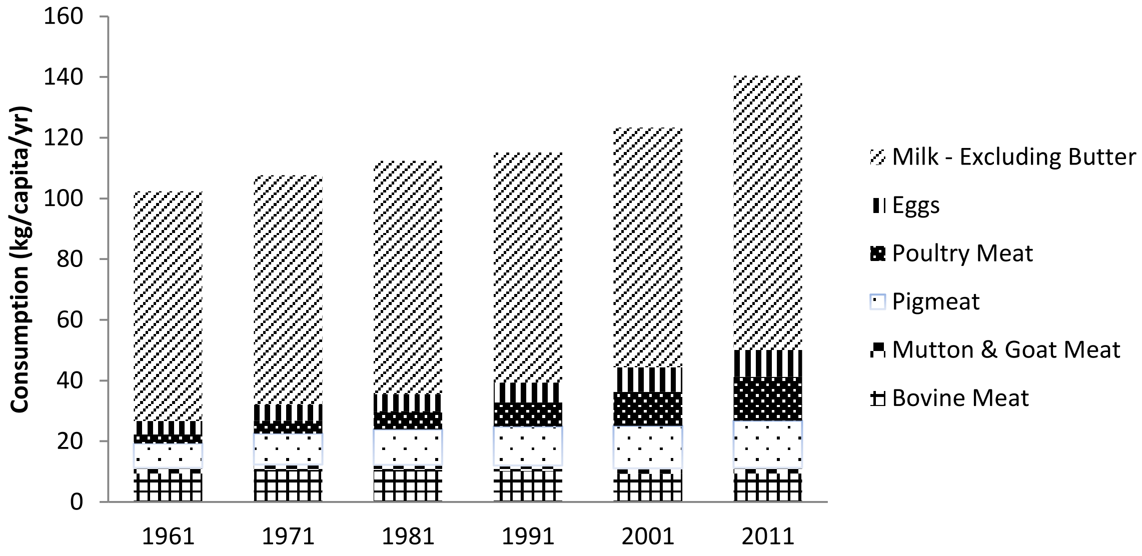

Figure 2.2 Per capita demand for livestock products (1961-2011)
Source: FAO, 2012

Per capita consumption of livestock products is closely related to per capita income. That is with growing household income consumers typically increase their consumption milk, meat and eggs until these animal products become fully integrated into the daily diet. Table 2.1 presents an overview of the important changes that have occurred in the average diet in various world regions. People in the world's developed region derive more than 50 % of their dietary protein intake from food of livestock origin, and minor change occurred between 1980 and 2011. Changes have been most dramatic in Eastern Asia, Southern Asia and, South-Eastern Asia where total protein supply from livestock for human diets increased by 223 %, 78 %, and 127 %, respectively. In contrary, there has been a decline in livestock consumption in sub-Saharan Africa (except Northern Africa), indicating economic stagnation and reduction in available incomes.

Table 2.1 Daily protein supply source from livestock and from all sources

	Protein Supply Quantity (g/capita/day)			
	Animal Products		**Grand Total**	
Regions	**1980**	**2011**	**1980**	**2011**
Developed regions				
Europe	55.1	57.5	101.3	101.8
Australia & New Zealand	67.8	71.0	101.6	105.5
Northern America	65.6	69.4	97.8	108.6
Developing regions				
Africa				
Eastern Africa	11.4	10.6	55.7	56.9
Middle Africa	13.0	16.0	49.6	61.7
Northern Africa	14.4	26.0	69.5	92.7
Southern Africa	25.0	32.5	73.9	81.1
Western Africa	11.6	12.8	46.8	64.0
Americas				
Caribbean	25.2	25.7	60.8	66.1
Central America	27.1	36.1	76.4	80.6
South America	31.0	46.4	67.1	86.3
Asia				
Central Asia	n.a	35.2	n.a	82.9
Eastern Asia	11.9	38.4	58.7	94.2
Southern Asia	7.8	13.9	49.7	61.4
South-Eastern Asia	10.6	24.1	46.1	66.0
Western Asia	25.2	28.5	85.7	86.3
World	**23.5**	**31.7**	**66.8**	**80.3**

Source: FAO, 2013

2.1.2 Livestock production and epidemic diseases in Southern Asia

Southern Asia or South Asia is the southern region of the Asia continent, and is the second most densely populated geographical region in the world. It is made-up of Sri Lanka, India, Bangladesh, Bhutan, Pakistan, Nepal, Afghanistan, and Maldives. The countries of South Asia home to over one fifth (1.4 billion) of the world's and livestock population. According to the World Bank estimates, about 43 % of people currently live on less than a dollar a day. Moreover, over 80 % of rural poor depend, directly or indirectly depend on agriculture and livestock for their livelihood.

There is a strong link between rural poverty and livestock production in South Asia compared with other regions of the world. Livestock production is a crucial livelihood asset for Southern Asia, and it makes an important contribution to nutrition security, household income, employment creation, economic growth, and poverty alleviation. The livestock population in 2011 accounted for 77.7 % of buffalo, 31.8 % of goat, 19.9 % of cattle, 14.6 % of sheep, and 11.9 of chicken of the total global livestock population (Table 2.2).

Table 2.2 Southern Asia's share of world livestock population (2011)

	World	**Southern Asia**	**As a % of world**
Livestock	**1,000 head**		
Buffaloes	195.4	151.8	77.7
Goats	981.9	312.6	31.8
Cattle	1471.9	292.4	19.9
Chickens	20877.6	2493.2	11.9
Sheep	1152.4	168.5	14.6
Pigs	968.2	10.7	1.1
Total	**25647.3**	**3429.3**	**13.4**

Source: FAOSTAT 2013

Meanwhile, Table 2.3 presents livestock population in Southern Asia, India is the leading producer compare to other countries in the region. India harbours the largest buffalo population (57 %) and cattle population (16 %) in the world (Patoo et al., 2011). India also had 157 million (50.5 % of South Asia's population) goats, 75 million (44.4 % of South Asia's population), sheep and 10 million (88.7 % of South Asia's population), pigs. Pakistan comes in second and it had 35 million cattle, 31 million buffalo, 61 million goats, and 28 million sheep. Sri Lanka has the least number of cattle in the region estimated to be 1.9 million cattle. Despite this, dairy industry is the most prioritized sub sector in Sri Lanka and it has huge potential to contribute to economic development.

In 2010, India was the most significant producer of milk and milk products in the world followed by the United States, China, Germany, Brazil and Russia (Blasko, 2011). Over 50 % of the world's buffalos and 20 % of its cattle population grazes are found in India. Livestock generates more than 90 million jobs approximately 75 % of them are women (Grain, 2014). This is true in the case of Bangladesh, 58 % of cattle and 68 % of sheep and goats are reared on farms less than a hectare, producing a 70 to 80 % of the country's total milk.

Table 2.3 Country's share of Southern Asia livestock population (2011)

Countries	Buffaloes	Goats	Cattle	Chickens	Sheep	Pigs
	1,000 head					
Afghanistan	0.0	2.4	1.9	0.5	8.5	0.0
Bangladesh	0.9	17.1	7.9	9.4	1.1	0.0
Bhutan	0.0	0.0	0.1	0.0	0.0	0.2
India	74.4	50.2	72.1	37.8	44.2	88.7
Iran (Islamic Republic of)	0.2	7.5	2.9	36.1	29.1	0.0
Nepal	3.3	2.9	2.5	1.6	0.5	10.3
Pakistan	20.9	19.7	12.2	14.0	16.7	0.0
Sri Lanka	0.3	0.1	0.4	0.6	0.0	0.8
Southern Asia	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Source: FAOSTAT 2013

In Southern Asia, dairy sector is the most important of all livestock sub sectors. This is mainly because of the impact it can make important contribution to sustainable rural development. The dairy industry in the Southern Asia countries is characterized by small-scale, scattered and unorganised dairy farmers, low productivity, low milk price, lack of profitability, unavailability of basic infrastructure for the provision of production inputs and services, absence of proper technology, unsatisfactory extension and other supporting services (Singh and Pundir, 2001). In addition, livestock diseases, particularly, Transboundary Animal Diseases (TADs) such as Foot-and-mouth disease (FMD) and Classical Swine Fever (CSF) are a permanent threat to the livelihood of livestock farmers in Southern Asia. Therefore, FAO is working to enhance prevention of transboundary animal and animal-related human diseases in partnership with the World Organization for Animal Health (OIE) and the World Health Organization (WHO).

Table 2.4 indicates the major epidemic (transboundary) animal diseases in Southern Asia between 2009 and 2013. FMD is the major disease of livestock in southern Asia, especially in Afghanistan, India, Iran, Nepal, and Sri Lanka. The estimated annual economic losses due to FMD in India and Nepal are 4.45 billion dollars and 60 million dollars, respectively (FAO/OIE, 2012). FM|D spreads rapidly in Sri Lanka, raising big concerns for the dairy sector and the welfare of the animal. In fact, according to a study by the Department of Animal Production and Health (DAPH, 2012), the cost on milk loss was Rs.14, 175.00 (IUSD=102 SLR) per farm in medium scale (>100 animals9 operations and Rs. 78, 250.00 in large scale (>100 animals) farms in extensive system. Additionally, on the average the monthly cost per unit was estimated to be Rs. 11,069.20 and Rs. 31,044.20 in medium and large scale farms respectively. Therefore, FMD has been recognized as the highest priority disease for control and eradication in Sri Lanka.

Table 2.4 Major Epidemic (transboundary) animal diseases in Southern Asia (2009-2013)

	Foot-and-mouth disease					**Classical swine fever**					**Haemorrhagic septicaemia**				
Countries	**2009**	**2010**	**2011**	**2012**	**2013**	**2009**	**2010**	**2011**	**2012**	**2013**	**2009**	**2010**	**2011**	**2012**	**2013**
Afghanistan	1044	76	294	45	134	0	0	0	0	0	141	187	53	2	58
Bangladesh	0	0	0	0	0	0	0	0	0	0	(+….)	(+….)	(+….)	(+….)	(+….)
India	902	422	701	879	139*	136	418	284	252	60*	296	380	315	248	46*
Iran	1707	2281	2053	850	292	0	0	0	0	0	1	6	2	0	0
Maldives	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nepal	204	22	72	41	66	29	14	34	10	6	126	113	165	82	52
Pakistan	0	0	0	0	0	0	0	0	0	0	(+….)	(+….)	(+….)	(+….)	(+….)
Sri Lanka	6	18	6	5	4	(+)	0	0	0	0	0	0	0	0	0
Total	3863	2819	3126	1820	496	165	432	318	262	6	564	686	535	332	110

Source: OIE 2013
Note: Legend: (+) – Disease present with quantitative data but with an unknown number of outbreaks
(+….) – Disease present but without quantitative data
* is denoted Data from January to June

2.2. Livestock production in Sri Lanka

2.2.1 Overview of livestock production

Livestock form an integral part of the Sri Lankan rural economy and plays a multifaceted role in providing livelihood support to the rural population. The livestock sub-sector contributes around 11.1 % to the agriculture GDP and nearly 0.8 % to the total national GDP (Department of Census and Statistics, 2012). There are about 670,000 marginal farmers are engaged in the sector and 30 to 60 % of their farm income is generated from livestock activities. However, there is a vast potential for future development of this sector.

In addition, the demand for the livestock produce as source of animal protein has been increasing in rapidly in Sri Lanka as in other developing countries, propelled by per capita income and urbanization. Current economic growth (7.3 % growth) (Central Bank, 2013) in the country and its forecast for the future is expected to shift proportion of composition of low, middle and high income groups and thereby enhance consumption levels of food sources of animal origin.

Female labor force participation is an important driver of growth and development and it act as a signal of the economic empowerment of women. However, out of total 'economically inactive population' of the country, 69 % are females, and out of the total 'economically active population' females account for only 34 % (Department of Census and Statistics, 2012). This indicates that there is a huge untapped reservoir of man power that could be utilized for the economic development of the country. The resource-poor landless, marginal and small farmers own majority of farm animals. Thus sustainable development of the livestock sector would lead to more inclusive development and women's empowerment.

The livestock population is comprised of about 1.25 million cattle, 0.46 million buffaloes, 0.39 goat and sheep, 0.08 million pigs, and 15.72 million poultry (Department of Animal Production and Health, 2012). They are raised under different environments which are defined in Agro-Climatic Zones and management systems.

Dairy is the one of the most important subsector in livestock due to the extensive employment opportunities the industry offers. Therefore, dairy sector is regarded as the priority sector for public investment in livestock development. Small-scale dairying is predominant in the country and its efficiency as an integrated farming system provides financial health and social securities for thousands of rural dwellers in Sri Lanka. According to the national policy on agriculture and livestock 2011-2015, it is planned to achieve self-sufficiency in milk and milk products by the year 2015. Thus, current milk production is needed to increase by 300 % in order to achieve self-sufficiency by the end of 2015. The total investment for the dairy sub-sector development is Rs. 18,241 millions (Ministry of Livestock and Rural Community Development, 2011).

Figure 2.3 indicates the trends in total milk production and milk imports. As of 2010, local milk production covers only 33 % of the national consumption and 75,482 metric tons (MT) of milk and milk products valued at over Rs. 30 billion have been imported and it represented 2.1 of Sri Lankan food imports (Department of Animal Production and Health, 2012). Around 56% of the total milk produced entered the formal milk market together with the imports and the rest is channeled via informal routes and consumed domestically, indicating that there is a huge potential for market development. Therefore, with the target of reducing the drain on foreign exchange resources and providing employment generation and income generating opportunity, dairy industry has promoted as complementary economic activity across the wide section of the population in the country.

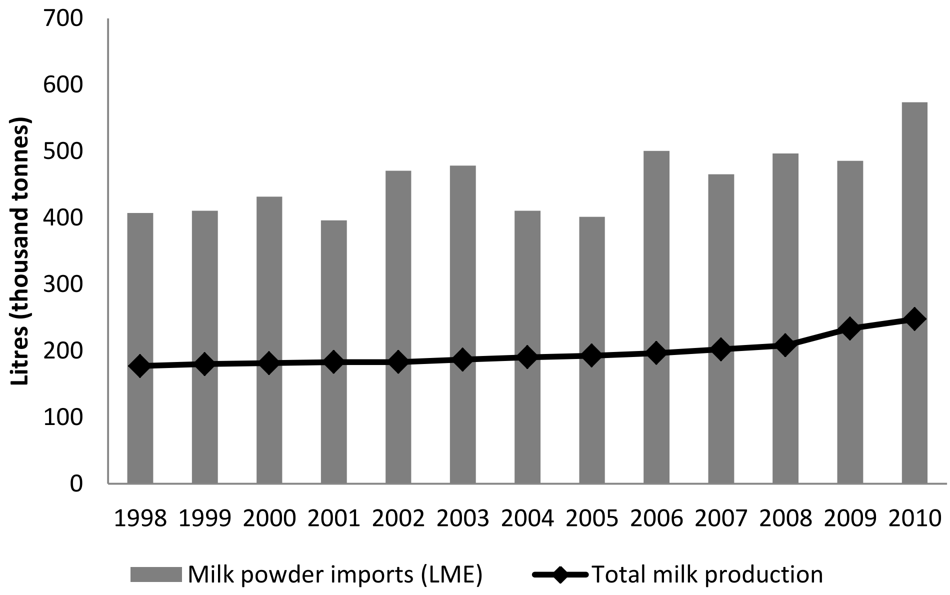

Figure 2.3 Trends in total milk production and milk powder imports (1998-2010)
Note: The conversion factors expressing product weight in fresh milk equivalent are 7.6 for milk powder, 2.1 for condensed milk, and I for milk product.
Total production includes both cow and buffalo milk.
Source: Department of Census and Statistics, 1998-2010 and Sri Lanka Custom Department, 1970-2010.

Hardly any studies have been undertaken in the past to address the socio-economic aspects of the dairy farmers in Sri Lanka, with stress on regional variation, production technology, and cattle management systems. Therefore, a detailed investigation of socio-economic characterization of milk production systems at the smallholder level in the different Agro-climatic Zones is timely and relevant. Also, characterization of dairy farms in different Agro-climatic Zones helps to identify the possible constraints and opportunities faced by farmers. Such opportunities and challenges are expected to vary according to socio-economic and agro-ecological conditions under which farmers operate.

Therefore, the objectives of this study were to;
1) Identify and determine the effect of socio-economic factors on milk production
2) Assess the milk marketing constraints and marketing channel

3) Draw some policy implications

Hypothesis: Farmers do not allocate resource efficiently and efficiency is significantly different among different management systems related to different agro-climatic zones.

A- Milk production determinants among dairy farms in different agro-climatic zones

1. Study area and data source

There are three main agro ecological zones in Sri Lanka. The dairy management system differs depending on the climatic zones. Among these climatic zones, 6 dominant dairy farming systems can be identified. Approximately 67% of the total cattle population in Sri Lanka is concentrated in the dry and the dry intermediate zones meanwhile the rest are in the wet zone. The common topographic and climatic features, type of animals and husbandry practices in the three agro-climatic zones are given in Table 2.5.

Table 2.5 Agro-climatic zones and salient characteristics

Characteristics	**Agro-climatic zones**					
	Up-country	**Mid-country**	**Coconut Triangle**	**Low country wet zone**	**Dry zone**	**Jaffna Peninsula**
Elevation (m)	>1,200	450-1,200	0-450	0-450	0-450	0-450
Rainfall (mm)	1,200-3,175	1,675-5,000	1,200-4,000	1,875-2,500	1,000-1,750	1,000-1,500
Temperature (°C)	10 to 24	21 to 32	24 to 39	24 to 35	21 to 38	27 to 35
Type of cattle	European crosses	European crosses	Local and cross breeds	Local and cross breeds	Local crosses	Local and cross breeds
Average herd size	2 to 5	2 to 5	5 to 20	2 to 10	25 to 100	30 to 50
Type of farmers	Plantation workers	Agricultural farmers	Coconut land owners and agricultural farmers	Agricultural farmers	Agricultural farmers	Agricultural farmers
Typical fodder base	Road sides and railway lines	Road side and home plots	Under coconut and post harvest crop fields	Post harvest crop fields and home plots	Post harvest crop field tank bunds and scrub jungle	Harvest and post harvest crop fields

Source: Ranaweera and Attapattu, 2006

The study was conducted in three different agro-climatic zones in Sri Lanka. The different agro-climatic zones were selected for study because of the significant variations in temperature, cattle breeds and dairy management systems.

Up-country

The Up-country is situated 1,200m above sea level and the ambient temperature range is between 10°C – 24°C. Farmers feed their cattle with weeds and fodder from the estate lands. They are mainly tea plantation workers, especially in the tea estates. Commonly in the up-country, the temperate breeds show higher performance. *Fresian*, *Jersey*, *Ayrshire* and their cross breeds are popular in this region. They mainly practice zero grazing or intensive system of management.

Mid-country

The elevation of the Mid-country varies from 450m – 1200m above sea level and the ambient temperature ranges between 21°C – 32°C. The animals feed on grass along the roadsides and home grass plots, crop residues, and tree fodder. The breed, which can be found in this region, is a European cross with Indian breeds. Animals are reared under intensive or semi-intensive management system.

Coconut Triangle

The Coconut Triangle goes from sea level – 450m and the average temperature is between 24°C – 29°C. Also, the Coconut Triangle has more than 70% of the nation's coconut plants and cattle are reared under tethered or free grazing conditions and fed mainly coconut processing by-products. The breeds are predominantly European and Indian crosses, especially *Sahiwal*, *Friesian* or *Jersey* crosses. Buffaloes are also reared in this region and the milk is normally converted to curd. They mostly practice the semi-intensive and extensive management systems.

The selected study districts were Nuwara-eliya, Kandy, and Kurunegala representing the Up-country, the Mid-country and the Coconut Triangle, respectively (Figure 2.4).

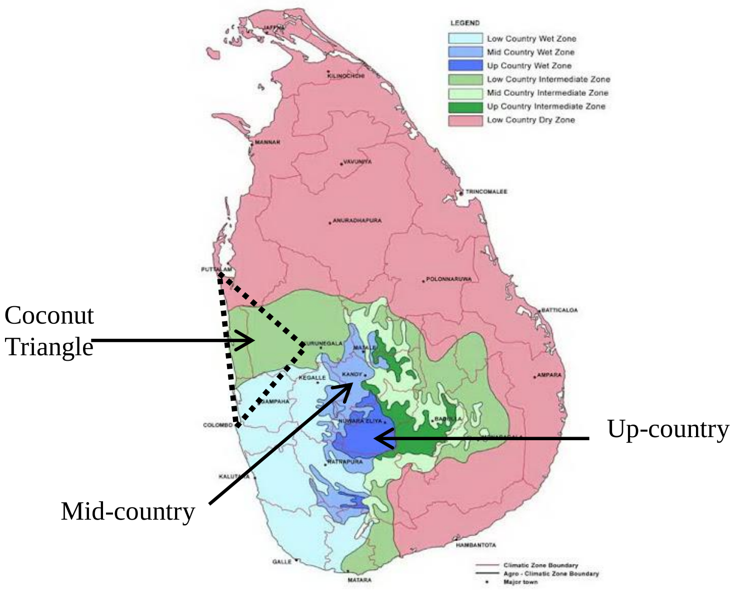

Figure 2.4 Map of the study area

The second highest cattle population (132.6 thousand numbers, 2011) is in the Kurunegala district and the monthly average milk production in Nuwara-eliya is the highest (2749.8 thousand liters, 2009) (Department of Census and Statistics, 2011) (Figure 2.5 and Figure 2.6). In addition, the Kandy district has the highest (75%) proportion of dairy cattle, mainly Jersey, Ayrshire and Friesian crosses, and the highest proportion of purebreds (25%). Average number of female animals are in the Nuwara-eliya, Kandy and the Kurunegala are 2.7 (least), 3.1 and 5.6, respectively.

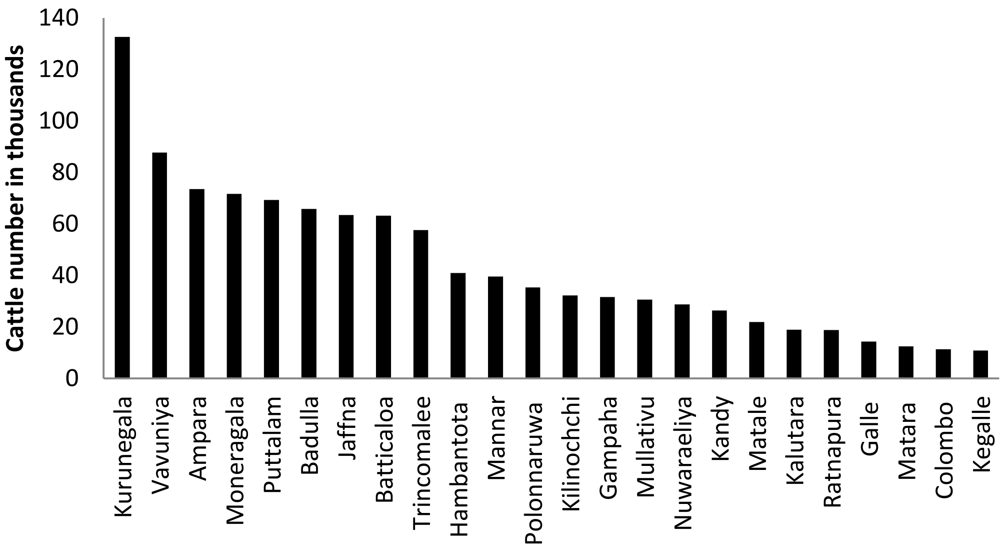

Figure 2.5 Cattle population by district -2011
Source: Department of Census and Statistics, 2011

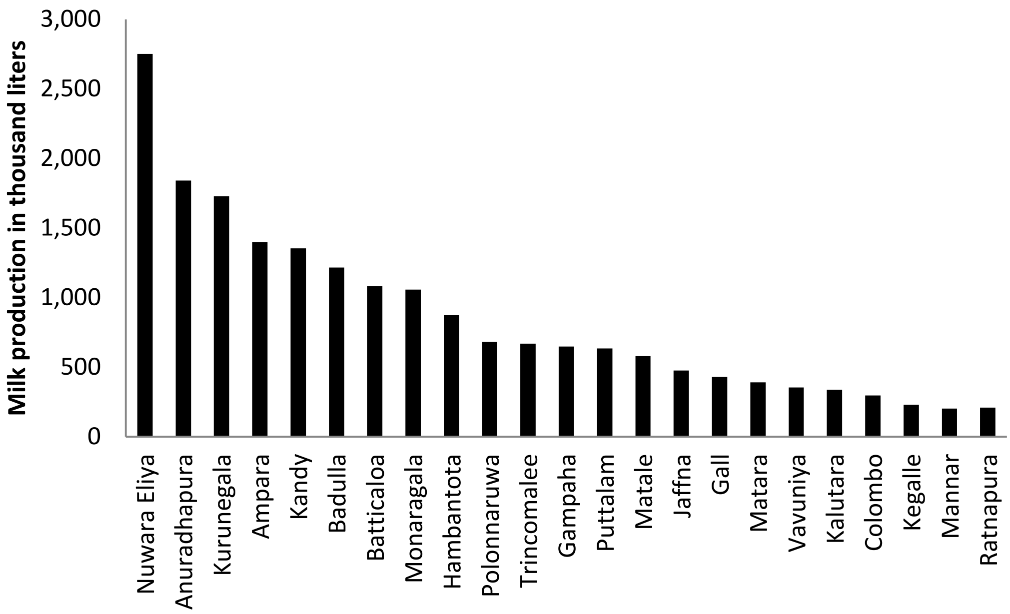

Figure 2.6 Monthly average milk production by district -2009
Source: Department of Census and Statistics, 2009

A cross-sectional survey was conducted using a multistage random stratified sample design. A total of 522 dairy farmers were interviewed and data were collected using a pre-tested structured questionnaire on socio-economic characteristics of households, dairy management practices, herd characteristics, feeding practices and expenditures, animal health and veterinary services, land utilization, and labor utilization.

2. *Methodology and Data*

Descriptive statistics such as mean, standard deviation, percentage and frequencies were used to analyze data using SPSS for windows version 16.0 (SPSS Inc., Chicago, Illinois, USA).

The linear, Cobb-Douglass and semi-log functional forms were used to determine the effect of socio-economic variables on milk production in the different agro-climatic zones. The semi-log form was selected on the basis of the number of significant variables, magnitude of R^2, F-statistics, standard error and the sign of coefficients.

The production function is estimated by;

$$\ln Q_i=\beta_0+\beta_1X_{1i}+\beta_2X_{2i}+\beta_3X_{3i}+\beta_4X_{4i}+\beta_5X_{5i}+\beta_6X_{6i}+\beta_7X_{7i}+\beta_8X_{8i}+\beta_9X_{9i}+\beta_{10}X_{10i}+\beta_{11}X_{11i}+\beta_{12}X_{12i}+e_i$$

Where Q_i is total milk yield in the i^{th} farm; Based on the literature and data available, the characteristics and related variables assumed to be affecting the milk production were included. X_{1i} is land area including both highland and lowland in the i^{th} farm. It is very difficult to measure the pasture intake of cattle. Hence, the land variable is included as an indicator of pasture source.

Increased land area may tend to increase pasture intake by cattle and therefore increase animal performance. In addition, this variable is important because the system of management and crop residuals available for the animals totally depends on the land availability; X_{2i} is labor hours per month used by the i^{th} farm and represents family and hired labor ; X_{3i} is total purchased feed quantity per month used by the i^{th} farm including formulated feed, broken rice and coconut poonac ; X_{4i} is number of cows in milk in the i^{th} farm; X_{5i} is experience of the i^{th} farmer; X_{6i} is age of i^{th} farmer; X_{7i} is cost of veterinary services (artificial insemination cost, disease treatment cost, transport cost, etc.) per month by the i^{th} farm including.; X_{8i} is a dummy variable equal to one if farmers received government subsidy (shed construction, animal purchasing, pasture cultivation, bio-gas, etc.) and zero otherwise; X_{9i} is a dummy variable equal to one if the farmers received any kind of training related to feed management, pasture cultivation, use of paddy straw, prevention of diseases etc. and zero otherwise. The training variable is included to capture directly the impact of the level of adaptation of dairy management practices on milk production; X_{10i} is a dummy variable equal to one if the farmers milked twice per day and zero otherwise; X_{11i} is a dummy variable equal to one if the farmers used natural service and equal to zero if the farmers used artificial insemination; X_{12i} is a dummy variable equal to one if the farmers practiced intensive system and equal to zero for extensive system; β_i are parameters to be estimated (i= 0,…..,12); and e is an error term.

3. *Results and discussion*

1. Socio-economic background of the dairy farmers

Out of the 522 dairy farmers selected for this study sample, 182 were from the Up-country, 144 from the Mid-country, and 196 from the Coconut Triangle.

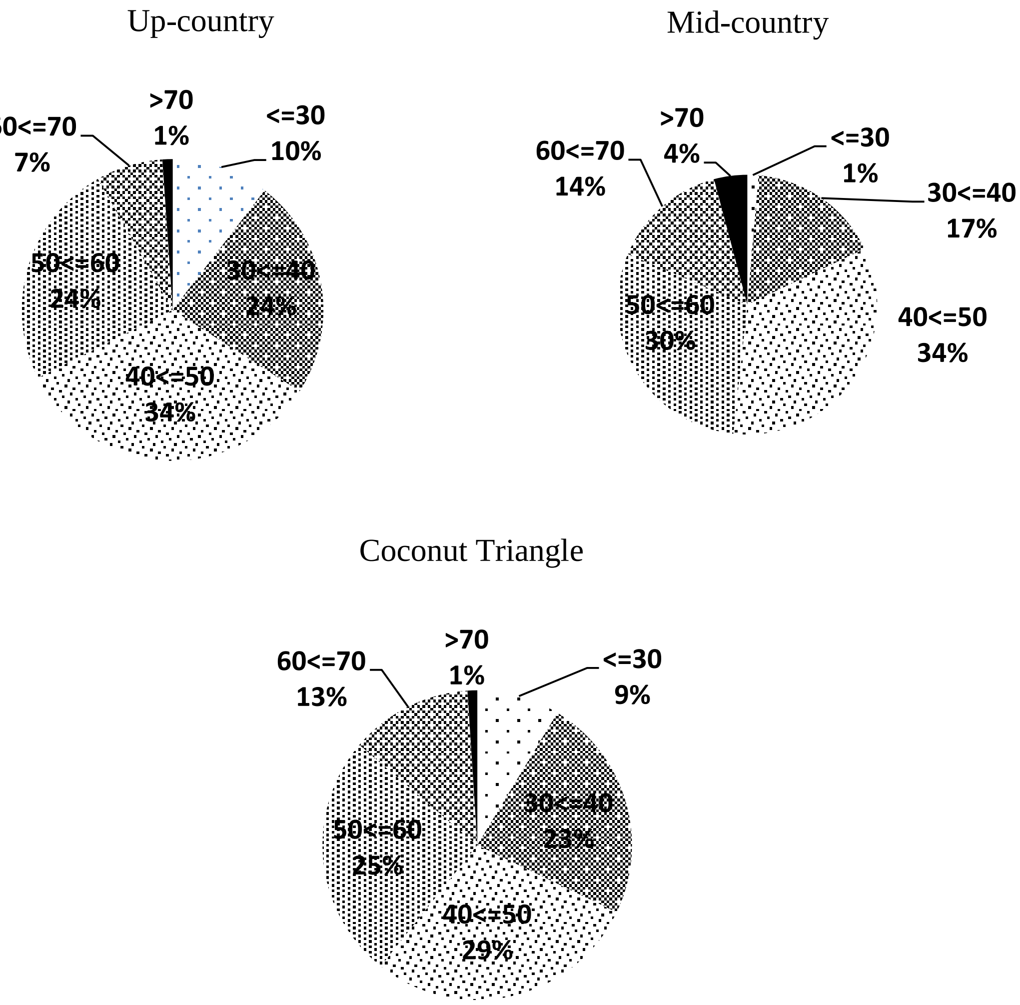

Figure 2.7 Age distribution of dairy farmers
Source: Survey cross-sectional data.

A considerable number of dairy farmers belong to the 40<=50 age group. The proportion of farmers below 30 years of age (10.4%) signifies that the involvement of the younger generation in dairy farming is relatively high in the Up-country. In the Mid-country, almost half of the dairy farmers (48.3%) of the dairy farmers were above the age of 51 years indicating that dairy is a reliable source of income after retirement (Figure 2.7).

The management of the dairy farming system can be classified into three groups: extensive, intensive, and semi-intensive. Extensive management system is low cost and has low productivity based on free grazing. The intensive system is characterized by the heavy use of efficient methods such as cut and fed in a shed, zero grazing, utilization of high yielding cows, fed compound feeds etc. The semi-intensive management system is a combination of intensive and extensive systems and it is less expensive compared with the intensive system and technically more advanced than the extensive system. The semi-intensive system is characterized by a medium level of input usage, where pregnant and lactating animals are housed indoors; others are allowed to graze in a paddock during the day and housed indoors at night.

The management system, land area and herd size are closely related and the average land area per farm in the Up-country, the Mid-country and the Coconut Triangle are 0.48, 1.04 and 3.17 acres respectively. The majority (70.3%) of the dairy farmers in the Up-country operate on land less than 0.25 acre and practiced intensive system with small herd size. In the Coconut Triangle 37.8% of the farmers used the semi-intensive system of management, with only 8.1% relying on the intensive system (Figure 2.8).

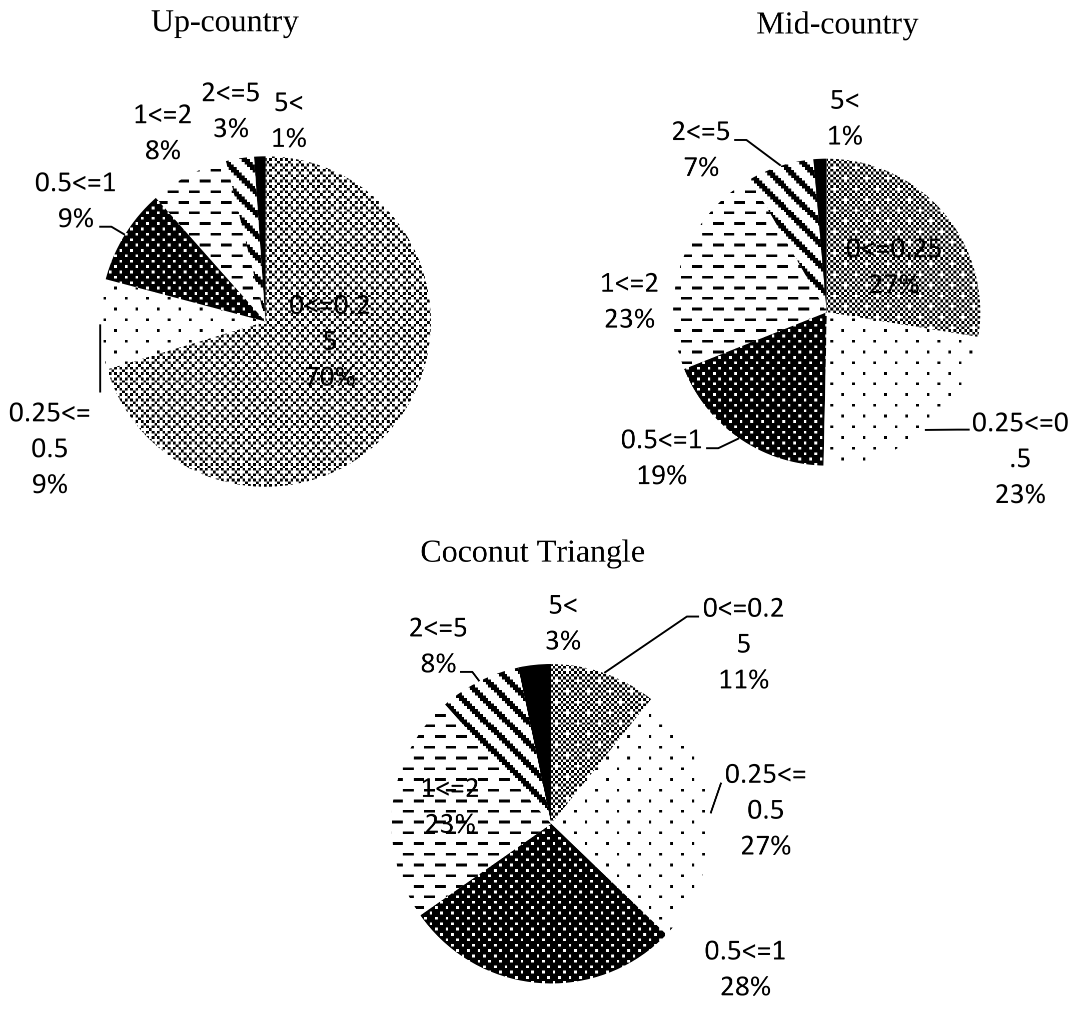

Figure 2.8 Operational extend of land area
Source: Survey cross-sectional data.

2. Multiple regression analysis

Descriptive statistics and explanation of variables used in the analysis are given in Table 2.6.The milk production depends on breed type, climatic condition, management practices and other related factors. The total milk yield per farm is highest in the Coconut Triangle and least in the Mid-country.

Table 2.6 Main characteristics of the study area

Variables	Up-country	Mid-country	Coconut Triangle
	Mean		
Total milk yield per month (000, liters)	0.532 (0.568)	0.387 (0.322)	0.647 (0.638)
Average milk production per cow per day (liter)	9.917 (4.419)	7.395 (3.399)	6.083 (2.383)
[1]Land area; Highland and lowland (acre)	0.484 (1.214)	1.050 (2.015)	3.172 (2.735)
Labor hours used per month (000, hours)	0.176 (0.079)	0.291 (0.138)	0.243 (0.109)
Total purchased feed per month (000, kilograms)	0.181 (0.263)	0.107 (0.129)	0.265 (0.533)
Cow number (head)	1.808 (1.524)	1.729 (0.984)	3.327 (2.187)
Farming experience (years)	16.745 (11.920)	17.545 (14.600)	12.001 (10.252)
Age of farm head	45.403 (11.050)	51.083 (10.478)	47.138 (11.886)
[2]Veterinary cost per month (000, rupees)	0.300 (0.425)	0.195 (0.296)	0.374 (0.723)
	Rate		
Government subsidy dummy	0.324 (0.469)	0.375 (0.486)	0.260 (0.423)
Training programs dummy	0.231 (0.422)	0.340 (0.475)	0.440 (0.495)
Milking time dummy	0.851 (0.357)	0.746 (0.437)	0.240 (0.428)
Breeding method dummy	0.040 (0.195)	0.042 (0.201)	0.153 (0.361)
Management system dummy			
Intensive system	0.654 (0.477)	0.493 (0.502)	0.082 (0.275)
Extensive system	0.033 (0.179)	0.014 (0.117)	0.378 (0.486)

Note: Standard deviations in parentheses.
[1]Highland includes pasture land, crop land and housing area; Lowland used for paddy cultivation.
[2]Deflated value is used, because, the study was conducted in three different time periods.
Source: Survey cross-sectional data.

Table 2.7 presents the results of multiple regression analysis. The variance inflation factor (VIF) was used to check for multicollinearity and employed a Ramsey reset test to diagnose omitted variable bias. The coefficients of total land area were found to be significant with a positive effect in the Mid-country and the Coconut-Triangle, but not in the Up-country. The average land area per farm in the

Up-country, the Mid-country and the Coconut Triangle are 0.48, 1.05 and 3.17 acres, respectively. Increased land area may tend to increase pasture intake by cattle and therefore increase animal performance and total milk production. In addition, this variable is important because the system of management and crop residuals available for the animals is totally dependent on land availability. The average land area per farm in the Up-country is very small and they are heavily dependent on purchased feed such as formulated feed, broken rice and coconut poonac (a by-product of coconut oil production).

Table 2.7 Socio-economic correlates of dairy farms in different agro-climatic zones

Variables	**Up-country**	**Mid-country**	**Coconut Triangle**
		Coefficients	
Constant	3.075 (0.087)***	3.069 (0.124)***	3.143 (0.075)***
Land area	0.002 (0.013)	0.023 (0.009)**	0.010 (0.005)***
Labor hours used	0.368 (0.076)*	0.006 (0.141)	0.380 (0.003)***
Total purchased feed	0.312 (0.090)***	0.301 (0.151)**	0.047 (0.035)
Cow number	0.067 (0.012)***	0.169 (0.021)***	0.122 (0.006)***
Farming experience	0.002 (0.001)	- 0.001 (0.002)	0.002 (0.001)
Age of farm head	- 0.003 (0.002)*	0.001 (0.002)	- 0.002 (0.001)
Veterinary cost	0.007 (0.038)	- 0.092 (0.061)	0.023 (0.018)
Subsidy dummy	0.042 (0.034)	0.109 (0.042)**	0.004 (0.032)
Training programs dummy	0.104 (0.039)***	0.055 (0.039)	0.025 (0.028)
Breeding method dummy	- 0.005 (0.081)	- 0.083 (0.088)	- 0.143 (0.039)***
Management dummy			
Intensive system	0.065 (0.074)*	0.113 (0.039)***	0.044 (0.048)
Extensive system	0.009 (0.122)	0.047 (0.151)	- 0.033 (0.031)
R-squared	0.68	0.60	0.80
Adjusted R-squared	0.65	0.56	0.78
F - statistic	26.60***	14.59***	55.12***
Sample size	182	144	196

Note: Standard errors in parentheses.
*, **, and *** are statistically significant at 10%, 5% and 1% level respectively.
Dependent variable – Log milk production per month per farm
Source: Survey cross-sectional data.

The intensive management system was found to be positive and significant in the Up-country and the Mid-country. A majority of the farmers in the Up-country (65%) and the Mid-country (49%) practice intensive management system due to land limitation and some characteristics associated with the breeds raised. This implies that milk production in these zones tends to increase as percentage of intensively managed farms increases. In the Coconut Triangle, a majority of the farmers were practicing semi-intensive (54%) and extensive (38%) management systems due to the greater availability of land and low cost breeds. The same coefficient had a positive relationship with milk production, although it was not significant. The reason is fewer farmers operate intensively in this area.

The average amount of purchased feed fed per milking cow per day in the Up-country, the Mid-country and the Coconut Triangle are 3.22, 2.28 and 2.06 kilograms, respectively. The coefficients of total purchased feed quantity were found significantly positive in the Up-country and the Mid-country, while it was insignificant in the Coconut Triangle. This happens because of the potential cattle-grazing area (number of animals per unit of land area) is comparatively high in the Coconut Triangle compared with the other two agro-climatic zones. Therefore, animals are either graze or tethered in the paddy fields along roadside or in the backyard.

Government subsidies have played a key role in the Mid-country and more than 37% of the farmers in the Mid-country have received money for cattle shed construction, while dairy extension and training plays a main role in milk production in the Up-country. These findings indicate that subsidy and training are important factors in milk production. Additionally, the Up-country farmers use high tech, expensive and efficient methods (in feeding and breeding) in dairy farming. Interestingly, “Age” of the farmers in the Up-country has a negative relationship with milk production, which suggests that older farmers tend to be less efficient. This agrees with the findings of Omonona *et al.*[12]. It could be that older farmers have a less access to technology than younger farmers. In the case of new technology, for example feed management, older farmers may be less adaptable than younger ones. This suggests that dairy farm training may improve the use of new technology making the production process efficient.

As expected, the coefficients of the milking time dummy were found highly significant with a positive impact on average milk production in all agro-climatic zones. The coefficient of natural service breeding method was found significantly negative in the Coconut Triangle while, it was insignificant in the Up-country and the Mid-country. In the Coconut Triangle, some dairy farmers (10%) tend to use natural service over artificial insemination for many reasons such as, availability of bulls, having enough land for mating, problems in getting timely artificial insemination and difficulties with heat detection. This suggests that a dairy farmer, who uses artificial insemination, will see milk production of the farm increase.

B- Milk marketing channel analysis

Table 2.8 shows the effect of milk marketing factors on milking frequency. Marketing channels dummy has a positive relationship with milking frequency, suggesting that when there are more marketing options farmers tend to be milk twice a day. In addition, there is a negative and significant relationship between distance to milk collecting center and milking frequency. In the study area, the distance between farm gate to milk collecting center ranged between 0 to 10 kilometers. The long distances between farmers and the milk collection center lead to milk once per day especially, due to poor farm milk storage and processing facilities. Therefore, the development of milk collection infrastructure facilities at the farmers door step is important.

Table 2.8 Effect of milk marketing factors on milking frequency

Spearman's correlation coefficient for the milking frequency

Variables	**Milking frequency dummy (twice/day=1, once/day=0)**
Marketing channels dummy (more than one marketing channel =1, one marketing channel =0)	0.235***
Distance to milk collecting center (km)	- 0.127**

Note: *, **, and *** are statistically significant at 10%, 5% and 1% level respectively (Two-tailed test).
Source: Survey cross-sectional data.

On-farm consumption (non-marketed milk) accounts for 3% of milk and the remaining 97% is marketed through various channels (Figure 2.9). 90% of marketed milk flows through dairy co-operative societies, milk collectors and processors. The balance of market milk sold to informal marketing channel. Informal marketing channel include: direct milk sales to neighbors (65%); individual milk traders who also sell either directly to consumer or to processors (21%) and 14% of farmers produced yogurt or curd.

The average farm gate milk price for the sample was Rs. 31.08 during the study period. The cost of production of liter of milk including family labor is Rs. 45.02 and family labor cost accounted for 68% of the total production cost. While excluding family labor cost was Rs. 10.90/liter. Despite family labor cost, the dairy farmers are enabling to cover the production cost but there are no opportunities for significant profit with labor cost.

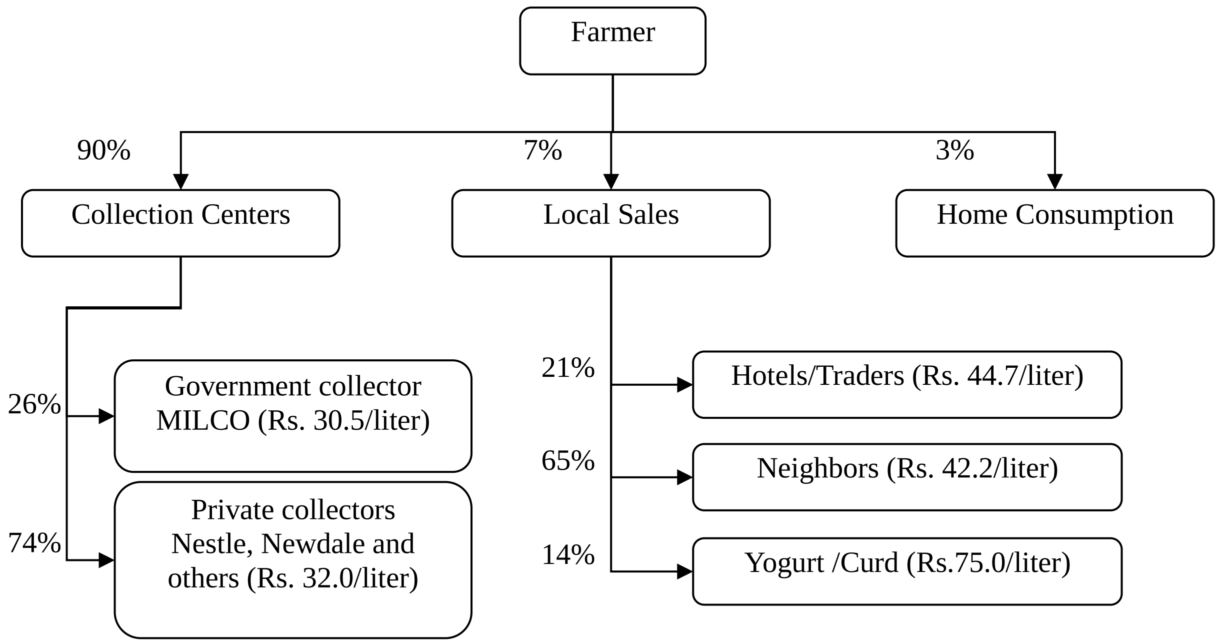

Figure 2.9 Milk marketing channel in the Coconut Triangle
Source: Cross-sectional data

2.3 Infectious diseases and its control

2.3.1 Infectious diseases

A- Mastitis

Mastitis is the most prevalent and most costly production disease in dairy herds' world-wide and is responsible for several production effects (Miller et al., 1993). It is characterized as a persistent, inflammatory reaction of the udder tissue in cows, and is a major endemic disease of dairy cattle. Mastitis is a worldwide problem as it adversely affects quality and yield of milk, economics of milk production, and animal health and welfare (Sharma et al., 2007). Maiti et al. (2003) recorded 70.37 % incidence of subclinical mastitis in cows, while Sharma et al. (2004) reported 70.32 % prevalence of subclinical mastitis in buffaloes.

Worldwide, total annual economic losses attributable to mastitis have been estimated at 35 billion annually (Chockalingam et al., 2007). Economic losses due to mastitis result from lower milk production per cow (up to 70 %), milk discard during and after treatment (9 %), and premature culling (14 %) (Bhikane and Kawitkar, 2000). Apart from its great economic significance it also carries public health importance (Vasavda, 1988).

Moreover, mastitis had been and continues to be recognized as one of the serious major disease problems concerning the dairy industry in Sri Lanka. Mastitis is the widespread, production disease among cows and it is 32.6 % in the Up-country, 21.5 % in the Mid-country, and 26.5 % in the Coconut Triangle (Figure 2.10).

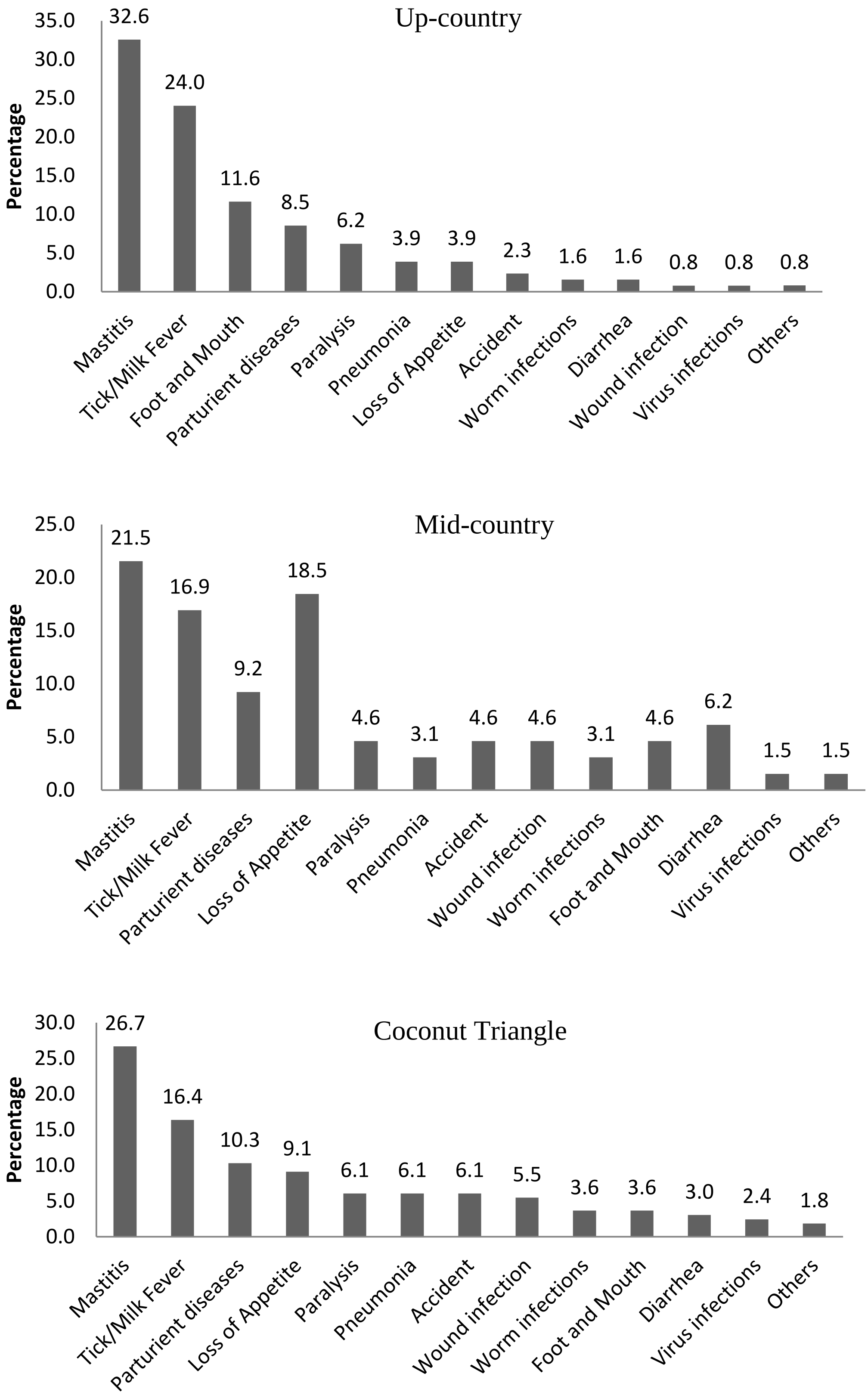

Figure 2.10 Disease of cows in the study areas
Source: Cross-sectional data

B- Food and Mouth Disease (FMD)

Foot and Mouth disease is an infectious, highly contagious viral disease of cloven-hoofed mammals (Alexandersen and Mowat, 2005). Also, it is the first disease in the OIE-list and the control is regarded as high priority. FMD has an ancient history in Sri Lanka. It is endemic in the country particularly in the eastern part of Northern and Eastern Provinces causing extensive outbreaks causing to major epidemics which often affect other areas too.

Figure 2.11 describes the number of the cases and the number of deaths due to FMD between 1997 and 2014. Further, FMD is the most serious outbreak was recorded in 2014. Within few months the disease has spread throughout the country, resulting 58, 645 cases and 1,265 deaths. Out of 9 provinces 8 provinces were affected (Figure 2.12). (See chapter 4 for more details).

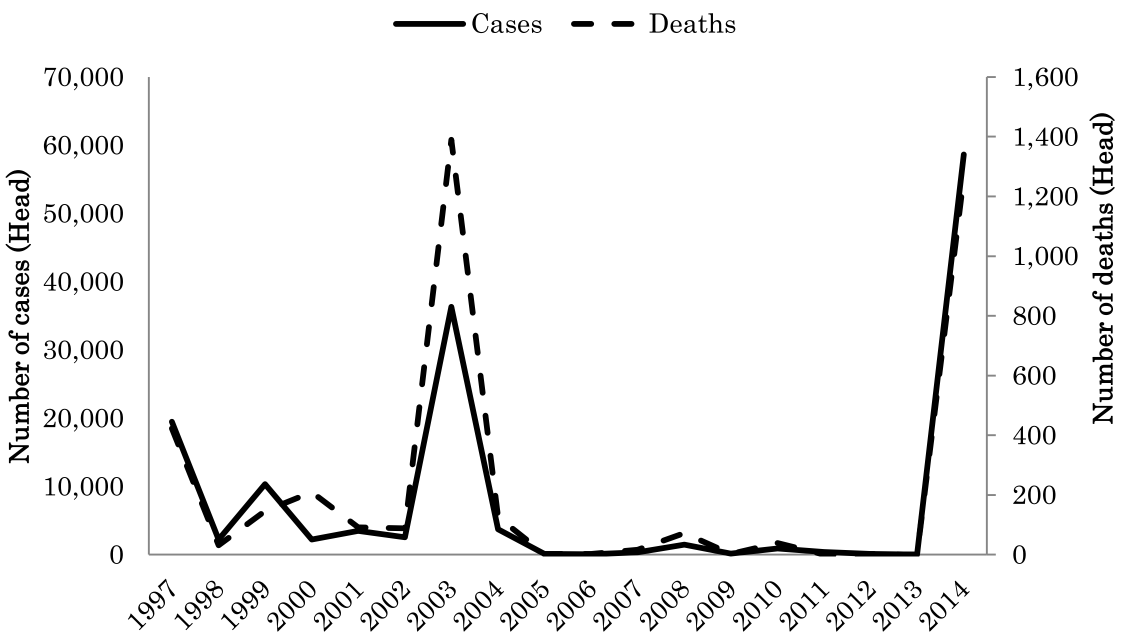

Figure 2.11 Distribution of FMD cases between 1997 and 2014 June
Source: Department of Animal Production and Health

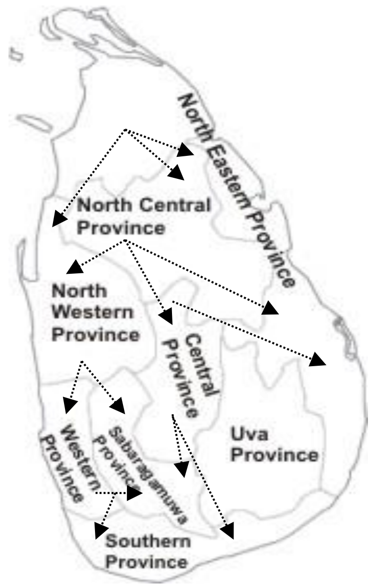

Figure 2.12 Spatial distribution of FMD

Summary of the investment program is shown in Table 2.9. The government has given a higher priority for disease control and prevention. Nearly 39 % (7,120 million rupees) of government spending on the livestock development goes to the health management and disease control program and the veterinary service improvement program. Further, 45 % of health management and disease control budget, 860 million rupees allocated for FMD control and eradication strategies (Figure 2.13).

Table 2.9 Summary of the invest program (Rs. Million)

Program	2011	2012	2013	2014	2015	Total
Small-medium dairy farm development program	678	997	1443	1805	1102	6025
Animal feed resources development program	18	33	37	37	25	150
Milk marketing program	50	466	528	372	253	1669
Animal breeding program	200	305	600	505	390	2000
Health management and disease control program	305	405	365	395	430	1900
Veterinary services improvement program	644	1094	1294	1294	894	5220
Research program	20	27	33	40	20	140
Man power development program	40	155	290	205	30	720
Institutional development	4	8	110	212	56	390
Grand Total	**1,959**	**3,490**	**4,700**	**4,865**	**3,200**	**18,214**

Source: Livestock Master Plan, Ministry of Livestock and Rural Community Development, 2011.

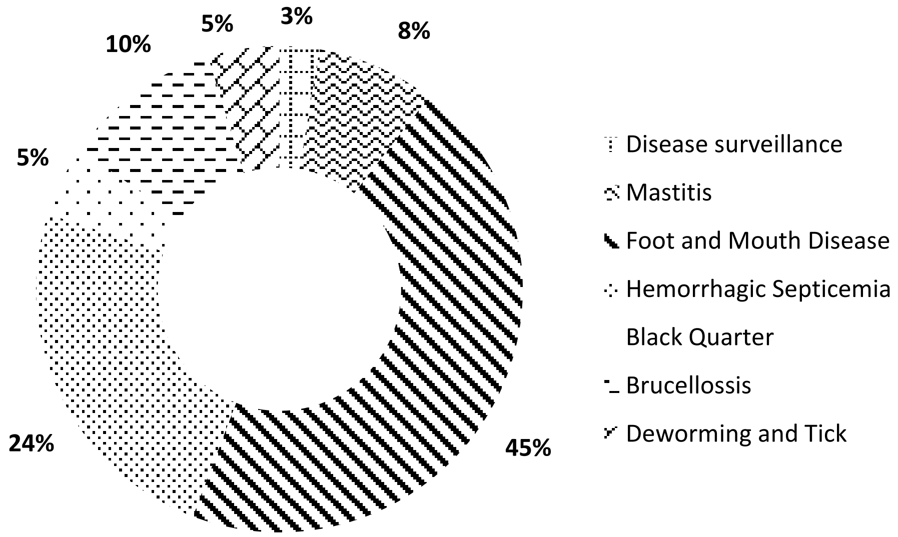

Figure 2.13 Health management and disease control programme
Source: Livestock Master Plan, Ministry of Livestock and Rural Community Development, 2011.

2.3.2 Institutional and policy support to the livestock sector

A- Government and non-government institutions

The institutional support is provided by the state sector, the public enterprises, the co-operative sector, and the private sector. The small holder livestock farmers are scattered all over the country. The following institutions are responsible for managing different functions in the livestock sector of Sri Lanka.

1. State Sector

Institution	Function
Ministry of Agriculture and Development	Policy formulation, allocation of other resources ,negotiation of external assistance to the sector, and for coordination among other ministries and relevant government agencies
Department of Animal Production and Health (DAPH)	Assisting policy planning, formulation, and monitoring, maintenance of animal quarantine, manpower planning, management of the National Diploma in Animal Husbandry, backstopping provincial extension activities, research and investigation on the livestock industry, production and distribution of vaccines, administration of legislation, livestock importation and execution of selected specific products
Provincial Department of Animal Production and Health (Provincial DAPHs)	Implementing, supervising and monitoring animal husbandry programs, extension activities, provision of animal health services, implementation of national breeding program, issuance/coordination of the supply of improved varieties, dissemination of knowledge, training of farmers, organization of livestock farmers into Farmers Associations, issues of suitable varieties of pastures and fodder plants
Faculty of Veterinary Medicine and Animal Science, University of Peradeniya	Academic degree for development of higher level expertise and skills for the livestock industry, livestock related research and dissemination of information
Seven Agricultural Faculties in the Universities	All faculties incorporate Department of Animal Science responsible for degree courses in a wide range of livestock relate disciplines

Source: Ministry of Agriculture and Development

2. Co-operative Sector

Institution	Function
Various Co-operative Societies including MILKFED	Promotion of procurement of milk and value added milk products, welfare schemes for members

Source: Ministry of Agriculture and Development

3. Public Enterprises

Institution	Function
National Livestock Development Board (NLDB)	Breeding and supplying improved varieties of livestock
MILCO	Procurement and processing of milk, institutional support for dairy sector development
Mahaweli Livestock Enterprise, of Mahaweli Authority of Sri Lanka	Promoting and popularizing boiler farming among the rural settlers in Mahaweli project area
Samurdhi Authority	promoting livestock relation micro projects effectively harnessing the rural man power

Source: Ministry of Agriculture and Development

4. Private Sector

Institution	Function
Dairy Industry: Nestle Lanka Ltd., Kothmale Dairy, Ariyakelle Farm, Newdale Dairies (Pvt) Ltd,	Procurement and processing of milk, packaging and marketing of milk products
Animal Feed Industry: New Bernards, Master Feeds, Prima, Nutrena Feeds	Manufacture and market animal feeds

Source: Ministry of Agriculture and Development

B- Veterinary services

Most of public veterinary services were via DAPH's Division of Animal Health and Extension (AH&E) and the Veterinary Research Institute (VRI). The profile of veterinary service arranged in the community level compromised of VS's, LDI's and LDT's covering AGA (Assistant Government Agent). VS was assigned by LDI's and LDT's in clinical animal treatments, vaccination, distribution of planting materials free of cost, distribution of low priced improved sires, provision of subsidized A.I services, organization and management supervision of single purpose livestock and dairy cooperatives, administration of subsidies for pasture development and livestock housing, holding of field days and farmer group discussions and farmer training.

The trend of demand for better veterinary services increasing day by day, when farmers more conscious about livestock productivity, since this would stimulate on going livestock services improvement via diagnosis of extraordinary and unexpected diseases in well-equipped laboratories.

C- Extension and training services

Most of public veterinary services were via DAPH's Division of Animal Health and Extension (AH&E) and the Veterinary Research Institute (VRI). The profile of veterinary service arranged in the community level compromised of VS's, LDI's and LDT's covering AGA (Assistant Government Agent). VS was assigned by LDI's and LDT's in clinical animal treatments, vaccination, distribution of planting materials free of cost, distribution of low priced improved sires, provision of subsidized A.I services, organization and management supervision of single purpose livestock and dairy cooperatives, administration of subsidies for pasture development and livestock housing, holding of field days and farmer group discussions and farmer training.

Veterinary ranges compromising Veterinary Surgeons (VS), Livestock Development Instructors (LDI's) and Livestock Development Technicians (LDT's). The field level extension staff spend about one third of their time on extension including AI services, disease investigation, castration, improved breeding stock and planning materials in addition to provide administer subsidies.

Private institutions such as PRIMA Ltd and Nestle Lanka Ltd also provide well organized extension programs to the farming community. The major element of the PRIMA Ltd is to distribute properly projected newsletter which provides information on marketing, technical and livestock. Nestle Lanka Ltd provide extension on dairy livestock feeding and management, and facilitate the provision of health services including private veterinary services to overcome the disparities in government veterinarians.

2.4. Conclusion

This chapter mainly examined the effect of socio-economic factors on milk production in different agro-climatic zones in Sri Lanka. The intensive system of farm management has a significantly positive impact on milk production in the Up-country and the Mid-country. Thus, the government should promote dairy farm intensification, taking into consideration resource availability, in each agro-climatic zone. However, because of land limitations due to population pressure, land segmentation and a small quantity of compound and coarse feed in the distribution system in Sri Lanka more than 90% of the farm herds in the Up-country and the Mid-country are less than five cattle. Thus, common pastures will be important in providing a continuous supply of milk production in the future. In order to have a long-term commitment to pasture management farmer management societies will need to be established.

The government training and extension service play an important role in the Up-country, while, in the Mid-country, government subsidies have had a significant influence on milk production. Therefore, the development of human capital is important through training and extension. Furthermore, as milking twice a day has been found to be more productive than once a day, it is important that efforts be made to increase milking frequencies through credit or subsidies for the purchase of milk storage and cooling facilities and to solve the major problem of insufficient capacity of the milk collection centers. In the Coconut Triangle farmers have enough pasture and they mainly used local and cross breeds. The negative impact of natural service breeding suggests that artificial insemination leads to higher average milk production in the Coconut Triangle. This finding has important implications and the progeny test could be used to select high yielding, heat tolerant and more feed efficient breeds. There are some constraints, however, since introducing exotic breeds from a temperate zone can reduce production and to complete a set of progeny tests will take at least seven years.

In addition, the poor marketing options and long distance from farm gate to milk collecting center have a negative influence on milking frequency. As milking twice a day has been found to be low cost than once a day, it is important that efforts be made to increase milking frequencies through credit or subsidies for the purchase of milk storage and cooling facilities. Thus, the milk collecting network of the area needed to be strengthened through improvement of milk collection infrastructural facilities at the farmers door step and milk delivery to the collecting centers. And even if farmers can find an alternative sale for the milk, some processors or markets, don't conduct milk testing for milk quality and milk composition and they accept lower quality milk. Thus, farmers have low incentive to improve hygienic quality of milk. Therefore, the training and extension programs are need to improve the farmer awareness about clean milking, milk handling and storage practices. Additionally, in the study area the main problem is insufficient capacity of the milk collecting centers. Thus, improving the capacity of milk collecting and chilling center will be important in providing a continuous supply of milk in the future.

CHAPTER 3

Technical efficiency and feed resource use in small-scale dairying

3.1 Introduction and objectives

The crucial role of efficiency in increasing agricultural productivity has been widely recognized by researchers and policy makers alike. It is not surprising; therefore, that considerable effort has been devoted to estimate the farm level technical efficiency in developing country agriculture. Studies of this have been published for the Philippine, Malaysia, India, Tanzania, Guatemala and Jamaica (Kalirajan and Shand, 1985; Rawlins, 1985; Kalirajan and Shans, 1986; Taylor and Shonkwiler, 1986). An underling premise behind much of this work is that if farmers are not making efficient use of available inputs (technology), then efforts designed to improve efficiency would be more cost-effective than introducing new technologies (Belbase and Grabowski, 1985).

Most farm households in developing countries are small-scale farmers, thus “Improving the efficiency of smallholder’ is a massively complicated challenge facing the developing world. Due to this reason, rather than advocating investment for the small-scale farmer, which may be beyond their capacity, it is prudent to inquire into the ways of using the available resources to the maximum.

There have been only a few studies that have attempted to assess the dairy production efficiency in developing countries. These include the work by Bailey et al (1989) who analyzed technical, allocative and economic efficiency for a sample of Ecuadoren milk producers; Kothalawala et al (2006), who measured resource use efficiency of small-scale dairying in Bareilly District of Uttar Pradesh in Indian; Edirisinghe et al (year), who measured technical efficiency for a sample of dairy farmers in Sri Lanka. However, this study has ignored the allocative efficiency. In addition, some studies have examined the characteristics and profitability of dairy farms in Sri Lanka (Navaratne et al , 2003; Jayaweera et al 2007)

The future development of the livestock sector in Sri Lanka is constrained by several factors: lack of profitability, insufficient use of new feeding technologies, and inadequate support services. In addition, the already high average feed cost (62% in intensive system), the highest cost element incurred in milk production (Department of Animal Production and Health 2009), leaves no room for additional feed cost increases. A number of papers have been published on economics of small scale dairy farming in Sri Lanka (Hitihamu et al 2007; Jayaweera et al 2007; Navaratne & Buchenrieder 2003). However, most of these works studied the cost of production and dairy profitability. There has been little research on dairy farm management that considers the impact of feed resource constraints, a common challenge for efficient dairy farm management in developing countries.

However, no study to date has examined the technical efficiency of dairy farms in different agro-climatic zones in Sri Lanka. Studying of the factors that determine milk production and farm efficiency in each agro-climatic zone are important from a farmer's, as well as, from a policy point of view. Policy makers can use this knowledge to identify and target public interventions to improve farm productivity and income, while farmers can use this information to improve their performance, which ultimately leads towards self-sufficiency in milk production.

Hypothesis: Farmers do not allocate resource efficiently and efficiency is significantly different among different management systems related to different agro-climatic zones.

Therefore, it is necessary to study the efficiency of resource utilization in order to enhance the profitability and productivity of the dairy sector. Consequently, the objective of this study is to:

1) Examine the level of technical efficiency of dairy farmers in Up-country and the Coconut Triangle
2) Evaluate the resource use efficiency of feed resources use Up-country and the Coconut Triangle
3) Draw some policy implication based on the findings

3.2 Background

Dairying is an important source of subsidiary income especially for the marginal farmers in the mixed crop livestock system in Sri Lanka. A traditional industry surviving thousands of years, thus their levels of technical efficiency must improve if they are to survive in this complex and evolving market (Tauer, 2001; Cabrera et al, 2010).

The type of dairy farming management system used in Sri Lanka is highly dependent on the agro- climatic zone where the farm is located. Each dairy farm and agro-climatic zone has its own unique ability to make decisions to produce a certain output given a set of inputs and technology. "Technical efficiency" is the ability of farms to produce the maximum possible output with a given set of inputs" (Farrell, 1957; Coelli, 1995). Thus, understanding technical efficiency, its measurement and determining factors, is of crucial importance in dairy production economics.

3.2.1 Theoretical frame work

A- Efficiency

The concept of efficiency is concerned with the relative performance of the processes used in transforming given inputs into outputs. Economic theory identifies three main types of efficiencies. These include: technical, allocative and economic efficiencies. Technical efficiency (TE) is the ability of a farmer to obtain the maximum possible output with given set of inputs and the technology. In contrast allocative efficiency (AE) refers to the ability of the farmer to use the inputs in optimal proportions given relative input prices (Farrell 1957; Coelli et al. 2005). Overall economic efficiency is the product of technical and allocative efficiency.

Efficiency is a very important factor of productivity growth especially in developing agricultural economics such as Sri Lanka, where resources are meager and opportunities to use new technologies are limited. Such economies can benefit greatly from efficiency studies which indicate that it is possible to raise productivity by improving efficiency; without increasing the resource base or developing new technologies (Ali and Chaudhry, 1991). For efficient production, non-physical inputs, such as experience, training, information and supervision, might influence the ability of a farmer to use the available technology more efficiently. Each type of inefficiency is costly to a firm or production unit in the sense that, each inefficiency causes a reduction in profit below the maximum value attainable under full efficiency (Bifarin et al., 2010).

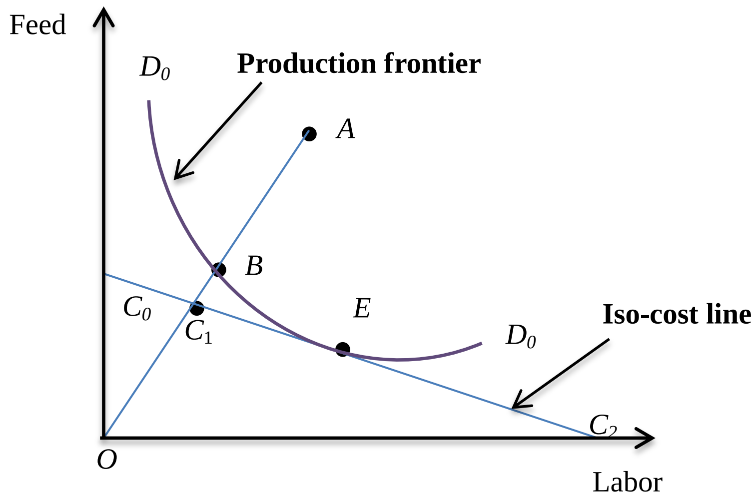

Figure 3.1 Technical, allocative and economic efficiency for an input oriented model

The concepts of technical and allocative efficiency and their measurements are graphically depicted in Figure 3.1. It is assumed that a farmer uses two inputs, labor and feed, to produce a single output under the assumption constant return to scale. The curve D_0D_0 indicates efficient combinations of inputs in producing output level D_0 (i.e., the isoquant of fully efficient farms). The efficient isoquant indicates the production "frontier" and all points on the curve $D_0D_0$are technical efficient. If a given farm uses quantities of inputs at the point *A* to produce a unit of output, the technical inefficiency could represent as the distance *AB*. It is the amount by which all inputs need to reduce to achieve technical efficient production. The value of technical efficiency ranges between 0 and 1, and the degree of technical efficiency at this point is given by the ratio:

$$\text{TE}=OB/OA$$

If TE is equal to 1, saying the farm produces with fully technical efficiency. For example, point B lies in the efficient isoquant therefore farm could gain full technical efficiency.

The iso-cost line C_0 C_1 depicts input combination of feed and labor having an aggregate cost of C_0. The degree of allocative efficiency at this point is given by the ration:

$$\text{AE}=OC_1/OB$$

The distance from *B* to C_1 indicates the decrease in production costs if production is performed at the point E with technically and allocativelly efficient instead of at the point B with technical efficient, but allocative inefficient.

The overall economic efficiency (EE) is identified by the ratio:

$$AE = OC_1/OA$$

Also the cost cut in production with the distance from A to C_1 would happen if a farmer produced at the allocativelly and technically efficient point C_1 instead of at the point A with allocative inefficiency and technical inefficiency.

B- Stochastic Production Frontier (SPF) Analysis and Data Envelopment Analysis (DEA)

In the literature, there are two most commonly-used empirical methods for measuring technical efficiency, assuming the presence of inefficiency in the production system. There are stochastic production frontier (SPF) analysis (Aigner et al. 1977; Meeusen and van den Broeck, 1977) and the data envelopment analysis (DEA) (Charnes at al, 1978. SPF is parametric, while the DEA is a nonparametric approach or mathematical programming method.

Farell (1957) distinguishes input and output oriented measures depending on which factors assume changing. Therefore, in the input oriented estimate the input quantities changing without altering the output quantities. The output oriented measure is the opposite of the input oriented (Farell, 1957 and Coelli, et al., 2005). Both input and output orientations generate the same technical efficiency level under the assumption constant return to scale. Figure 3.2 and Figure 3.3 present the technical efficiencies from an input orientation and an output orientation, respectively.

A farm with two outputs (Milk and meat) and a single input (Feed) and keep the input quantity fixed; E_0E_1 represents the production frontier and point A the inefficient farm. The distance between A and B measure the technical inefficiency therefore the output oriented technical efficiency is the ratio of OA and OB, which represents the percentage by which output could be raised without requiring extra input quantities.

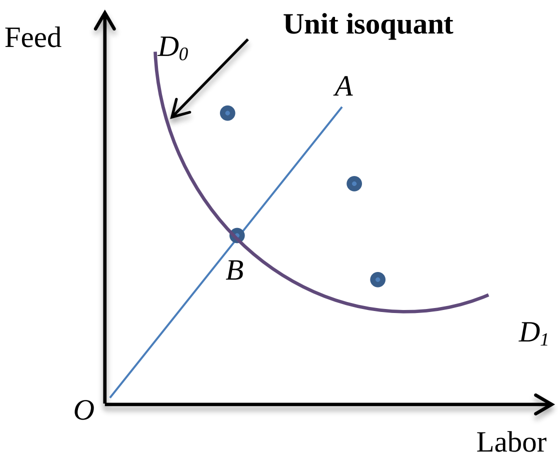

Figure 3.2 Technical efficiency from an input orientation
Note: TE of farm A = OB/OA

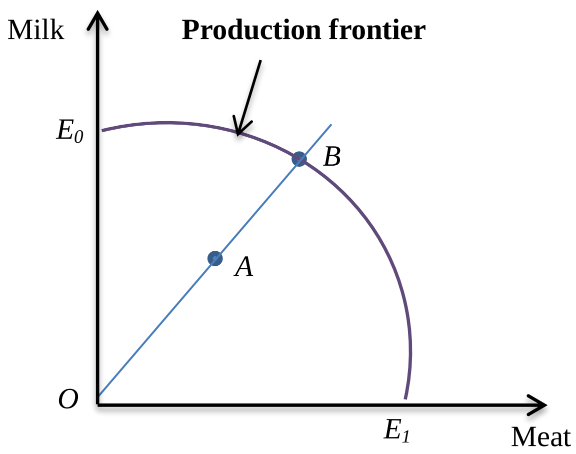

Figure 3.3 Technical efficiency from an output orientation
Note: TE of farm A = *OA/OB*

In practice the efficient isoquant is not known, therefore the researches have to measure it from the sample data using different kind of analyses. In the previous literature, most studies have used either a nonparametric method such as DEA (Tauer, 1998; Yin, 1998; Sharma, et al. 1999; Stokes et al., 2007) or a parametric method such as SPF method (Heshmati and Kumbhakar, 1994; Parikh and shah, 1999; Ajibefun and Daramola, 1999; Cuesta 2000; Bravo-Ureta et al., 2008) to analyze the potential sources of inefficiencies.

Coelli (1995) compared two methods and concluded the main advantages of the SPF approach. The SPF allows dealing with stochastic noise (inefficiency effects) and statistical tests also can incorporate pertaining to structure of production and the degree of in efficiency. The SPF is considered more appropriate for measuring the level of technical efficiency in developing economies, where data are often effected by stochastic noise (such as diseases, weather conditions, etc.) and other measurement errors (Fare et al, 1985; Coelli et al, 2005).

Therefore, most studies have used the SPF analysis to measure technical efficiency. In the study of dairy farming in Wisconsin, Cabrera et al (2010), using the Cobb-Douglas production frontier found that production exhibits constant return to scale and that, additionally, farm intensification, the level of contribution of family labor in the farm activities, the use of a total mixed ration feeding system, and milking frequency had a positive association with farm technical efficiency. Ajewole and Folayan (2008) investigated the technical efficiency in dry season leaf vegetable production among smallholders in Ekiti State, Nigeria. The study concluded that older and more experience farmers tended to be less efficient in dry season leaf vegetable production, and that the higher the level of education, the credit accessibility and the extension visits, the less the level of technical inefficiency.

The DEA, on the contrary, allows multiple inputs and outputs when constructing a production frontier. Further, the approach does not require imposing any assumption regarding a structural relationship between the sets of inputs and the outputs in the production process. An extensive technical details and discussion is available in Ali and Seiford (1993).

3.3 Materials and methods

3.3.1 Study area, data source and collection procedure

The study was conducted in the “Coconut Triangle”, an intermediate dry zone, which consists of the Kurunegala, Puttalam, Gampaha and Colombo districts and has more than 70% of the nation’s coconut plants and the “Up-country”, a wet-zone, made up of the North Western and Central provinces of Sri Lanka (Figure 3.4). The Coconut Triangle is situated 0-450m from the sea level and the annual rainfall ranges between 1,200 and 4,000mm. In contrast, the Up-country is located 1,200 m above sea level and the annual rainfall is between 1,200 and 3,175 mm (Ibrahim *et al* 1999). The main rainy season occurs from November to February due to the North-East monsoon called the *maha* season. The long dry season lasts from May to September, which brings little rainfall from the South-West monsoon called the *yala* season (Survey Department 1998).

Figure 3.4 Map of the study area

The breeds, which can be found in the Coconut Triangle, are European and Indian crosses, especially Sahiwal, Friesian or Jersey crosses. They mostly practiced the semi-intensive type of management system. In the Up-country, Friesian, Ayrshire, Jersey and their cross breeds are reared under intensive or semi-intensive management system (Table 3.1).

Table 3.1 Main characteristics of the study area

Characteristics	Coconut Triangle	Up-country
Main Districts	Kurunegala, Puttalam, Gampaha and Colombo	Nuwaraeliya
Elevation (m)	0-450	>1,200
Rainfall (mm)	1,200-4,000	1,200-3,175
Temperature (° C)	24 to 39	10 to 24
Type of cattle	Local and cross breeds	European crosses
Management system	Intensive and Semi-intensive	Intensive, Semi-intensive and Extensive

Source: Ibrahim et.al 1999.

The two different agro-climatic zones (Coconut Triangle and Up-country) were selected intentionally to study the significant variations in temperature, cattle breeds and dairy management systems. The selected study districts were Kurunegala and Nuwara-eliya representing the Coconut Triangle and Up-country, respectively. The monthly average milk production in Nuwara-eliya is the highest (2749.8 thousand Liters, 2009) and the second highest cattle population (138.3thousand numbers, 2009) is in Kurunegala district (Department of Census and Statistics 2010). Studying farm efficiency is important because policy makers can use this knowledge to identify potential areas for dairy development and target public interventions to improve farm productivity and self-sufficiency.

The first survey was carried out in 2009 and the second 2010 in the Coconut Triangle and Up-country areas, respectively. In the Coconut Triangle, due to financial limitations, the sample size was limited to 6 dairy farmers. Farmers were selected randomly representing different management systems in the area according to the farm distribution ratio for the intensive, the semi-intensive and the extensive management systems. In the Up-country, 10 dairy farmers were selected randomly from the intensive and semi-intensive management systems. The extensive management system was not found in the Up-county area (Table 3.2). For two years regular monthly panel data were collected between January 1st to December 31st in 2009 and 2010 from the Coconut Triangle and the Up-country, respectively. The total number of observations for the 16 farmers over the two years involved was 192[2)].

Table 3.2 Sample of the study

Agro-climatic Zone	Intensive	Semi-intensive	Extensive
Up-country	5	5	0
Coconut Triangle	2	3	1

3.3.2 Data analysis

A- Stochastic Production Frontier Analysis

Firstly, the Cobb-Douglas stochastic production frontier (Coelli & Battese 1996) was used in the analysis of time-varying technical efficiency estimates of each farm. The stochastic frontier model for panel data is written as:

$$\ln y_{it} = \beta_0 + \sum_n \beta_n \ln x_{nit} + v_{it} - u_i$$

Where, y_{it} represents each farm's output level at time t, x_{nit} denotes vector in production inputs (feed, labor etc), v_{it} represents random noise and u_i represents the farm-level effect. The term v_{it} associated with random factors not under the control of the farmers and assumed to be independently and identically distributed (i.i.d). The term u_i captures technical inefficiency (*TI*) relative to the stochastic frontier. The inefficiency term u_i, is non negative and it is assumed to follow a half-nominal distribution (Kumbhakar & Lovell 2000). "Technical efficiency" is the ability of farms to produce the maximum possible output with a given set of inputs (Coelli *et al* 2005).

$$TE_{it} = \frac{y_{it}}{y_{it}^*} = \frac{f(x_{nit};\beta).\exp(v_{it} - u_i)}{f(x_{nit};\beta).\exp(v_{it})} = \exp(-u_i)$$

$$TE_{it} = 1 - TI_{it}$$

Whereby y_{it} is the observed output and y_{it}^* is maximum possible output. Because y_{it} is always smaller than y_{it}^* , the technical efficiency is greater than zero and less than one.

In this model, the dependent variable is the gross return from milk per month (*Y*). Based on the literature and data available, the model included the following 4 production inputs: "Feed", defined as the total cost of purchased feed stuff including the value of formulated feed, broken rice and coconut poonac (X_1); "Labor", defined as the total cost of labor including family and hired labor (X_2); "Cow", defined as the number of adult cows in the herd (X_3); and, "Land", which includes high land and low land (X_4). It is very difficult to measure the pasture intake of cattle hence; land variable is included as an indicator of pasture source. Increased land area may tend to increase pasture intake by cattle and therefore increase animal performance. In addition, this variable is important because the system of management and crop residuals available for the animals totally depends on the land availability.

B- Ordinary Least Squares (OLS) Regression Analysis

For the second stage we used, the OLS regression (Al-hassan 2008) to analyze the effect of farm-specific variables on the technical efficiency (TE) of the farmers.

The OLS specification is given as,

$$TE = \beta + \alpha_1 X_5 + \alpha_2 X_6 + \alpha_3 X_7 + \alpha_4 X_8 + \alpha_5 X_9 + \alpha_6 X_{10} + \alpha_7 X_{11} + \varepsilon$$

Where ε = error term. The variables used in the OLS model are defined as follows: agro-climatic zone is a dummy variable trying to capture whether the physical environment has significant impact on dairy farm production and performance. The favorable climatic condition would have better influence on efficiency (X_5); Seasonality is a binary variable that is included to estimate the impact of rainfall. Relatively high pasture availability can be expected during the rainy season (X_6); Cattle disease occurrences variable try to capture the impact of cattle disease on farm technical efficiency. Mastitis is the widespread disease among cows in the study areas, hence study focused on mastitis incidence in dairy cattle. Mastitis will decrease the milk production and farm profitably and ultimately it would leads to technical inefficiency in the farm (X_7); House hold size is the number of family member in the house. This variable is capturing the effect of family labor availability on technical efficiency of the farm (X_8); Feed cost is the total cost of purchased feedstuffs (formulated feed, rice bran and coconut poonac) per cow per month in rupees. Feed cost is one of the most important input variables in the production frontier and intensification of feeding would have positive impact on the technical efficiency of the farm (X_9); Age of the farmer in years can serve as a proxy for farming experience and it estimates the impact on the level of technical efficiency (X_{10}) and finally, the training variable is included to capture directly the impact of the level of adaptation of dairy management practices on technical efficiency (X_{11}).

C- Marginal Value Product (MVP) to Marginal Factor Cost (MFC) Ratio

The ratio of the MVP to MFC was used to determine the allocative efficiency (AE) as shown in the following equations (Chapke *et al.* 2011).
The MVPs were calculated using the following equation.

$$MVP_{X_i} = b_i \frac{\overline{Y}}{\overline{X}_i}$$

The ratio of the MVP to MFC was used to determine the allocative efficiency (AE) as shown in the following equations (Chapke *et al.* 2011).

Where,

$\overline{Y}$ = the geometric mean value of dependent variable

$\overline{X}_i$ = the geometric mean value of independent i^{th} variable

b_i = the regression coefficient of i^{th} variable

MFC = cost per unit of i^{th} variable used in the production process. The study only focused on the purchased feeds and variables include formulated feed, rice bran and coconut poonac. It was calculated by dividing the total cost of the i^{th} variable by the quantity of such an input used in the production or market price of each variable in a competitive market (Ugwumba 2010).

3.4 Results and discussion

3.4.1 Descriptive statistics of the sample

The age of the farm head ranged between 28-56 years, which indicates that dairy farming is attractive to middle age people than young age people. Also, the overall average land holding per household was 0.26 acre (Table 3.3).

The age of the farm head ranged between 23-50 years, which indicates that dairy farming is attractive for relatively young and educated people. Also, the overall average land holding per household was 3.4 acre. The amount of the crop residues available and type of cattle management system mainly depend on the pattern of land use. The average highland and low land holding ranged between 2.3±3.3 and 1.1±0.4ac respectively (Table 3.4).

The dairy farming system in Up-country can be categorized in to two systems. They are village based system and estate based system. In village-based system small scale vegetable cultivation is based on the utilization of cattle manure. While, in the estate-based system many of the farmers employed as tea workers. The per capita land availability in the Up-country is low compared to Coconut triangle. The amount of the crop residues available and type of cattle management system mainly depend on the pattern of land use (Table 3.3 and Table 3.4).

In Up-country Friesian, Jersey and Ayrshire, and their crosses of cattle are reared under intensive or semi-intensive system. Whereas, in Coconut triangle Friesian, Australian Friesian Sahiwal, Jersey, Sahiwal and Ayrshire and their crosses of cattle reared under intensive, semi-intensive and extensive system. Most of the time they cattle are reared under tethered of free grazing conditions under coconut plantation or inundated paddy lands (Table 3.3 and Table 3.4).

Table 3.3 Characteristics of ten (10) dairy farms in the Up-country

Parameter	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**	**Farm 5**	**Farm 6**	**Farm 7**	**Farm 8**	**Farm 9**	**Farm 10**
Rearing system[1)]			Intensive					Semi-intensive		
Breed [2)]	F,J	F	F,J	F	F	F,J	F,J,A	F,J,A	F,J	F,J
Experience of dairy farming(years)	16	25	28	20	25	25	19	12	11	20
Age of the farm head(years)	35	49	56	52	42	42	32	28	46	44
Education [3)]	Secondary		Primary				Secondary			
Labor availability	1	2	3	1	1	3	3	4	3	2
Labor hours per day	7.1	5.0	5.6	3.8	3.5	5.3	9.5	10.0	11.3	4.0
Land area(ac) Low land	0.3	1.0	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.3
Pasture source[4)]	CS	OS				CS				

Table 3.4 Characteristics of six (6) dairy farms in the Coconut Triangle

Parameter	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**	**Farm 5**	**Farm 6**
Rearing system[1)]	I	I	SI	SI	SI	E
Breed [2)]	F,AFS,J	F,AFS	F,J,S	F,J,A	F,J	AFS,J,S
Experience of dairy farming(years)	24	7	5	3	1	10
Education [3)]	P	S	S	HS	S	P
Labor availability	2	2	4	3	2	3
Labor hours per day	11.0	5.0	4.0	4.5	5.3	3.3
Land area(ac)						
Highland	9.0	0.5	0.8	2.0	1.0	0.5
Low land	1.5	1.5	0.5	1.0	1.0	1.3
Pasture source[4)]	OS	CS	O+C	O+C	O+C	FG

Note: [1]I- Intensive, SI-Semi-intensive, E-Extensive.
[2] F-Friesian, AFS-Australian Friesian Sahiwal, J-Jersey, A-Ayrshire, S-Sahiwal.
[3] P-Primary, S-Secondary, HS-High school.
[4] OS-Own pasture source, CS- Common source (pastures along the road sides, paddy land sides, coconut lands etc.), FG-Free grazing
Source: Survey panel data

3.4.2 Economics of milk production

A- Up-country

Table 3.5 shows the distribution of production costs, gross margins and profits across the different management systems. Farms 1-5 are intensively managed estate-based system and Farms 6-10 are semi-intensively managed vegetable systems. Gross milk income varied from 108.7 to 829.9 (thousand Rs) based on the milk yield/cow/year and milk price. The highest labor costs are recorded in semi-intensive dairy Farms 7 and 8, which used hired labor as a main source of labor. The total cost is significantly higher in intensive farms than semi-intensive farms. The best resource use efficiency is recorded in semi-intensive Farm 9.

Table 3.5 Comparison of production costs, gross margins and profits across farms in the Up-country

Parameter	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**	**Farm 5**	**Farm 6**	**Farm 7**	**Farm 8**	**Farm 9**	**Farm 10**
Gross milk income(a)	291.3	497.4	240.3	121.5	155.9	829.9	742.6	749.7	675.8	108.7
Costs										
Feed cost[1)]	69.5	293.3	231.6	45.1	58.7	387.7	382.0	656.0	216.9	58.9
Veterinary cost[2)]	2.0	3.0	4.5	2.6	0.4	8.8	12.7	25.3	4.2	2.3
Labor cost[3)]	164.4	111.9	124.9	93.2	81.6	172.5	314.0	382.8	310.3	96.6
Depreciation and others[4)]	28.2	33.9	45.1	11.3	11.3	62.1	67.7	56.4	28.2	22.6
Including labor										
Total cost (b)	264.2	441.9	406.1	152.1	151.9	631.1	776.5	1120.5	559.6	180.4
Dairy profit (a) – (b)	27.1	55.4	-165.8	-30.6	4.0	198.8	-33.9	-370.8	116.2	-71.7
Excluding labor										
Total cost (c)	99.7	330.1	281.2	58.9	70.3	458.6	462.4	737.7	249.3	83.8
Dairy profit (a) – (c)	191.6	167.3	-41.0	62.6	85.6	371.3	280.2	12.0	426.5	24.9
Dairy income/cow/yr	35.9	27.9	-5.1	26.8	42.8	33.3	24.4	1.2	94.8	6.2

Note: [1]Feed cost = Value of all coconut poonac, rice bran, formulated feed, and mineral mixtures
[2] Veterinary cost = Value of all veterinary services including artificial insemination costs
[3] Labor cost = Family labor opportunity cost (number of hours spend * Value per hour)
[4] Depreciation cost = (Purchase cost of animal - Reestablish value of cow's life) / Number of years of productive life
Assumption: We assume that productive life of the cow is 7 years.
Source: Survey panel data

B- Coconut Triangle

Table 3.6 indicates the distribution of production costs, gross margins and profits across the different management systems. Gross milk income varied from 120.0 to 787.4 (thousand Rs) based on the milk yield/cow/year and milk price. The highest feed costs is recorded in intensive dairy Farm 1 which provides formulated feed as main source of animal feed while it is low in other farms which provide milling by product of coconut poonac as main animal feed. Moreover, the Farm 1 is the largest farm and dairy profit/cow/year is only 7.2 (thousand Rs), indicate the high feed cost and high yielding *Friesian* cross replacement cost and high feeding cost. The minimum labor cost is recorded in extensive Farm 6 and the highest economic efficiency excluding family labor is indicated in intensive Farm 2.

Table 3.6 Comparison of production costs, gross margins and profits across farms in the Coconut Triangle

Parameter	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**	**Farm 5**	**Farm 6**
Gross milk income (a)	787.4	720.6	157.5	120.0	140.8	156.7
Costs						
Feed cost[1)]	649.6	274.9	28.1	21.4	46.0	6.3
Veterinary cost[2)]	4.4	3.8	1.2	1.4	0.8	0.8
Labor cost[3)]	246.1	111.9	89.5	100.7	117.5	72.7
Depreciation and others[4)]	50.3	25.9	12.7	17.3	13.0	30.0
Including labor						
Total cost (b)	950.4	416.5	131.5	140.8	177.3	109.8
Dairy profit (a) – (b)	-163.0	304.1	26.0	-20.8	-36.5	46.9
Excluding labor						
Total cost (c)	704.3	304.6	42.0	40.1	59.8	37.1
Dairy profit (a) – (c)	83.1	416.0	115.5	79.9	81.0	119.6
Dairy income/cow/yr	7.2	64.0	29.6	20.5	20.8	19.9

Note: [1]Feed cost = Value of all coconut poonac, rice bran, formulated feed, and mineral mixtures
[2] Veterinary cost = Value of all veterinary services including artificial insemination costs
[3] Labor cost = Family labor opportunity cost (number of hours spend * Value per hour)
[4] Depreciation cost = (Purchase cost of animal - Reestablish value of cow's life) / Number of years of productive life
Assumption: We assume that productive life of the cow is 7 years.
Source: Survey panel data

3.4.3 Descriptive analysis

Descriptive statistics and explanation of variables used in the analysis are given in Table 3.7. The average land area is 1.43 acre with a standard deviation of 2.51 acre, suggesting a large variability of land sizes among dairy farmers. The average land area per farm in the Up-country is very small compared to Coconut Triangle and they are heavily dependent on purchased feed. The monthly average expenditure on feed is 17.8 thousand rupees. The dairy farmers used purchased feed, heavily during the initial and peak stage of the lactation based on individual animal productivity. Generally, in the Up-country, the temperate breeds show higher performance. Average daily milk is reported as 8 liters/cow. But in the Coconut Triangle, the average milk production is about 4 liters/cow. The average cow number (given birth to at least one calf) in the study areas is 6. The average herd size in the Up-country and the Coconut Triangle were 2-5 and 5-20 respectively (Ibrahim *et al* 1999). Sri Lanka's average household size is 4.0 (Department of Census and Statistics 2011) compared with the sample average of 5.1.

Table 3.7 Descriptive statistics of dairy farms (N=192)

Variable	Explanation	Mean	
Stochastic frontier variables			
Y	Gross return from milk (thousand rupees/month)	38.87	(26.66)
X_1	Expenditure on feeds (thousand rupees/month)	17.84	(17.90)
X_2	Expenditure on labor including hired labor and family labor opportunity cost (thousand rupees/month)	13.03	(7.73)
X_3	Cow (number)	6.28	(3.13)
X_4	Land area including both high land and low land (acre)	1.43	(2.51)
Farm-specific variables			
X_5	Agro-climatic zone dummy (Up-country=1, Coconut Triangle=0)	0.63	(0.49)
X_6	Seasonality dummy (*Yala* season=1, *Maha* season=0)	0.67	(0.49)
X_7	Cattle disease occurrences (recorded; yes=1, otherwise=0)	0.18	(0.39)
X_8	Household size (number)	5.19	(1.24)
X_9	Feed cost (thousand rupees/month/cow)	2.40	(1.71)
X_{10}	Age of farmers (years)	39.94	(10.45)
X_{11}	Training of dairy farming (received; yes=1, otherwise=0)	0.94	(0.24)

Note: Standard deviations in parentheses.
Source: Survey panel data.

According to Table 3.8, the management of the dairy farming system can be classified into three groups: intensive, semi-intensive and extensive. The intensive system is characterized by the heavy use of efficient methods such as cut and fed in a shed, zero grazing, utilization of high yielding cows, fed compound feeds etc. The semi-intensive management system is a combination of intensive and extensive systems and it is less expensive compared with the intensive system and technically more advanced than the extensive system. The semi-intensive system is characterized by a medium level of input usage, where pregnant and lactating animals are housed indoors; others are allowed to graze in a paddock during the day and housed indoors at night. Extensive management system is low cost and has low productivity based on free grazing.

In Up-country, the average milk yield per cow was 7.8 and 8.8 kg under intensive and semi-intensive systems, respectively. In the Coconut Triangle, intensively managed dairy farms use formulated feed and rice bran for a large part of the lactation period based on individual animal productivity. In the semi-intensive system, farmers supplement grazing with broken rice and coconut poonac, especially during the initial and peak stage of lactation. Extensive farmers are highly dependent on commonly held pastures. Moreover, in the Coconut Triangle, all farmers use rice straw as a strategy to overcome feed shortages during the *yala* season.

Table 3.8 Feeding pattern in different agro-climatic zones (Mean values)

Agro-climatic Zone	**Up-country**		**Coconut Triangle**		
Rearing System	**Intensive**	**Semi-intensive**	**Intensive**	**Semi-intensive**	**Extensive**
FF(kg/cow/day)	0.93(0.36)	1.04(0.48)	2.38(1.40)	Not use	
RB(kg/cow/day)	Not use	0.63(0.74)	4.12(1.30)	0.79(0.41)	Not use*
CP(kg/cow/day)	1.72(0.80)	1.44(0.81)	Not use	0.49(0.38)	
Milk yield (kg/cow/day)	7.78(2.06)	8.77(3.29)	10.05(4.26)	4.48(1.49)	1.82(0.70)
Milk price (Rs/kg)	32.56(3.49)	33.62(5.31)	30.39(0.80)	30.50(1.20)	29.57(1.10)

Note: Standard deviations in parentheses.
FF=Formulated Feed, RB=Rice Bran and CP=Coconut Poonac.
*=Use grasses only.
Source: Survey panel data.

3.4.4. Production function and technical efficiency

Table 3.9 presents the maximum likelihood estimates of the estimated stochastic production frontier model.

Table 3.9 Stochastic frontier production estimates

Variable	Coefficients	Standard error	P-value
Intercept	0.682	0.007	0.000***
Expenditure on feeds	0.110	0.030	0.000***
Expenditure on labor	0.460	0.033	0.000***
Cow number	0.676	0.023	0.000***
Land area	0.122	0.034	0.000***
Sigma Square	0.170	0.020	
$\lambda=\sigma_u/\sigma_v$	34.314	0.032	
Log-likelihood	26.755		
N=192			

Note: *** is statistically significant at 1% level.
Source: Survey panel data.

The estimated value of λ=34.314 is significantly different from zero, therefore, the null hypothesis of no inefficiency was strongly rejected. All output elasticities were positive and statistically significant at the 1% significance level. This indicates that the output increases as each of the independent variable increases and all the independent variables were significantly different from zero, which indicates that they are all important factors in dairy production. In addition the estimate for Return to Scale (RTS)[3)] is 1.368 showing the possibility of Sri Lankan farmers increasing return to scale in dairy production. The mean technical efficiency was 0.68 and 0.77 under Coconut Triangle and Up-country respectively (Figure 3.5).

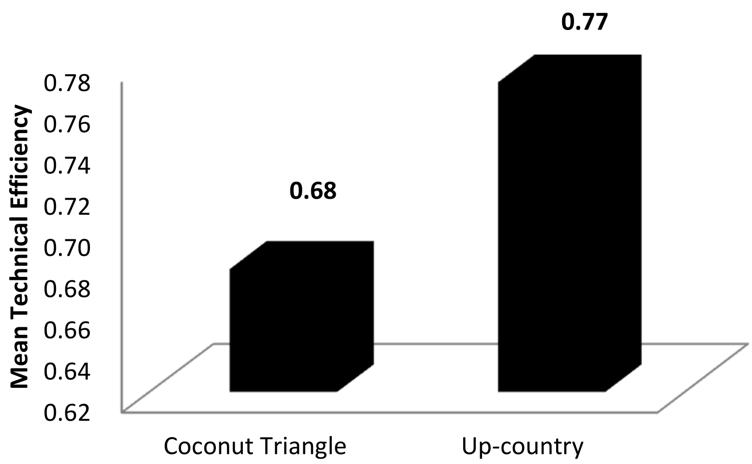

Figure 3.5 Mean technical efficiencies under Coconut triangle and Up-country

3.4.5 Factors effecting technical efficiency

The OLS estimation results are shown in Table 3.10. Variance inflation factors (VIF) were used to detect collinearity. The variables estimated in the OLS model are statistically significant at 0.1 %. The coefficient R-squared is equal to 0.34, showing that around 30 % of the dependent variable is explained by independent variables in the OLS model. The adjusted R-squared value of 0.32 testified to the adequacy of the model used.

Table 3.10: Factors associated with technical efficiency

Variable	Coefficients	Standard error	P-value
Intercept	0.458	0.076	0.000
Agro-climatic zone	0.042	0.025	0.095*
Seasonality	0.028	0.020	0.169
Cattle disease occurrences	-0.203	0.037	0.000***
Household size	0.021	0.009	0.024**
Feed cost/cow	0.049	0.007	0.000***
Age of farmers	-0.005	0.001	0.002**
Training	0.249	0.061	0.000***
R-squared	0.349		
Adj R-squared	0.324		
F-statistic	14.13***		

Note: *, ** and *** are statistically significant at 10%, 5% and 1% level.
Source: Survey panel data.

All the variables have positive relationship with TE except “Cattle disease occurrences” and “Age”. The positive coefficient of the “agro-climatic zone” implies that dairy producers in the Up-country area tend to be more technically efficient than producers in the Coconut Triangle. The mean technical efficiency was higher in Up-country than the Coconut Triangle. In Up-country, the mean temperature ranges from 10 to 24°C and mainly Friesian crossbreds are reared under an intensive management system. Hence, high technical efficiency may be due to this favorable climatic condition for dairy farming activities in the Up-country as compared with the Coconut Triangle.

The coefficient of “Cattle disease occurrences” was found highly significant with a negative effect, which shows that animal diseases on the dairy farm decreases efficiency. Meanwhile, the “Household size” was found to be positive and significant. A household includes all the family members (women and children) in the same house. The family members form the major source of labor and when the members are readily available they provide needed labor. In the study area, most of the dairy activities including grass cutting, milking, cleaning the animals etc, are carried out with the support of women and children. Children go to school in the morning and in the evening they help with the dairy activities. Moreover, older members of the family help with dairy activities such as cleaning the cattle shed and observing the signs of heat of the cattle to detect the correct time for artificial insemination. This implies that technical efficiency tends to increase as household size increases. The finding suggests that family labor makes an important contribution to the operation of the family dairy farm.

Additionally, the "Feed cost" per cow coefficient was positive and significant, implying that intensification of cattle feeding techniques tends to increase farm technical efficiency. This is in line with earlier findings in the literature that intensification (ratio of feed purchased per cow on the farm) improves farmers' efficiency (Cabrera *et al.* 2010).

Interestingly, "Age" of the farmers has a negative relationship with technical efficiency, suggesting that older farmers tend to be less efficient. This agrees with the findings of Omonona *et al.* (2010). It could be that older farmers have more experience in farming and have a less access to the technologies than young farmers. In the case of new technologies, for example feed management, older farmers may be less adaptable than younger ones. As expected the training coefficient was positive and significant. The above findings show that training was an important factor in determining technical efficiency in the study areas. This is consistent with several other studies that have found a positive connection between farm level efficiency and availability of training and extension services (Kaliranjan & Shand 1985; Bravo–Ureta *et al* 1994).

3.4.6 Distribution of average technical efficiency

A- Up-country

As shown in Figure 3.6, technical efficiency is highly varied across the different farm management systems in Up-country, irrespective of the management system. It is ranged from 0.53 to 0.89.

The lowest value of 0.57 is recorded in semi-intensive management farm-10, because of poor animal productivity. The highest values of 0.85, 0.87, 0.89 and 0.88 are recorded in intensive farm 2, intensive farm 5, semi-intensive farm 6 and semi-intensive farm 9 respectively. Because they supplemented cattle feed based on individual animal performance. Moreover, these differences can be attributed to different feeding technologies and differences in quality of inputs. The technical efficiency in the Semi-intensive farm 7 and 8 are 0.72 and 0.79, it is mainly due to high hired labor cost. Furthermore, the technical efficiency is 0.87 in intensive farm 5, because of lowest feed cost. The farmer provided only coconut poonac as cattle feed. And also, in intensive farm 3 technical efficiency is 0.63 implies higher feed cost over herd productivity.

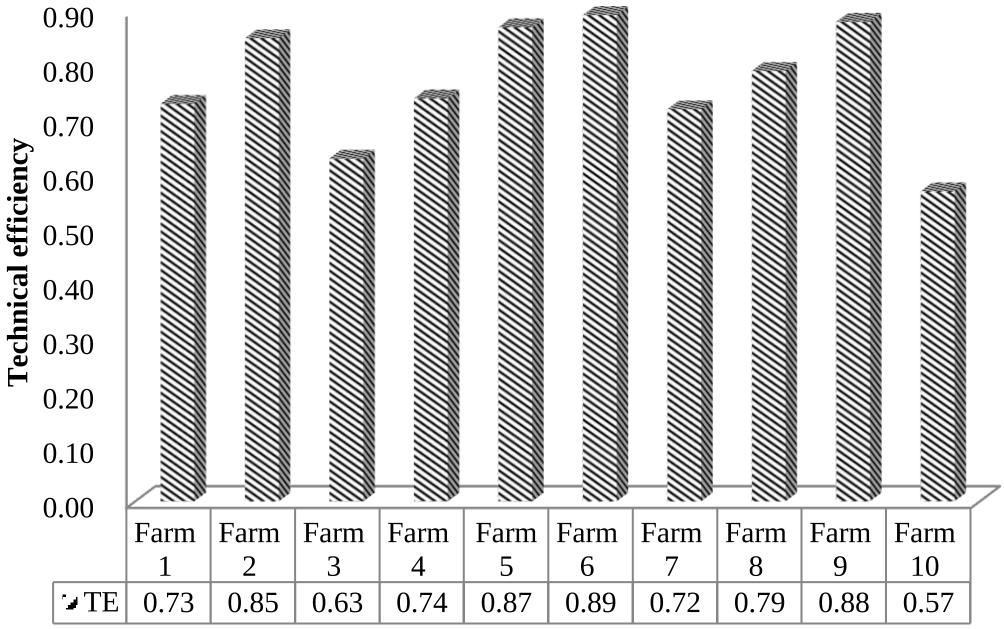

Figure 3.6 Mean technical efficiencies among different farms in the Up-country

B- Coconut Triangle

As indicated in Figure 3.7, technical efficiency is highly varied across the different farm management systems in Coconut triangle. The highest value 0.94 is recorded in intensive management farm-2 while the second highest values are 0.75 in semi-intensive farm 2 and extensive management farm 6 respectively. However, this difference can be attributed to different feeding technologies and differences in quality of the inputs. It is noted that, the highest technical efficiency is recorded in farm 2 and it supplemented with formulated feed which based on individual animal performance. On the other hand, in intensive farm 1 technical efficiency is 0.61 implies higher feed cost over herd productivity. The dairy farm efficiency increases to a greater degree as feed cost increases, but ultimately the dairy farm efficiency decreases as a result of too much increases of feed cost. The technical efficiency in the Semi-intensive farms 3, 4 and 5 ranged between 0.63 – 0.75, who offered compounded feeds only during the initial months of the lactation and stop during the dry period. Furthermore, the technical is 0.75 in extensive farm 6, because of lowest feed cost.

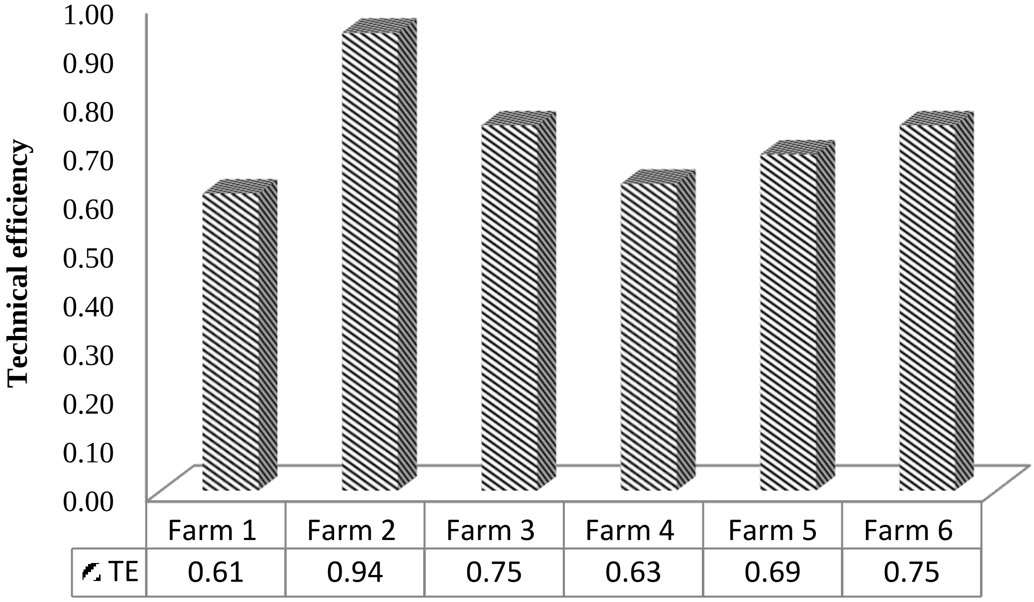

Figure 3.7 Mean technical efficiencies among different farms in the Coconut Triangle

3.4.7 Allocative efficiency of feed resources

Table 3.11 shows the MVP to MFC for feeds under Up-country and Coconut Triangle dairy management systems[4)].

Table 3.11 MVP to MFC ratios for feeds in different agro-climatic zones (Mean values)

Feed Type	Up-country					Coconut Triangle				
	MFC		MVP/MFC		N	MFC		MVP/MFC		N
Formulated Feed	29.08	(2.99)	0.76	(0.45)	83	28.19	(1.95)	3.91	(2.62)	43
Rice Bran	24.33	(1.29)	0.79	(0.53)	13	6.55	(3.06)	8.53	(6.29)	55
Coconut Poonac	28.47	(0.90)	0.47	(0.29)	120	15.55	(1.68)	9.61	(10.72)	28

Note: Standard deviations in parentheses, N=sample size.
Source: Survey panel data.

In the Coconut Triangle, all MVP to MFC ratios were greater than one, which shows an underutilization of these resources. One of the reasons for the underutilization of purchased feed resources is the producer cannot obtain sufficient purchased resources due to credit constraints in the input market. Moreover, the Coconut Triangle farmers depend heavily on free commonly available grass and rice straw. The purchased feed usage per farm is considerably low. However, coconut poonac, a by-product of coconut oil production process, is a very common and cheap compound feed in the Coconut Triangle. In addition, paddy and coconuts are dominant in the Coconut Triangle compared to Up-country, so there is room for increasing the use of these feed inputs to increase the gross milk income in the Coconut Triangle.

On the other hand, in the Up-country study area the MFC of broken rice and coconut poonac were significantly higher. This may be due to the dairy farmers underestimating the cost of rice bran and coconut poonac due to the lack of information about production function. In the Up-country area, farmers have limited pasture, so farmers depend heavily on purchased concentrate feed. All MVP to MFC ratios were less than one, which indicates the over utilization of resources in the Up-country. Withdrawing a certain amount of these over-utilized resources could increase the gross milk income.

3.5 Conclusion

This study estimates the determinants and their quantities impacting farm level specific technical efficiency in dairy production using the stochastic frontier production function model. The results indicate that there are ample opportunities to improve production efficiency by using inputs more efficiently. The socio-economic factors, which will significantly increase the farmers' efficiency, are household size, feed cost per cow and training, while cattle disease occurrences and a farmer's age reduces efficiency. Therefore, the government should concentrate on encouraging older dairy farmers to produce more efficiently by giving them training and extension services in new feed management technologies. Furthermore, the results of the MVP to MFC ratio revealed that feed resources are under-utilized in the Coconut Triangle, while over-utilized in Up-country. Hence, in order to improve the dairy farming efficiency, the government should provide information on the prices and the availability of feed resources which can be purchased from different agro-climatic zones in Sri Lanka.

<Notes>

1) One Japanese Yen was equal to 1.29 Sri Lankan Rupee (2009 Monthly Average).
2) The total sample was composed of 5 and 10 farmers in Coconut Triangle and Up-country, respectively. The data were collected every month in 2009 and 2010 from the Coconut Triangle and Up-country. The total number of observations for the 16 farmers over the two years involved was 192 ([Coconut Triangle 6 farmers x 12 months] + [Up-country 10 farmers x 12 months]).
3) The return to scale (RTS) which is the summation of all the estimated elasticities of production.
4) In the MVP to MFC ration analysis, the study only focused on purchased feed resources. Farmers do not have their own pasture source in the Up-country, but farmers do in the Coconut Triangle. In the current study, farmers own pasture source is not valued at the market price in the Coconut Triangle. If we include farmer's own pasture sources for MVP to MFC ratio analysis, in the Coconut Triangle the MVP to MFC ratio is lower than the current values.

CHAPTER 4

An economic viability analysis of FMD vaccination programme

4.1 Introduction and objectives

Livestock play a vital role in economic development in South Asia (reference), and the livestock industries within region has changed dramatically in recent years. In developing countries the demand for livestock products such as milk, beef, and pork is rising rapidly, primarily as a consequence of high population growth and rapidly increasing incomes, mainly in South Asia. However, effective animal disease control is vital to the development of the optimal contribution of livestock to the economies of South Asian countries. The region is affected by many diseases that constraints the productivity, and these include foot and mouth disease (FMD), hemorrhagic septicaemia, classical swine fever, avian influenza, and porcine reproductive and respiratory syndrome, among many others. Much discussion has in fact focused on the identification of the disease control priorities, as different diseases, and alternative control policies for these diseases. More importantly, FMD has been listed in type A category of OIE infectious disease list (OIE, year).

Despite the constraints discussed in chapter 2 and 3, FMD is one of the most threatening trans-boundary diseases to animal health and is one of the major impediments for growth of livestock sector in Sri Lanka. Although FMD does not cause high mortality in adult animals, its high morbidity and extreme contagiousness can lead to enormous economic consequences (Bronsvoort et al. 2004; Guzman et al., 2008).

The production losses arising from lower milk yields, abortion, perinatal mortality, lameness, poor growth, and premature cull as a result of permanent udder or foot damage (James and Rushton, 2002). Moreover, FMD being highly contagious, the action of one farmer affect the risk of FMD occurring on other holdings; therefore such effects generate what economists call “externalities”**.** If a FMD outbreak occurs due to one farmer did not protect his livestock may suffer and he will generate a ‘negative externality’ as the disease is likely to spread. On the contrary, when a livestock farmer protects his animals from FMD infection he will create a ‘positive externality’ as he is less likely to spread the pathogen to other farms (Knight-Jones and Rushton, 2013). These externalities create a public good problem and the under-production of FMD control efforts, and may warrant public sector intervention.

FMD has an ancient history in Sri Lanka and it is endemic in the country particularly in the eastern part of Northern and Eastern province. Therefore, FMD has been ranked as the highest priority disease for control and eradication. Nevertheless, in Sri Lanka, currently there is no country-wide vaccination programme aimed to control FMD. The budget for FMD control and eradication has always been low and stagnant. It has remained around 20 million during the past fiscal years. In addition, there is an insufficient FMD vaccine production capacity and Sri Lanka spends a lot of country foreign exchange to import FMD vaccines. But sometimes these are produced for foreign strains of FMD viruses, and they are ineffective against the virus strain circulating in Sri Lanka. On the other hand, the economic return from the FMD vaccination at a dairy subsector level is unknown.

There has been no study published on the economies of FMD outbreak and on costs and benefits of preventive vaccination in Sri Lankan dairy farmers. Literature related to the economics of FMD in Sri Lanka is limited and only one available focus on the economic impact of FMD outbreak in Dry Zone and Wet Zone (Hettiarachchi and Kothalawala, 2012). The experience of many developing countries clearly shows that preventive vaccination against FMD in dairy cattle is important to avoid losses that emanate from FMD outbreak. Estimation of economic losses can provide a better overall view of the impact of the disease and contribute in estimating the extent of the losses to be avoided.

The objectives of the study were:

1) To clarify whether the FMD vaccination program is sufficient to control and eradicate FMD
2) To make an appropriate control strategy for FMD
3) To draw some policy implications based on the results

4.2 Background

4.2.1 What is FMD?

FMD is a viral infection caused by an aphthovirus belonging to the family of picornaviridae which affects practically all cloven-hoofed domesticated mammals, including cattle, buffalo, sheep, goats, and pigs (Alexandersen et al., 2003; Kitching et al., 2005). Wild herbivores, namely bison, deer, antelope, reindeer llama, camel, giraffe, and elephant are also susceptible (Anonymous, 2013). The disease is primarily characterized by the formation of painful fluid-filled vesicles (blisters) on the tongue, lips, and other tissues of the mouth and on parts of the body where the skin is thin, as on the udder and teats, between the two toes of the feet, and around the coronary band above the hoof. Laboratory tests are required to confirm the diagnosis because several other diseases can produce similar lesions. In addition, the specific strain of the foot and mouth disease virus (FMDV) has to be identified in order to plan appropriate disease control policies (Hettiarachchi et al., 2009).

The incubation period, the time between infection and clinical signs of disease, for FMD in cattle is 2-14 days depending on the infective dose, the strain of the virus and the susceptibility of the individual host (Kitching, 2002). The clinical signs are marked by acute febrile vesicular illness and accompanied by variable appearance of epithelial vesicles on the tongue, dental pad, gums, lips, and on the coronary band and interdigital cleft of the feet (Merck, 2012).They may also be seen on the teats particularly of lactating cows. Acutely affected cattle salivate profusely and have nasal discharge, at first mucoid and then muco-purulent, which covers the muzzle. Further, it has a predilection to invade and destroy cells of the developing heart muscle (Kitching, 2002), also leading to high calf mortality, which may die before appearance of vesicles. Infected cattle become lethargic, may quickly lose condition and the drop in milk yield can be dramatic and will not recover during the remaining lactation. Furthermore, secondary bacterial mastitis and abortion are common.

4.2.2 FMD situation in Sri Lanka

FMD is one of the world's most infectious diseases that cause severe economic losses (James and Rushton, 2002). The disease has been considered as the oldest cattle disease in Sri Lanka and found endemic in various parts of the country particularly, in the eastern part of Northern and Eastern Provinces. These areas hold more than half of the national cattle and buffalo population and make a substantial contribution to the total milk production in the country.

There was only a single epidemic of FMD recorded during the first decade of 21^{st} century in the country (Figure 4.1). This epidemic which occurred in 2003 recorded 36,340 cases, of which 96 % were confined to the endemic zones. Since then FMD appeared to be well under control and the total number of cases recorded annually were less than 2000. However, a massive epidemic in 2014 swept through all the Provinces resulting in 58,645 cases and 1,265 deaths, the largest number recorded since 1987.

Majority of FMD cases were observed at North Central Province with some spill over in other Provinces (Figure 4.2).

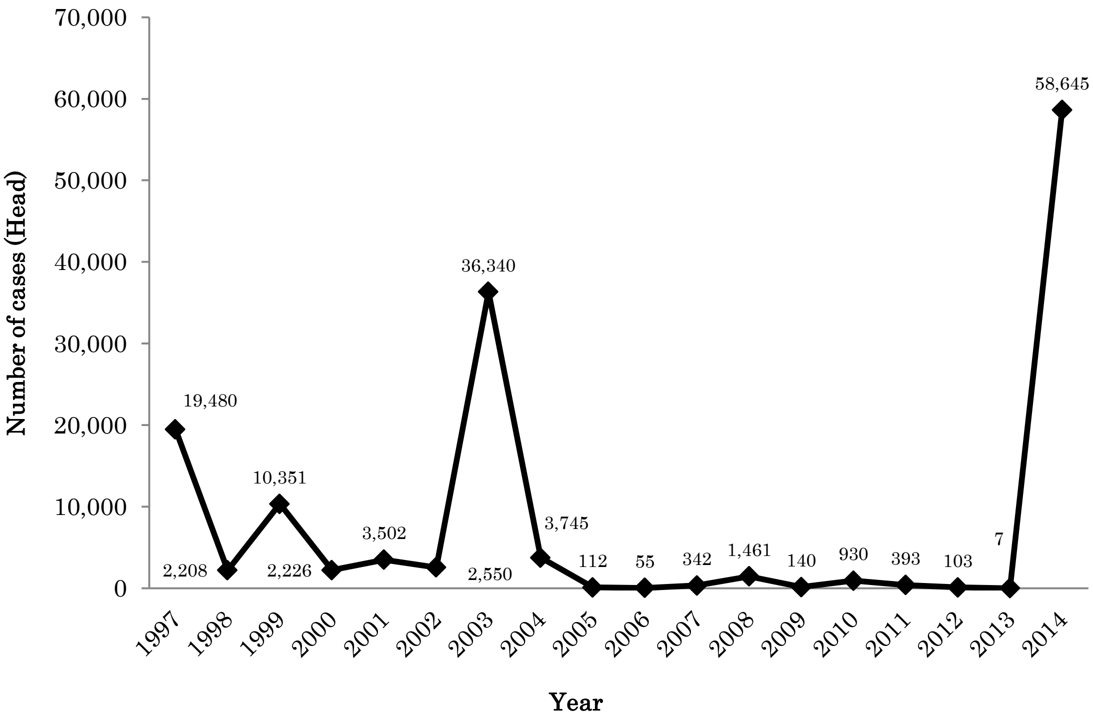

Figure 4.1 Recorded cases of FMD between 1997 and 2014 June
Source: Department of Animal Production and Health

The disease spread extensively in the North and Eastern, North- Central and North-Western Provinces mainly with the movement of cattle and buffaloes as part of dairy farming management practices. There is a high demand for beef in Western Province compared to other parts of the country. Generally, cattle traders purchase animals in the FMD-affected areas for very low price and slaughter cattle transport to urban areas. Thereafter, infection is introduced into Western Province. Later on the cattle salvaged from the slaughterhouses and distributed among the farmers introduced the infection in to the Central Province. Moreover, the disease also intruded the Southern Province via cattle transported in from North Central Province with inadequate health precautions. Finally, it leaked into the Uva Province again through the slaughter cattle. It was true in 1997 FMD epidemic too (Hettiarachchi et al., 2009).

Additionally, Sri Lanka is a predominantly Buddhist country and the credence of salvaging cattle in order to receive merit in life is greatly appreciated. A Buddhist monk immolates himself to protest against the slaughter of cattle in Sri Lanka in 2013. Consequently, there are many fast-to-death campaigns to ban cattle slaughter in the country. Cattle bought for slaughter are released by Buddhist monks and in many occasions, some FMD infected animals are supplied to dairy farmers in rural areas. Therefore, FMD was introduced into other provinces via these animals in March 2014.

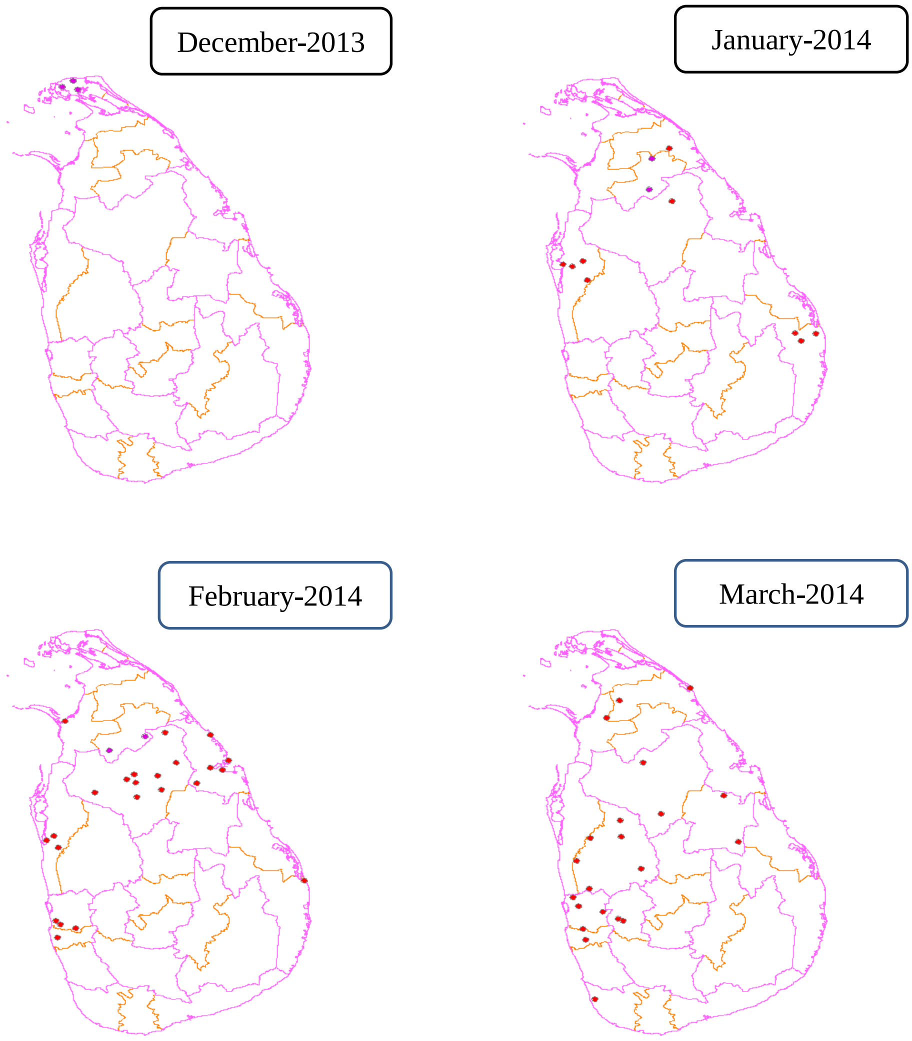

Figure 4.2 Spatial distribution of FMD outbreaks in 2014 Epidemic
Note: Spots are denoted affected areas
Source: Department of Animal Production and Health

4.2.3 Vaccination strategy for FMD

In Sri Lanka, currently there is no nationwide regular vaccination programme devised to control FMD. Vaccination for FMD in the country has always been limited to the endemic and buffer zones and ring vaccination during an outbreak in order to arrest further spread of the outbreak to other areas. The vaccine is always been supplied free of charge through the Department of Animal Production and Health (DAPH) and farmers have been advised to get their animals vaccinated unfailingly. Nevertheless, the cooperation by the farmers is not sufficient and vaccination rate is still remained low (Figure 4.3). Moreover, the first batch of FMD vaccine was successfully produced in March 2012, after 1994. But this strategy has not given substantial impact due to shortage in local production and prevalence of other virus strains that are not included in the vaccine formulation. Therefore, the Sri Lankan government spends a substantial amount of money to import FMD vaccines from India.

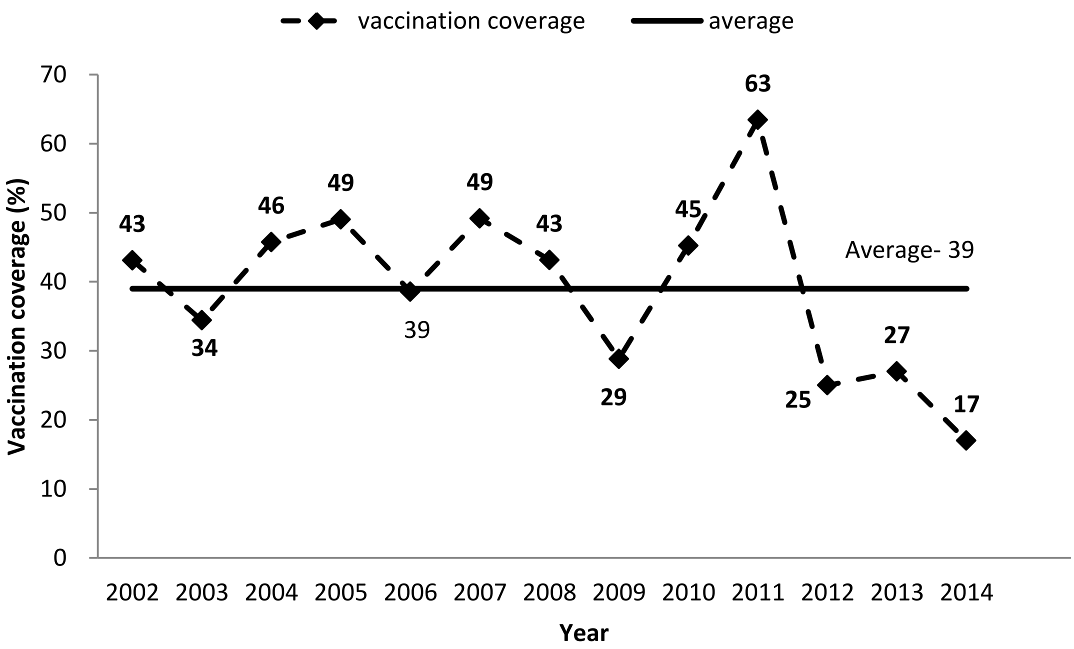

Figure 4.3 Vaccination coverage in Sri Lanka
Note: 2014 –data from January to March
Vaccination coverage (Number of doses issued/cattle population) *100
Source: Department of Animal Production and Health

4.3 Materials and methods

4.3.1 Study area, data source and collection procedure

The research was conducted in North Central Province in Sri Lanka. According to the classification of agro-ecological zones of Sri Lanka, North Central Province falls under Low Country Dry Zone and which is the largest province in the country covered 16 % of total land area. North Central Province consist two districts called Polonnaruwa and Anuradhapura. North Central Province was chosen for the following reasons: First, FMD is endemic in the area and it appears that FMD has been emerging as the major killer disease among cattle especially in the North Central Province; second, it has second largest cattle and buffalo population (0.17 million cattle and 0.07 million buffalo) of Sri Lanka (DAPH, 2011), implying large potential impact of FMD outbreak; third, out of 30 divisional secretariats[1], 18 were seriously affected by FMD and a total of 8,384 confirmed cases (51.78 % of the total) of FMD were reported in the first three months of the outbreak (Table 4.1 and Figure 4.4); and finally, in addition to large number of outbreaks, this area has a high vaccination coverage compared with another provinces in the country (Table 4.2).

Table 4.1 Distribution of FMD cases in Provinces

Province	Cases (heads)	As a percentage of total cases (%)
Northcentral	**8,384**	**51.78**
Western	2,645	16.34
Northern	3,010	18.59
Northwestern	1,800	11.12
Eastern	315	1.95
Central	28	0.17
Sabaragamuwa	7	0.04
Southern	3	0.02
Uva	0	0.00
Total	**16,192**	**100.00**

Source: Department of Animal Production and Health (Data from 2013/12/30 to 2014/03/30)
Note: Livestock population =cattle+ buffaloes+ goat+ swine.

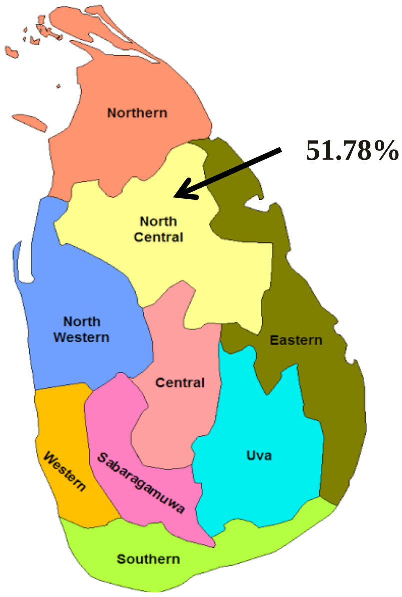

Figure 4.4 Distribution of FMD cases in Provinces

Figure 4.5 FMD disease affected divisional secretariats of North Central Province
Note: * is a denoted affected divisional secretariat and ** are denoted seriously affected divisional secretariats.
Source: Department of Animal Production and Health, North Central Province

Table 4.2 Vaccination coverage among provinces (2013 and 2014)

Province	Livestock population (Head)	Number of doses issued (FMD)			
		2013 (Jan-Dec)	Vaccination coverage (%)	2014 (upto March)	Vaccination coverage (%)
Northcentral	**327,687**	**105,078**	**32.07**	**26,378**	**8.05**
Western	151,058	26,048	17.24	17,507	11.59
Northern	393,852	27,750	7.05	103,633	26.31
Northwestern	347,013	58,230	16.78	26,631	7.67
Eastern	496,339	96,986	19.54	14,476	2.92
Central	137,393	360	0.26	2,437	1.77
Sabaragamuwa	54,387	51	0.09	2,420	4.45
Southern	135,838	14,131	10.40	9,282	6.83
Uva	193,503	0	0.00	3,917	2.02
Island Total	2,237,070	328,635	14.69	206,681	9.24

Note: 2014 –data from January to March
Vaccination coverage (Number of doses issued/Livestock population) *100
Livestock population =cattle+ buffaloes+ goat+ swine.
Source: Department of Animal Production and Health

The study was conducted during the early of the rainy season (South West monsoon) in April and May 2014. Data from the FMD epidemic took place in North Central province in 2014 was obtained from the Provincial Department of Animal Production and Health - North Central Province. FMD infection was recognized by divisional veterinary offices based on the observation of FMD-like clinical signs and lesions (vesicular lesions in tongue, inter digital, dental pad, coronary and teat, salivation, lameness, pyrexia and, mortality in young calves) in at least one animal in the herd, the results of the field investigation and/or serological sampling. The index case of this epidemic in the North Central Province was reported on 17 January 2014 (epidemic day 1). Over 102 consecutive days, 8,385 cases (infected animals) were reported (Figure 4.6).

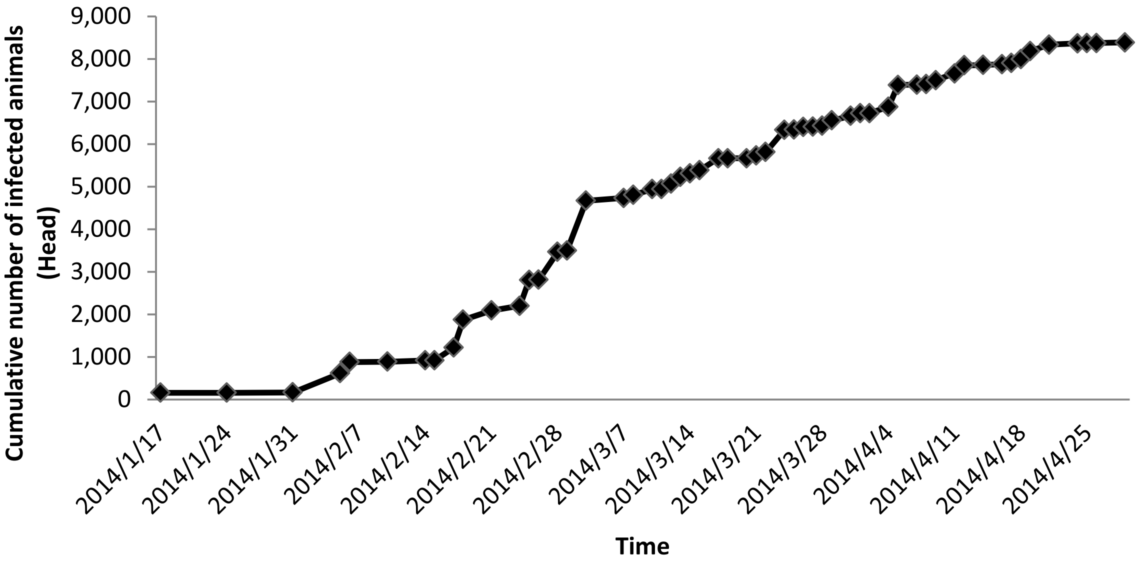

Figure 4.6 Cumulative number of reported FMD cases in North Central Province
Source: Department of Animal Production and Health, North Central Province.

In addition, available secondary data through official reports and past publications and from key informants interviews were used to estimate the key epidemiological parameters. Furthermore, field survey was carried out in four divisional secretariats (Kebithigollewa, Rambewa, Kahatagasdigiliya, and Padaviya) to collect the information for cost-benefit analysis.

4.3.2 Data analysis- Integrated Epidemiological-Economic Model

An FMD outbreak has the potential to cause enormous economic losses both for individual farmers and at national or regional levels, both directly and indirectly. Moreover, an FMD can have economic impact even where it is not present, if preventive measures are required. However, the key criteria for evaluating national FMD control measures to date have been related mainly to economic cost - either the total perceived cost of the disease or the cost benefit of controlling the disease.

One of the major obstacles in cost benefit analysis has been the lack of substantive data on the relationship between control measures (vaccination strategies) and the resultant incidence of FMD. Previous literature have been considered these two variables as almost separate entities or tended to assume a simple linear relationship (Harrison and Tisdell, 1999). Such cases, nevertheless, the difficulty appears to be establishing what vaccination coverage are actually being achieved and how different levels of herd immunity impact FMD occurrence. Estimates of disease costs based on the output of epidemiological models can draw on scientific knowledge of the mechanisms that govern disease spread. They may thereby escape any bias inherent in studies based on empirical observation. More likely, they will be used in the absence of data required for economic analysis (Dijkhuizen et al., 1991).

Integrated epinomic (epidemic and economic) modelling has certainly advanced significantly since McCauley et al. (1979) studied the cost of controlling and eradicating an FMD outbreak in the United States. Today, there are many epidemiological models which can vary from simple deterministic mathematical models through to complex spatially-explicit stochastic simulation and decision support systems (Garner and Hamilton, 2011). An important characteristic of mathematical models is the ability to mimic "what-if" scenarios and the possible effect of intervention strategies to control disease spread. In reality, control programmes may be targeted to geographic locations most affected or at greatest risk of secondary infection and thus realistic and useful mathematical models should be able to readily determine the effect of specific spatially-targeted strategies like emergency ring vaccination or contagious slaughter. The probability of infecting another farm decreased with the distance, thus, incorporating spatial components into models of epidemic models are becoming more important in epidemiological studies (Garner and Beckett, 2005). In addition, mixing matrices was used by previous researchers to describe subgroup interaction in mathematical models which have heterogeneity in population structure. Many studies have reported data on social mixing patterns from different population and their impact of transmitted diseases (Glass and Glass, 2008: Johnstone-Robertson et al., 2011; Wallinga et al., 2006). Nevertheless, however, only a limited number of studies have reported data on mixing patterns that could lead to the airborne transmission of animal diseases.

A- Epidemiological Model (Susceptible-Exposed-Infectious-Recovered model)

1. SEIR model

In order to investigate the economic benefits and costs of alternative vaccination coverage rates the epidemiological model must be able to predict the number of total infected animals under different level of vaccination coverage rates. The model used in this study was similar to that employed by Perry et al. Ordinary differential equations were used to formulate the model equation. One of the major limitations of the Perry et al. model is that it excludes the spatial spread of FMD. This study built a SEIR (Susceptible – Exposed – Infectious – Recovered) deterministic model at the animal level with a single day time step.

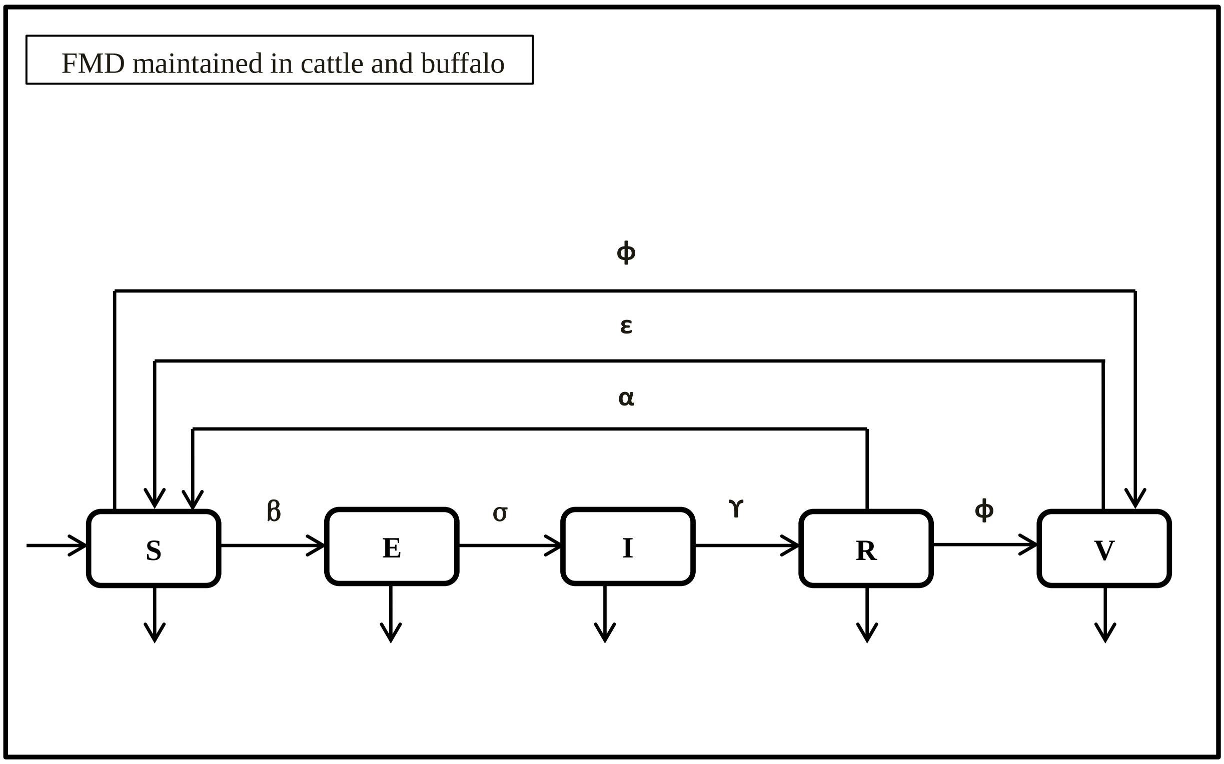

Figure 4.7 Diagram of the compartmental model of FMD in populations of cattle and buffalo
Source: Perry et al. 1999.

In the SEIR model, the total population is divided into four separate groups: Susceptible (S), Exposed (E), infective (I) and, Recovered (R). Susceptible animals can contact the disease if they have been exposed to the FMD, while those in the exposed group are individuals infected with the FMD but not yet infectious and are not able to transmit the FMD to others. Infective are the individuals who are infectious and capable of transmitting the infection to any susceptible that they come in contact with. Those in the recovered compartment are individuals previously infected but currently neither susceptible nor infected. They have an infection-acquired immunity (permanent immunity). The proportion of individuals in each compartment S, E, I and, R at the time t is given as S (t), E(t), I(t) and R(t). Figure 4.7 is the diagram of the compartment model of FMD with vaccination.

Further, the flow diagram and the model assumptions can describe as follows:

Solid lines represent transitions between states; unlabelled inputs and outputs indicate births and deaths, respectively. The population size N=S+E+I+R+V; parameter β is the transmission coefficienct, the per capita rate at which infectious animals infect susceptible cattle; $1/\sigma$ is the mean latent period; $1/\gamma$ is the mean infectious period before cattle showing clinical signs are removed from the population; $1/\alpha$ is the mean period of natural immunity; ε is the rate at which vaccinated animals lose immunity and become susceptible to infection, and 1/ε is therefore the mean period of vaccine-induced immunity.

For simplicity and due to limited data, it was assumed that α=ε. The demography of the population is explained by the per capita birth rate , v and death rate δ (where mean life expectancy of a cattle is 1/δ), Thus the population will grow at a per capita rate g = v-δ. The proportion of the population vaccinated at each time step is φ. Routine vaccination is assumed to take place in a pulse, such that over a short period of time a proportion, ρ of the total population is vaccinated. The inward and outward arrows indicate births and deaths respectively.

2. *Estimation of transmission coefficient*

The coefficient of transmission (denoted β) was defined as the average number of individuals that are newly infected from an infectious individual per unit time (De Jong et al. 1995).

Firstly, the β value was estimated for each divisional secretariat. Since, heterogeneity varied widely among divisional secretariats, the number of FMD infected animals at the end of the epidemic was adjusted by the duration of the outbreak using following formula:

$$C_a = \frac{C}{t} \tag{4.1}$$

Where, C is the number of new cases identified in the FMD epidemic, C_a is the adjusted number of cases, and t is the duration of the outbreak in days; therefore, C_a is an estimate of the expected number of cases caused by an individual FMD infected animal in a single day (Brito et al 2011). Thus, the value of β was consequently estimated as:

$$\beta = \frac{NC_a}{SIt} \tag{4.2}$$

Where N is the number of animals (cattle and buffalo) in the divisional secretariat, which was assumed to be constant through the duration of the epidemic, justify by the zero mortality and, by the prohibition of all animal movement susceptible for FMD imposed at the beginning of the epidemic, I denoted the number of animals infected at the time of outbreak detection, and S is the number of susceptible animals at the beginning of the epidemic, $S = N-I$.

In addition, as described in assumptions the transmission coefficient β_{ij} between divisional secretariats i and j decreased exponentially with increase of Euclidean distance of their respective divisional secretariat centroids (Chowell et al. 2006).

Therefore, the elements of the "mixing" or "contact" matrix β_{ij} (Anderson and May, 1991) were therefore described as:

$$\beta_{ij} = \beta(t)e^{-qd_{ij}} \tag{4.3}$$

Where β_t is the average transmission coefficienct of each infectious divisional secretariat at time t, d_{ij} the distance between the centroids of divisional secretariat i and j, and the parameter q(km^{-1}) which indicates the extend of average spread in each secretariat. According to the Chowell et al (2006) small values of q lead to widespread effect, on the other hand, large values of q lead to narrowspread influence. Additionally, for simplicity, homogeneous mixing within each divisional secretariat was assumed, that is, $d_{ii} = 0$. In addition, this parameters (d_{ij}) able to capture the effect of local transmission factors like animal density within the divisional secretariat and wind direction Chowell et al (2006).

Secondly, β_{ij} were calculated for each of the 18 FMD affected divisional secretariat. The following diagram describes the equation 4.3, where DS is the divisional secretariat (Figure 4.9).

Distance- d_{ij}

DS	DS -1	DS -2	DS -3	DS -4
DS-1	0	74	59	67
DS-2	74	0	20	62
DS-3	59	20	0	38
DS-4	67	62	38	0

Transmission coefficient - β

DS	DS -1	DS -2	DS -3	DS -4
DS-1	β_1	β_2	β_3	β_4
DS-2	β_2	β_2	β_3	β_4
DS-3	β_3	β_3	β_3	β_4
DS-4	β_4	β_4	β_4	β_4

Extend of average local spread - q_i

DS	DS -1	DS -2	DS -3	DS -4
DS-1	q_1	q_2	q_3	q_4
DS-2	q_2	q_2	q_3	q_4
DS-3	q_3	β_3	q_3	q_4
DS-4	q_4	q_4	q_4	q_4

Overall coefficient of FMD transmission – β_0

Figure 4.9 Contact matrix

The above explanations and assumptions led to the following SEIR model.

$$\frac{dS}{dt} = -\frac{S\beta I}{N} \qquad (4.4)$$

$$\frac{dE}{dt} = -\frac{S\beta I}{N} - \sigma E \qquad (4.5)$$

$$\frac{dI}{dt} = \sigma E - \gamma I \qquad (4.6)$$

$$\frac{dR}{dt} = \gamma I \qquad (4.7)$$

Where *S, E, I,* and R indicate the number of susceptible, exposed, infectious animals in the all divisional secretariats.

The number who are infected by FMD (infective individual) per unit time is proportional to the total number of those infected by FMD (new infective) per unit time is given as – *SβI/N*, the negative sign represents a decrease in the number of susceptible. The rate at which individual leave the exposed compartment (E) into the infective (I) compartment at the time t; t is given by σE, where σ is the latency rate of individuals exposed to the FMD. The number of individuals from the infective compartment to the recovered (R) at the time t is given as γI, where γ is the recovery rate coefficient of FMD and those who recovered from FMD gain immunity.

The incorporation of vaccination led to the following modified model.

$$\frac{dS}{dt} = -\frac{S\beta I}{N} - \phi S + \varepsilon V + \alpha R \qquad (4.8)$$

$$\frac{dV}{dt} = \phi R - \varepsilon V + \phi S \qquad (4.9)$$

$$\frac{dI}{dt} = \sigma E - \gamma I \qquad (4.10)$$

$$\frac{dR}{dt} = \gamma I - \alpha R - \phi R \qquad (4.11)$$

This model is useful for understanding the impact of vaccination. The solutions to equation Eqs 4.8 and 4.9 are shows when vaccination is introduced into the model run.

Thirdly, the compartmental model was simulated in ModelMaker 4 using a daily time interval. The ability to identify target vaccination levels predicted to lead to FMD eradication has been widely influential in policy making process (Babad HE et al., 1995). Therefore, models with the same fundamental structure as the SEIR models are used to set targets for vaccination coverage in many settings.

Definitions of variables and, initial parameter estimates used in the SEIR model are given in Table 4.3.

Finally, a sensitivity analysis was conducted to assess the robustness of the modelling results by changing selected input parameters in the model.

Table 4.3 Definitions of variables and initial parameter estimates in the SEIR model

Symbol	Unit	Definition	Estimates	Source
Variables				
S	Head	Susceptible	Initial=244,140	Field survey,2014
E	Head	Exposed	0	
I	Head	Infectious	0	
R	Head	Recovered	0	
N	Head	Total population	Initial=244,140 (S+I+R)	
Parameters				
σ	Day^{-1}	1/mean latent period	0.3333	Chowell et al, 2006
ϒ	Day^{-1}	1/mean infectious period	0.0714	Field survey,2014
α	Day^{-1}	1/mean period of natural immunity	0.0056	Sharma, 1981
ε	Day^{-1}	1/mean period of vaccine-induced immunity	0.0056	Sharma, 1981
φ		proportion of the population vaccinated at each time step	0.0714	Perry et al, 1999
p	%	Total population vaccinated	10-100	
g	%	Population growth rate	6.5E-09	DAPH (1998-2013)

3. Assumptions of the model

The major assumptions used in the model are as follows:

1. FMD virus is persists in cattle and buffalo population. This assumption is reasonable because historically, FMD epidemics mainly affected cattle and buffalo population in the country (Figure 4.8).
2. Uniform mixing of individuals within each divisional secretariat.
3. No external introduction of FMD from surrounding countries.
4. FMD outbreak is located in the center of each corresponding divisional secretariats.
5. The coefficient of transmission β_{ij} between divisional secretariats i and j decayed exponentially fast with the Euclidean distance of their respective divisional secretariat centroids.
6. Vaccine efficacy is 85 %.
7. Age, breed, sex and management system do not affect the probability of being infected.

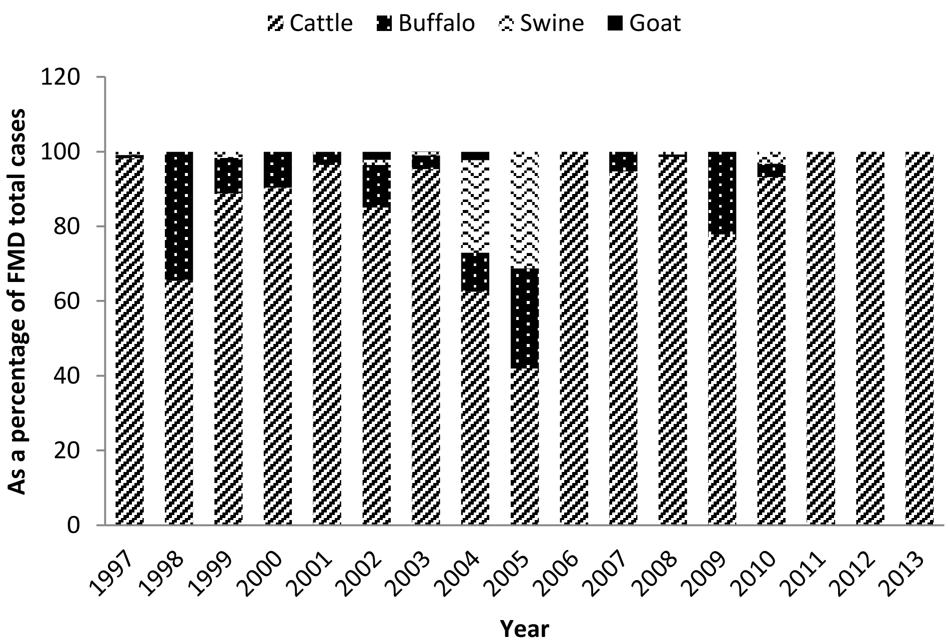

Figure 4.8 Share of FMD occurrence in livestock species
Source: Department of Animal Production and Health.

4. Vaccine efficacy

Vaccine efficacy (VE) is defined as the percentage reduction of disease incidence among population who have received a vaccine compared to the incidence in an unvaccinated group, under ideal conditions. The standard formula for calculating VE as a percentage is (Orenstein et al. 1988; Weinberg and Szilagyi, 2010).

$$VE = \frac{ARU-ARV}{ARU} * 100$$

Where,
ARU = attack rate in the unvaccinated population
ARV = attack rate in the vaccinated population.

However, in Sri Lanka efficacy of FMD vaccine has not been tested in a field trial. Many previous studies have assumed (Keeling et al. 2003; Tildesley et al. 2008; Bates et al. 2003) this rate to be 80-90 % for FMD vaccine in cattle and buffalo. Thus, current study modelling catch-up FMD vaccination assumed 85 % efficacy and six months immunity (Sharma, 1981). Although, efficacy and effectiveness are used interchangeably, vaccine efficacy differs from vaccine effectiveness. Vaccine effectiveness measures how well a vaccine performs when it is used in routine circumstances in the community (Center for Disease Control and Prevention, 2011).

5. Critical vaccination coverage to eradicate a disease

Anderson and May (1991) indicate the following equation for estimating the minimum or critical proportion of a susceptible population that must be vaccinated to eradicate a disease:

$$P_c = 1 - \frac{1}{R_0}$$

Where P_c is the critical proportion and R_0 is the basic reproductive number. The basic reproductive number is the number of secondary cases caused by one primary case introduced into a susceptible population. In other words, R_0 is a threshold that determines whether a disease will spread die out or whether it may become epidemic in the population (Van Den Driessche and Watmough, 2002). Whenever, R_0 is >1, the disease will spread in a population. If R_0 <1, the disease will be able to spread in a population. Generally, the larger the value of R_0, the harder it is to control the epidemic.

Therefore, to calculate numerical values of pc requires estimates of R_0. Generally, as R_0 increases, eradication by vaccination becomes very challenging due to logistical problems in achieving high coverage levels. Using the above equation and data from a variety of sources, Anderson and May presented estimates of the critical value P_c for well-known infectious diseases (Table 4.4).

Table 4.4 Estimates of the critical proportion of susceptible population that must be vaccinated to eradicate a given disease from a population

Infectious disease	**Critical proportions of the population to be vaccinated to eradicate a disease**
Malaria (*P. falciparum* in a hyper endemic region)	99%
Measles	90-95%
Whooping cough	90-95%
Fifths disease (human parvovirus infection)	90-95%
Chicken pox	85-90%
Mumps	85-90%
Rubella	82-87%
Poliomyelitis	82-87%
Diphtheria	82-87%
Scarlet fever	82-87%
Small pox	70-80%

Source: Anderson and May (1991)

However, the literature was limited related to the value of P_c for FMD because lack of published mathematical models describing the spread of FMD has resulted in a lack of readily available published estimates of the value of R_0.

Moreover,

$$R_0 = \frac{\beta}{\gamma}$$

Where, β is the transmission rate and γ is the recovery rate, and affected animals recover within 8-14 days (reference book).

B- Economic Model (Benefit-Cost Analysis – BCA)

Economic evaluations of health interventions, such as vaccinations, culling, etc. are important tools for informing health policy (Barnighausen et al 2011). Cost-benefit analysis is a well-known static technique commonly applied in evaluation major public policy decisions, regulations and projects.This technique is best used on a limited scale, since it is frequently employed assuming no changes in market prices or costs.

The benefit of FMD vaccination were calculated by estimating the direct losses (milk loss costs and mortality costs) which occurred due to FMD during 2014 in North Central Province.

The calculation of losses due to reduced milk yield due to FMD used the following formulae:

Milk loss costs
= Average duration (days) of reduced milk production per FMD case * Volume of milk loss (liter) per day per FMD case*Average milk price per liter (Sri Lankan Rupee) *Number of lactating sick animals (head)

The estimation of costs of FMD vaccination comprised the costs of the vaccine purchase and importation into Sri Lanka, vaccinators cost per animal per day, transportation of vaccine into North Central Province, cold chain storage costs and electricity cost and, fuel cost. Biannual vaccination using monovalent FMD vaccine was assumed, with 85 % vaccine efficacy. A cattle and buffalo population in North Central Province of 168,212 was estimated based on records.

The benefit-cost ratio (BCR) of FMD vaccination is therefore:

$$\text{BCR} = \frac{\text{Milk loss costs}}{\text{FMD vaccination costs}}$$

The benefit-cost model explained above was developed in an MS Excel spreadsheet. Copies of the spreadsheet were also used to conduct sensitivity analysis by changing selected parameters in the model.

In addition, the annual costs and benefits were projected over time and discounted at 10% over a ten year time period to compute the BCR and NPV (Net Present Value) as follows:

$$BCR = \sum_{t=1}^{n} \frac{\left[B_t/(1+d)t\right]}{\left[C_t/(1+d)t\right]} \qquad \text{(for t=1,2………,10)}$$

$$NPV = \sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+d)t} \qquad \text{(for t=1,2………,10)}$$

Where B_t is the benefit in year t, C_t is cost in year t, d is the discount rate and n is the number of years in the future (10 years). The larger the value of BCR and NPV, the vaccination strategy is more efficient and feasible.

4.4 Results and discussion

4.4.1 Disease surveillance and outbreak investigation

The Department of Animal Production and Health (DAPH) is the main state organization which is responsible for providing technical leadership to the livestock Industry and its stakeholders in Sri Lanka. The DAPH currently operates through its five (05) technical divisions such as Animal Health, Veterinary Research, Livestock Planning and Economics, Animal Breeding and Human Resource Development, and two (02) support services divisions (Administration and Finance) (Figure 4.10).

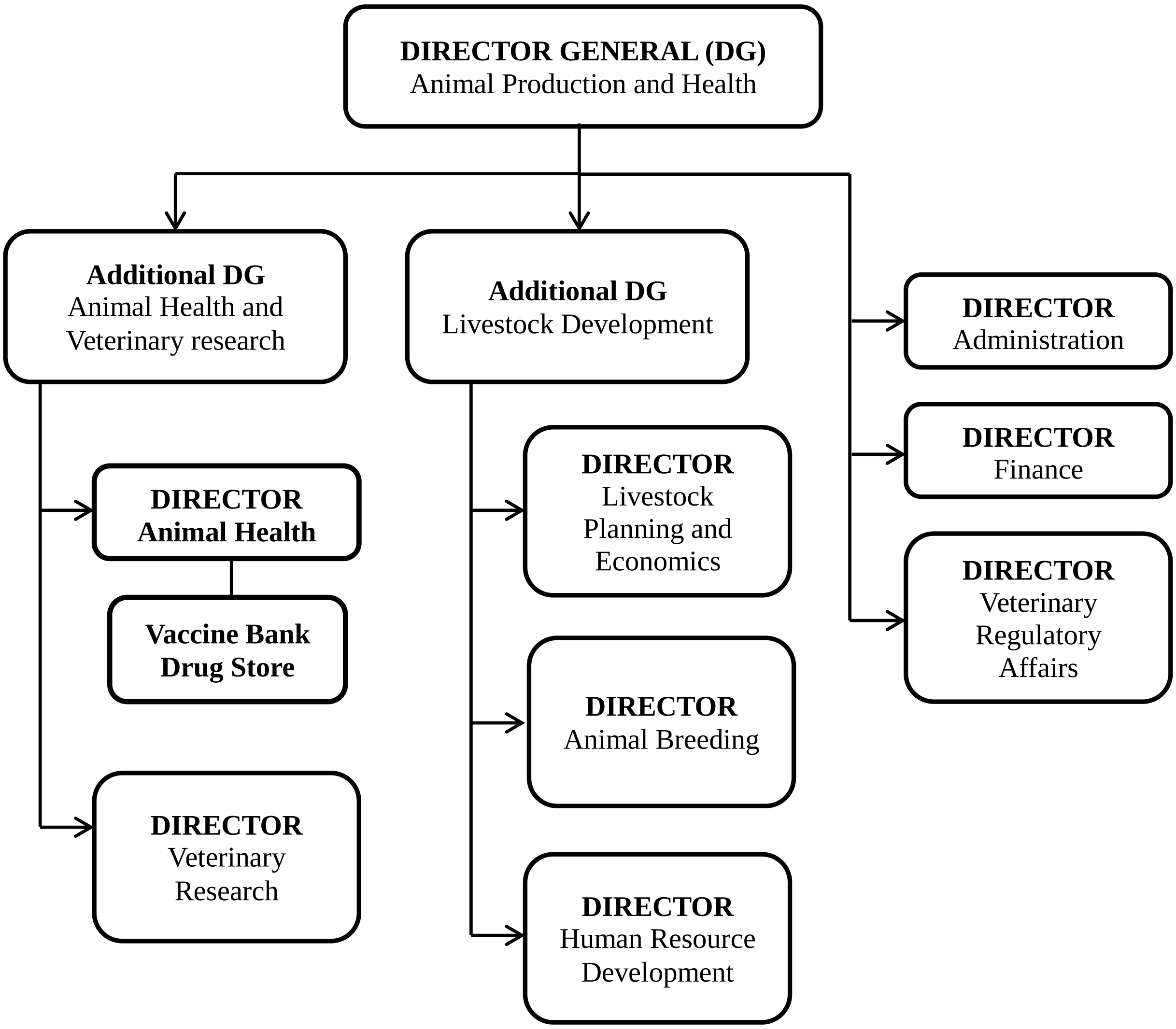

Figure 4.10 Organization structure of the Department of Animal Production and Health (DAPH)
Source: Department of Animal Production and Health (DAPH), 2013

The Animal Health division is the main implementing organization in Sri Lanka responsible for disease surveillance and control for ensuring required animal health status for development of livestock production in the country. Animal Health division has the national unit located at Head Quarters of DAPH with its components, namely vaccine bank and veterinary store. The peripheral units (country subdivisions), called Veterinary Investigation Centres (VIC) are established at district level. Among 25 Administrative Districts, 18 of them have established functional VIC. But, still seven administrative districts are managed by the VIC located in the adjoining districts. Comprehensive animal disease surveillance is generally conducted through 305 Veterinary Officers established in the country. Under this responsibility FMD is monitored by clinical surveillance and monthly animal disease report is submitted to the national animal health division by the field veterinary surgeons. In the event of an FMD outbreak, a descriptive epidemiological investigation is carried out by the Veterinary Investigation Officers (VIO) and the feature in the infected population is revealed and documented (Figure 4.11) (DAPH, 2014).

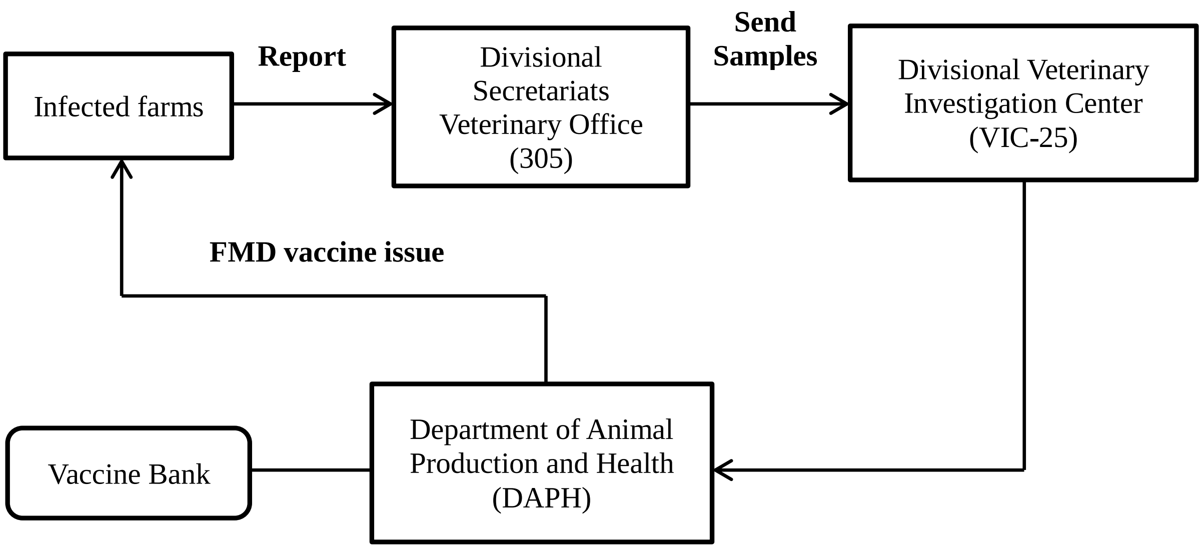

Figure 4.11 National FMD control strategy

A- Vaccination strategy

In Sri Lanka, currently there is no country-wide vaccination programme aimed to control FMD. The FMD vaccination in the country has always been limited to the endemic and buffer zones and identified locations based on the level of risk. The objective of mass-scale preventive vaccination campaign is to ensure required level of herd and individual immunity. Despite the preventive vaccination campaign, the protective vaccination also has been used as a compulsory 'ring vaccination' in order to control the spread of FMD. Generally, this vaccination is practiced as an area in the radius of 3-5 km around affected premises. FAO developed the Progressive Control Pathway for Foot-and-Mouth Disease (PCP-FMD) to assist and facilitate countries where FMD is still endemic to progressively reduce the effect of FMD and the load of FMD virus (FAO/OIE, 2011). However, according to the DAPH, in order to proceed in the progressive control for FMD 100 % vaccination coverage is required to be achieved at Eastern, Northern, North-Central and North-Western Provinces for at least five years consecutive years (DAPH, 2014).

B- FMD post vaccination sero-monitoring

Sero-monitoring is an essential component of any vaccination campaign. It is used to monitor the performance of the vaccination teams and, to establish levels of herd immunity. This test requires a minimum of 30 samples collected in each area that would be selected in a stratified multi-stage sampling design. In total 300 serum samples collected from the population of vaccination, preferably after a month of each FMD vaccination campaign. Any area that may fail to achieve the desired will be investigated for its deficiencies and corrective measures implement accordingly (DAPH, 2014).

C- Animal identification and movement control

Animal identification and the management of animal movements are critical to the control of animal diseases and access to trade in animals and animal products. In Sri Lanka the animals have been commonly identified by various methods such as ear tagging, brand marks on the skin, and ear tattooing. All animals being registered with a respective government Veterinary Office with a unique identification number. The identification number composed of 12 digits; the first 2 digits designate the province and the district, respectively. The next two indicates the Divisional Secretariat division, and the following four digits indicate the farm and the last 4 indicate the animal number. The district level data is maintained at District Veterinary Surgeon's office while the national level data-base is being maintained at the Livestock Planning and Economic Division of DAPH. In addition, Animals Act No. 29 of 1958 regulates the movement of animals, particularly between districts. Accordingly, the animal ownership has to be proven and the Government Veterinary Surgeon has to ensure the absence of FMD in the area from where the animals will be moved for a period of 3 months immediately prior to the movement. Further, the Director General of the DAPH is empowered to close roads to all animal traffic by proclaiming the area as FMD infected area and publish the same in the government gazette. This ban is effective over a period of three months unless and otherwise it is revoked prior that (DAPH, 2014). (See chapter 5 for more details). The most effective approach for controlling FMD transmission is to restrict animal movement but this is very difficult in Sri Lanka particularly in pastoral areas and where cross-border movement of animals is not regulated.

D- Import control

The Animal Disease Act No. 59 of 1992 governs the prevention and introduction of contagious diseases in animals in to Sri Lanka through the import of live animals and animal products. If imports live animals and/or products of animal origin into the country a set of procedures to be followed and stipulated health requirements should be fulfilled. The importer should initially submit the basic information regarding the import in order to request permission from the Director General. The risk associated with import is analysed based on the species and type of animal or products of animal origin and the country of origin following the OIE recommendations and guidelines. After the risk assessment a 'permit' is issued together with a set of conditions as sanitary measures (DAPH, 2014).

4.4.2 Epidemiological model (Susceptible-Exposed-Infectious-Recovered model)

In this study, the value of the transmission coefficient or β was estimated from the weekly data obtained from the Department of Animal Production and Health, North Central Province. The transmission coefficient was estimated to be 0.618 by the SEIR model. Chowell et al (2006) modelled the epidemiology of FMD in Uruguay in 2011 and found transmission coefficients of 0.77 and 0.33 for non-spatial epidemic model and spatial epidemic model, respectively. In many previous studies, the range of the values of the transmission coefficient was found to lie between 0.1 and 0.9 (Hyeyoung et al. year; references).

The following figure shows the distribution of infected animals (infected compartments of the four SEIR compartments) through different FMD vaccination coverage. The numbers of infected animals tend to decrease with increasing vaccination coverage (Figure 4.12). Indeed, effective vaccination acts as though the number of susceptibles were reduced; this will therefore affect the contact rate and the reproduction number R (Trottier and Philippe, 2002). Ultimately, vaccination against FMD reduced the number of infected animals.

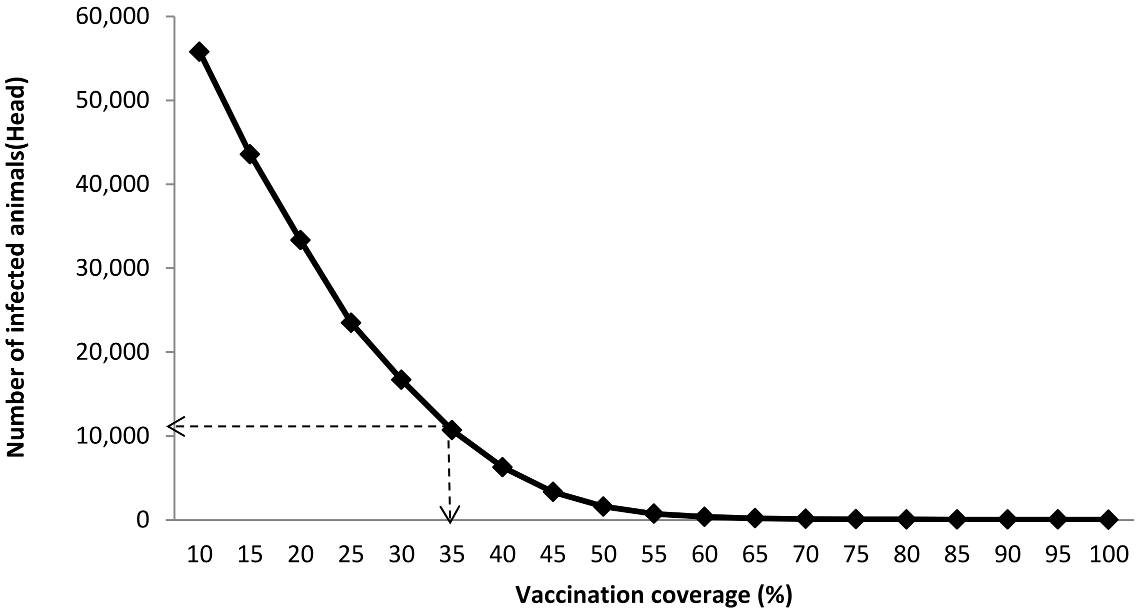

Figure 4.12 Number of infected animals, by FMD vaccination coverage

Figure 4.13 shows the number of animals vaccinated animals in 2013 vaccine season in the North Central Province (The North Central Province is composed of two districts ; Anuradhapura and Polonnaruwa). There was no regular (bi-annual) vaccination programme in the study areas and vaccine offered cattle only. The vaccination coverage at 6 months was found to be 35 % in the North Central Province. The number of infected animals was 10,676, corresponding to a vaccination coverage of 35 % (Under condition of 85 % vaccine efficacy) (Figure 4.12). The actual reported cases were 8,384 during the same period and model over estimated cases by + 21.5 % (See chapter 5 for more details).

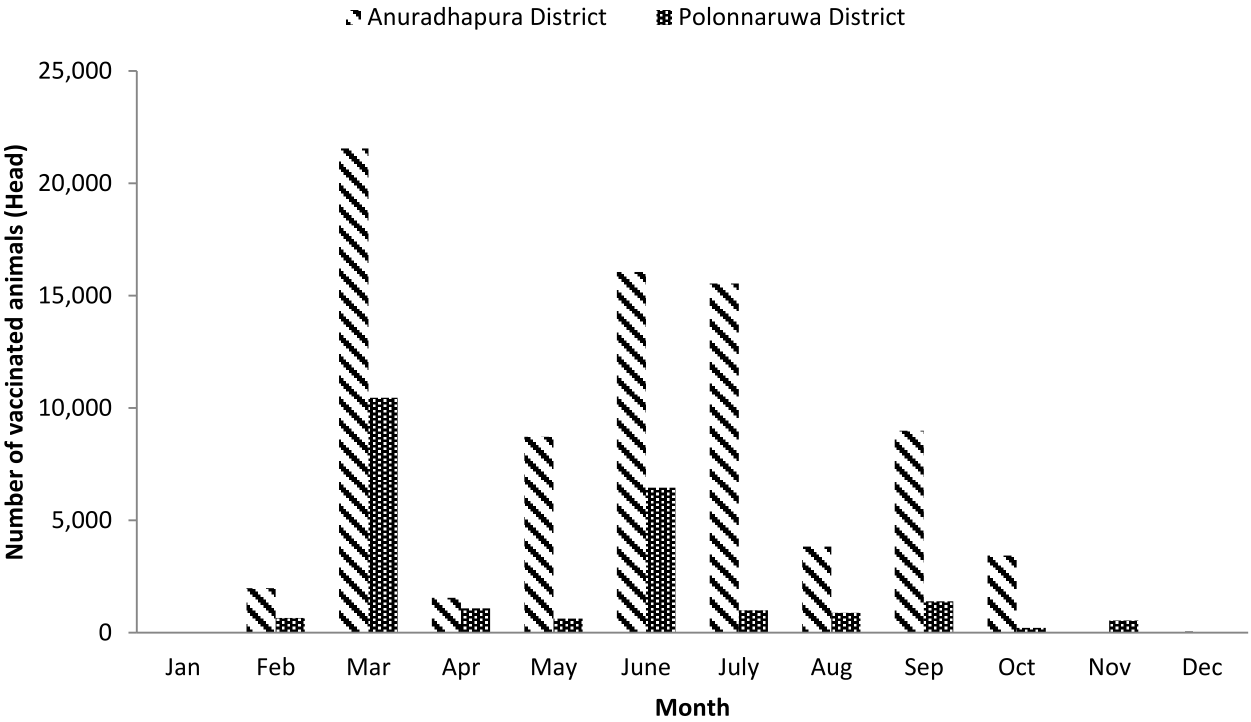

Figure 4.13 FMD vaccination coverage – 2013 North Central Province

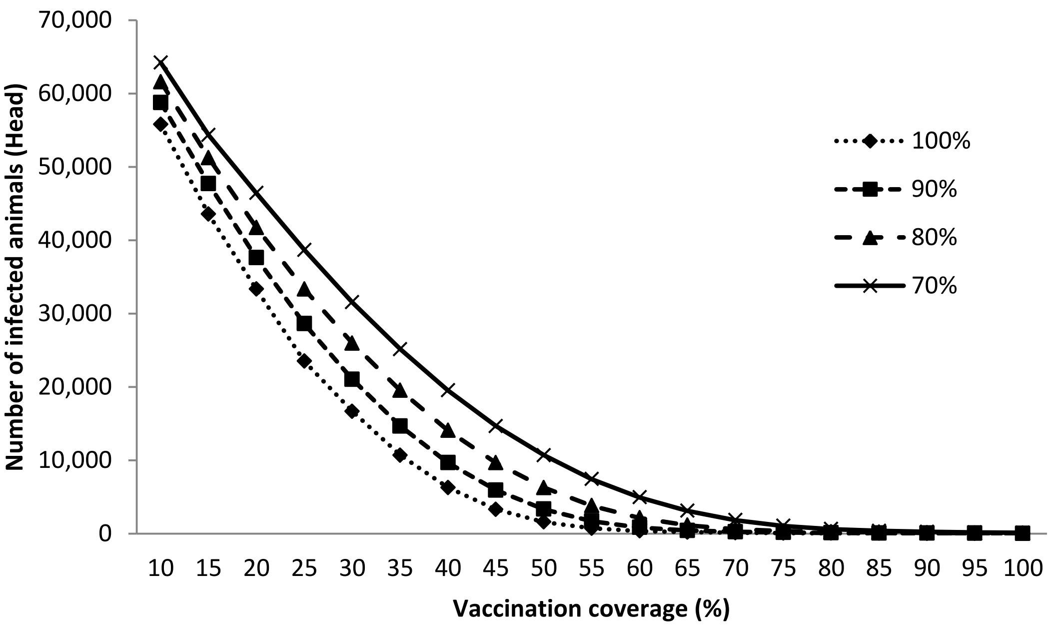

Figure 4.14 Number of infected animals and vaccine efficacy, by FMD vaccination coverage

In addition, even though FMD vaccines have very high effectiveness rates; they are not completely effective for 100% of the animals who receive them. Vaccine efficacy of FMD in cattle has not yet been fully tested in field conditions. Figure 4.14 shows the number of infected animals with selected vaccine efficacies and, with different vaccines coverage. By increasing vaccine efficacy, vaccine will protect more animals and curve shifts towards right side.

In all models, parameters are more-or-less uncertain. Sensitivity analysis of simulation model quantifies the change in the simulation output as the simulation input parameter changes (Kleijnen, 2011). The following figure shows a graph of sensitivity analysis (Figure 4.15). As the level of vaccinations coverage increase, the herd immunity threshold[2] increases and have led to a reduction of infected animals. On the other hand, by decreasing the transmission coefficient, the number of infected animals decreases.

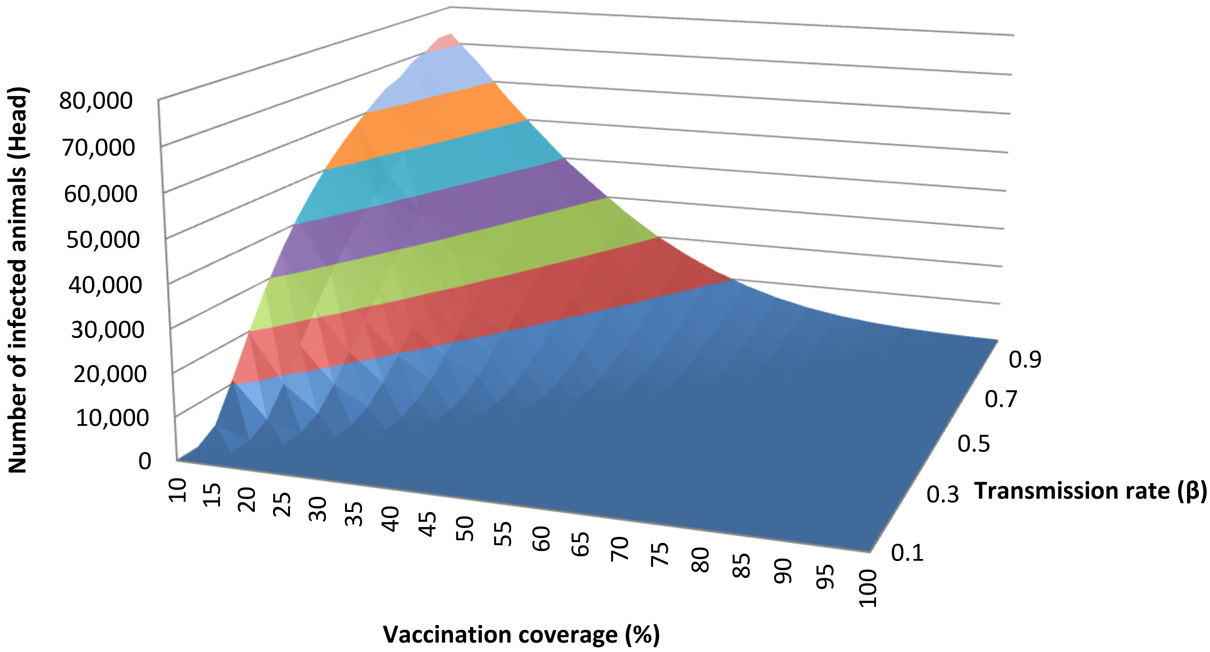

Figure 4.15 Number of infected animals when vaccination coverage and transmission rates are varied

The basic reproduction number at the beginning of the epidemic initial were found to be 9.3 and 9.8, respectively (Durand and Mahul, 2000; Rubel, 2003). In the current study, the reproduction number, R_0 varied between 4.9 and 8.6, corresponding to recovery rate of 0.125 and 0.071. Thus, lower and upper bounds of the critical vaccination coverage, P_c were estimated to be 79.5 % and 90.5 % (Figure 4.16). The area above the curve represents an eradication of FMD outbreak while area under the curve indicates no eradication. But the FMD vaccination coverage in the study area remains low and it is nearly 35 %. Therefore, in order to eradicate FMD by the year 2020, the current vaccination coverage is required to rise by at least 45 %.

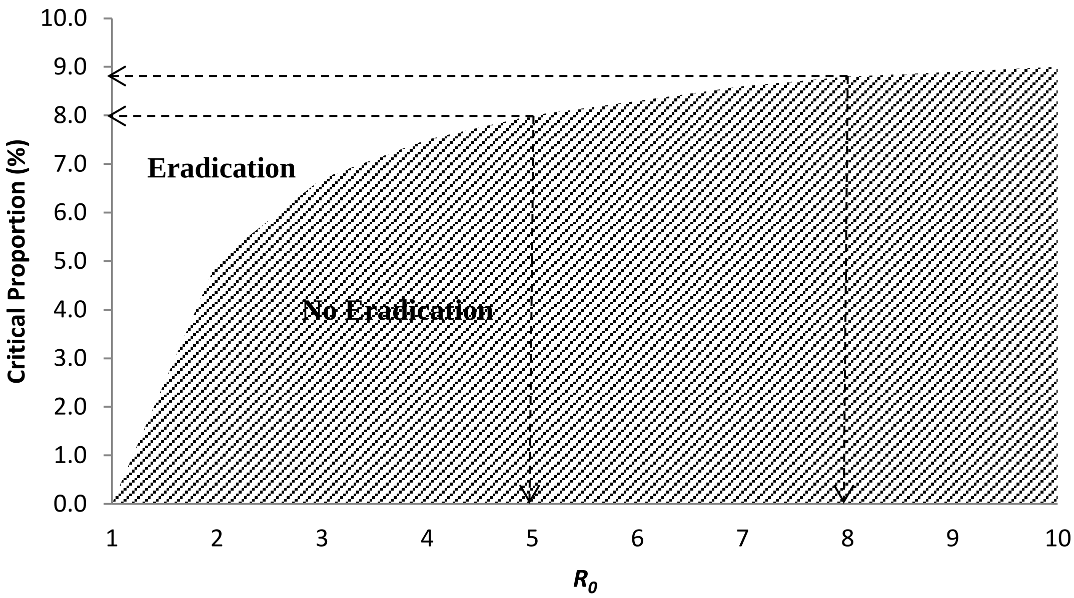

Figure 4.16 Critical vaccination proportion to eradicate FMD disease

4.4.3 Economic model (Benefit-Cost Analysis – BCA)

In order to estimate the benefit-cost of FMD vaccination, some epidemiological parameters were fixed as follows; Transmission coefficient (β) = 0.618, Vacccine efficay = 85 %, the total cattle and buffalo population in the North Central Province = 244,140. Furthermore, the epidemiological analysis concluded that using the SEIR model, the vaccination coverage required for FMD eradication is 80 %.

The benefit-cost analyses was performed to evaluate the economic viability of FMD vaccination.

Table 4.5 presents variables related to milk production and milk losses due to FMD.

Table 4.5 Variables related to milk production and milk losses due to FMD

Variables	Unit	Parameter	Data Source
Mean prevalence of FMD in adult animal	%	32.23	Chowdhury, 1993
Mean prevalence of FMD in young animal	%	15.25	Gorsi et al., 2011
Average duration of reduced milk production per FMD case	Days	33.74	Field survey, 2014
Drop in milk production	%	18.00	Hettiarachchi and Kothalawala, 2012
Average milk price per liter	Sri Lankan Rupee	48.00	Field survey, 2014

Table 4.6 FMD vaccination cost calculation, 2014 – Sri Lankan Rupee

	Variable		Cost	Data Source
1	Vaccine price per dose/2ml (imported from India - Monovalent Type "O" Vaccine Strain)		35.00	DAPH
2	Vaccinators cost per day (a)	400		Field investigation
	Vaccinators cost for vaccination per animal per day (a/b)		8.00	
3	Fuel cost per animal		10.00	Field investigation
4	Other costs (Electricity and cooling facilities, etc.)		0.75	Field investigation
	Total vaccination cost per animal		**53.75**	

Estimates of the variables used for the BCA calculation of FMD vaccination are presented in Table 4.6. The highest cost was vaccine procurement, which presented 61 % of the direct costs.

The BCA for biannual vaccination with 80 % coverage and the sensitivity analysis for vaccination against FMD are presented in Table 4.7. The results suggest that, every Sri Lankan Rupee 1 spent on vaccination resulted in positive benefits of Sri Lankan Rupee 3.7. The sensitivity analysis showed that reduction in the FMD prevalence of 25 % and 50 % and increases in market values of milk of 10 % and 20 %

produced the same reductions and similar increases in the befit-cost ratio, respectively.

Table 4.7 Benefit-cost calculation and sensitivity analysis for FMD vaccination

Summary variable	Benefit/Cost	Unit
Losses due to reduced milk production (Benefit)	78.093	million Sri Lankan rupees
Cost of vaccination program (Cost)	20.996	million Sri Lankan rupees
Benefit-cost ratio (at current vaccination price)	3.719	
Sensitivity analysis		
	Market value of milk increased by 10%	Market value of milk increased by 20%
FMD prevalence		
Reduce by 25%	1.546	1.698
Reduce by 50%	1.038	1.140
Vaccination cost		
Increase by 25%	3.285	3.595
Increase by 50%	2.738	2.996

A- Budget allocation for FMD eradication

As indicated in Figure 4.17, the Sri Lankan government has allocated 53.56 billion Sri Lankan rupees, or 6 % for agriculture and irrigation.

The budget for FMD control and eradication has always been low and stagnant. It has remained around 20 million during the past fiscal years. But its budget allocation increased by 225 % due to the major FMD epidemic occurred in 2014. The government has allocated 65 million Sri Lankan rupees to the Department of Animal Production and Health (DAPH) under the ministry of livestock and rural community development on FMD control and eradication. (DAPH, 2014) Currently, there are nine provinces and each will roughly receive 7.22 million Sri Lankan rupees (assuming equal allocation) for FMD control. According to the above calculation (Table 4.7), there is a shortfall from the actual allocation and the required allocation of 13.80 million Sri Lankan rupees. If the government can allocate 0.025 % of additional budget annually for each province from the expenditure on agriculture and irrigation, it would generate 78.09 Sri Lankan rupees additional benefits from FMD eradication.

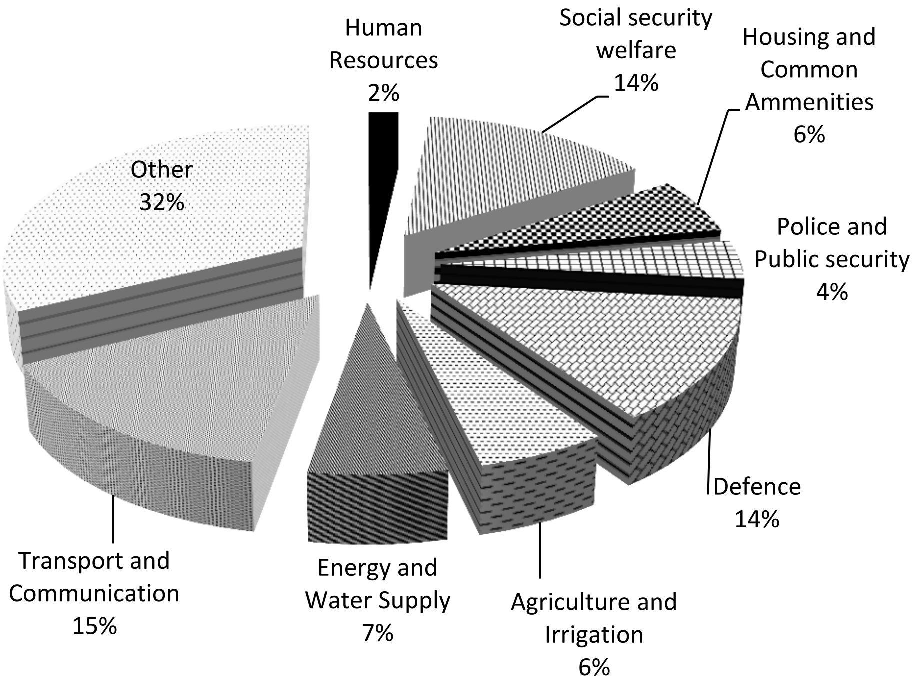

Figure 4.17 Composition of Average Government Expenditure (2002-2011)
Source: Ministry of Finance and Planning Sri Lanka, Annual report, 2012

B- Multi-year analysis

FMD outbreaks can occur each year, once per two year, rarely or once per ten year. Table 4.8 indiacted the data used to calculate the BCR and NPV.

Table 4.8 Data used for calculation of BCR and NPV

Year	Benefit (Million Sri Lankan Rupees)	Cost (Million Sri Lankan Rupees)	Discount rate (%)
1. FMD occurs every year			
1	78.093	20.996	10
2	78.093	20.996	10
3	78.093	20.996	10
4	78.093	20.996	10
5	78.093	20.996	10
6	78.093	20.996	10
7	78.093	20.996	10
8	78.093	20.996	10
9	78.093	20.996	10
10	78.093	20.996	10
2. FMD occurs every two years			
1	78.093	20.996	10
2	78.093	0.000	10
3	78.093	20.996	10
4	78.093	0.000	10
5	78.093	20.996	10
6	78.093	0.000	10
7	78.093	20.996	10
8	78.093	0.000	10
9	78.093	20.996	10
10	78.093	0.000	10
3. FMD occurs once per ten years			
1	78.093	20.996	10
2	78.093	0.000	10
3	78.093	0.000	10
4	78.093	0.000	10
5	78.093	0.000	10
6	78.093	0.000	10
7	78.093	0.000	10
8	78.093	0.000	10
9	78.093	0.000	10
10	78.093	0.000	10

The Table 4.9 indicates the districution of total Net Present Value (NPV) of benefits, total NPV of costs, and benefit cost ratios (BCR) with changing frequency of FMD outbreak occurance.

Table 4.9 Distribution of NPV's and BCR's with changing frequency of FMD outbreaks occurrence (Discount rate =10%)

	Frequency of occurrence		
	Every year	**Once per two years**	**Once per ten years**
Total NPV of benefit (Million Sri Lankan Rupee)	301.084	150.542	30.108
Total NPV of cost (Million Sri Lankan Rupee)	80.949	80.949	80.949
NPV	220.135	69.593	-50.840
BCR	3.719	1.860	0.372

A positive NPV indicates that the investment for FMD vaccination earns a higher rate of return than the required rate. Coversely, a negative NPV means that cash flows yield a return less than the required level. Therefore, the vaccination against FMD is economically efficient if FMD epidemic occurs every year or every two years. But, current study only included the cost of reduced milk yield, therefore benefit is much lower compared to a economic model which included other costs (death loss, abortion loss, treatment costs, etc.).

4.5 Conclusion

Employing the integrated epidemiological and economic model, the economic viability of preventive biannual vaccination against FMD was identified and quantified. From the epidemiological model, it clearly showed that, current vaccination rate of 35 % is not sufficient to eradicate the FMD disease by 2020. In order to eradicate FMD, the current level of vaccination coverage required to be increased by 45 %. Moreover, from the economic model, it is clearly indicated that, every Sri Lankan Rupee 1 spent on biannual vaccination resulted in positive benefits of Sri Lankan Rupee 3.7. Nevertheless, FMD disease control is constrained by a low budget allocation and there is a shortfall from the actual allocation and the required allocation of 13.80 million Sri Lankan rupees. If the government can just allocate 0.025 % of additional budget annually for each province from the expenditure on agriculture and irrigation, it would generate 78.09 million Sri Lankan rupees additional benefits each year from FMD eradication. Therefore, preventive biannual vaccination is recommended for the dairy sector in Sri Lanka.

<Notes>

1) For administrative purposes, Sri Lanka is divided into 9 provinces and 25 districts ("Districts of Sri Lanka", 2013). Once again each district is divided in to divisional secretariats and each district is administered under a District Secretary. North Central province consist two districts namely Polonnaruwa and Anuradhapure. There are 23 and 7 Divisional Secretariats in Anuradhapura and Polonnaruwa districts, respectively ("Divisional Secretariats of Sri Lanka", 2014).
2) The "Herd Immunity Threshold" can be defined as the percentage of the population that needs to be immune to control transmission of a disease (Johnson, 2009).

CHAPTER 5

Farmers’ knowledge and behaviour towards FMD outbreak

5.1 Introduction and objectives

The use of FMD vaccines is generally controlled by regional or national FMD control policy. In country like Sri Lanka where FMD is endemic or sporadic, vaccination is an essential component of FMD prevention and control. However, according to the Chapter 4, vaccination alone is not always sufficient to control spread of FMD outbreak. In addition, currently there is no nationwide regular vaccination programme devised to control FMD. Moreover, FMD disease control is constrained by a low budget allocation. Nevertheless, improving the farmer’s knowledge on distinguishing FMD from other diseases, prompt reporting of any suspicion of FMD, as well as, restrict of all movements of animals or animal products are critical activities for an effective FMD response effort.

A major factor useful in the control of this disease is the ability of farmers to suspect FMD cases (Talabi et al, 2013). There is a complex but important inter-relationship between the level of farmers’ knowledge about FMD and its prevention and control (Goswami and Sagar, 1996).

Early detection and prompt reporting of suspicion of FMD is critically important to limit the risk of any further spread of disease before control measures are applied, thereby limiting the size and duration of the outbreak. Thus, FMD can be controlled effectively if a strong awareness of it is created among the farmers regarding its symptoms, routes of transmission, disease management, prevention and control.

Moreover, animal movements and trade play a significant role in the spread of FMD. Hence, despite the significant economic losses involved (James and Rushton, 2002), movement and trade restriction at domestic and international level are fundamental to control (Sutmoller et al., 2003). In addition, raw milk (untreated) and raw milk products may act as sources of FMD infection and primary risk from raw products is in transmission of the virus to susceptible animals.

Dairy is the main income source for the poor rural farmers, particularly in the dry zone of Sri Lanka. Therefore, this study hypothesized that farmers have poor knowledge to identify FMD infected animals, farmers are reluctant to report a suspicion of FMD to the veterinary authorities, and farmers sell raw milk from FMD-infected cattle in the market. If the farmers have high – level knowledge about the FMD disease and FMD transmission, farmers may not sell raw milk from FMD-infected animals or raw milk from FMD-infected animals. But, farmers’ knowledge level and behaviors towards FMD control are unknown. On the other hand, there has been no study published on the knowledge level and behaviors of dairy farmers in Sri Lanka.

Therefore, the main purpose of this study was to clarify the relationship between farmers’ knowledge level and their behaviour to make a strategy to control the FMD.

The specific objectives of the study were:

1) To investigate the farmers' knowledge level on FMD symptoms, sources of FMD transmission and FMD control methods
2) To investigate the farmers behaviors towards FMD and its control

5.2 Background

Foot-and-mouth disease (FMD) is a severe, extremely contagious viral disease of cloven-hoofed animals. FMD permanently affects the productivity and health of infected animals and it can spread quickly. Because of the potential for rapid spread, with nearly 100 % of exposed animals ultimately becoming infected. Therefore, identifying the main routes of transmission between farms and animals are important to eradicate and control the FMD disease. The figure below shows the possible routes of FMD transmission (Figure 5.1).

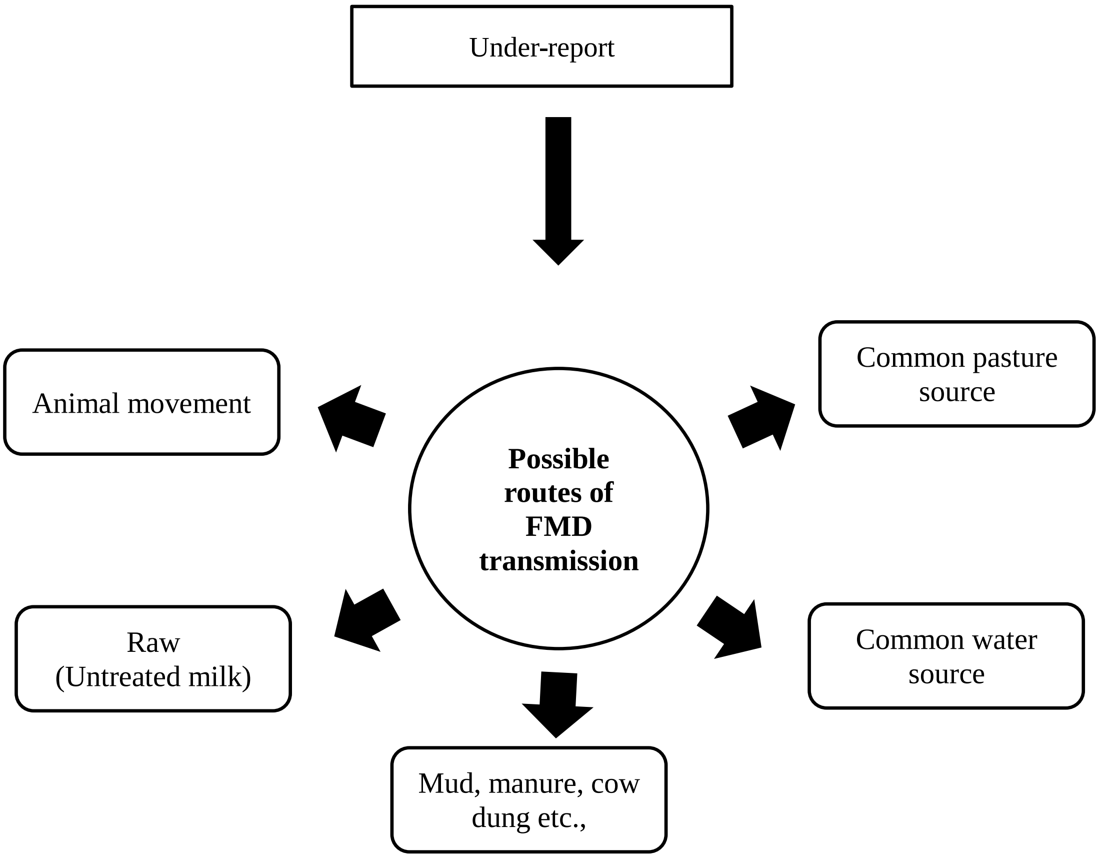

Figure 5.1 Possible routes of FMD transmission

Early reporting constitutes the most important factor in reducing the cost of an FMD outbreak (McLaws, 2009). A major obstacle to early detection is the low level of awareness among farmers and veterinarians. In addition, effective control of movement of animals plays a significant role in stopping or slowing the spread of FMD. Moreover, there is abundant evidence that the movement of FMD infective raw (untreated) milk can play and important part in the spread of FMD during outbreaks (Donaldson, 1997). Also, materials like mud, manure, cow dung, bedding or feed stuffs and any vehicles (trucks, trailers, etc.) lowed on the farm can carry virus and have the potential to spread disease. Moreover, common water sources and grazing ground are major risk factors for the spread of FMD virus (Sinkala et al., 2014).

5.3 Materials and methods

5.3.1 Study area, data source and collection procedure

The target area is in the Dry Zone of Sri Lanka. The elevation of the Dry Zone lies between 0m-450m from the sea level and the average ambient temperature is between 21 C^0- 35 C^0.Two thirds of the national cattle and buffalo population are found in the dry and the dry intermediate zones of Sri Lanka, but the average milk production is relatively low. The breeds, which can be found in the region, are *Zebu*, *Sahiwal* cross-bred cattle, improved buffalo and indigenous breeds. Farmers here commonly practice the extensive management system and cattle are not fed with concentrate feeds. Generally, animals graze in the scrub jungles and other grasslands. Most of the farmers practice zero input production system and the average herd size varies from 25-100/farm. The average daily milk production is reported as 2 liters/cow or around 500 liters/cow/lactation (Reference). In the study area, the seasonal availability of grass can be seen and straw feeding is a mostly common practice.

The study was conducted in divisional secretariats of Anuradhapura districts, namely Padaviya, Kebithigollewa, Kahatagasdigiliya and, Rambewa (Figure 5.2). The mentioned areas were selected because they had recorded the highest number of FMD cases during the outbreak period (Figure 5.3).

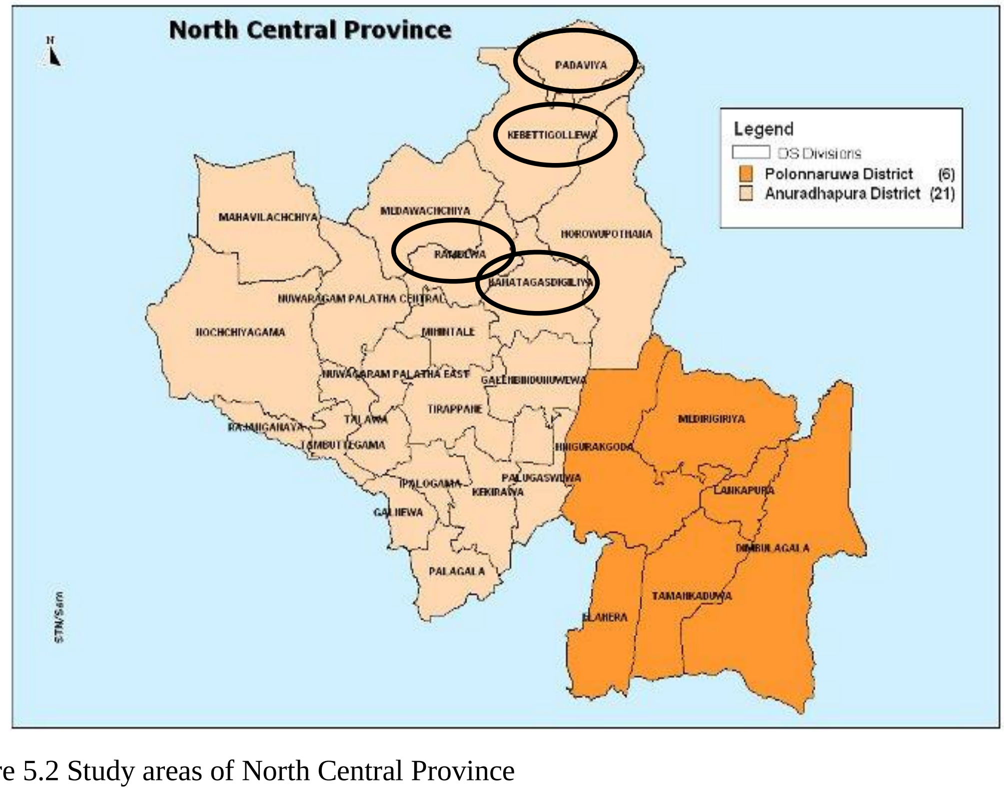

Figure 5.2 Study areas of North Central Province
Source: Department of Animal Production and Health, North Central Province

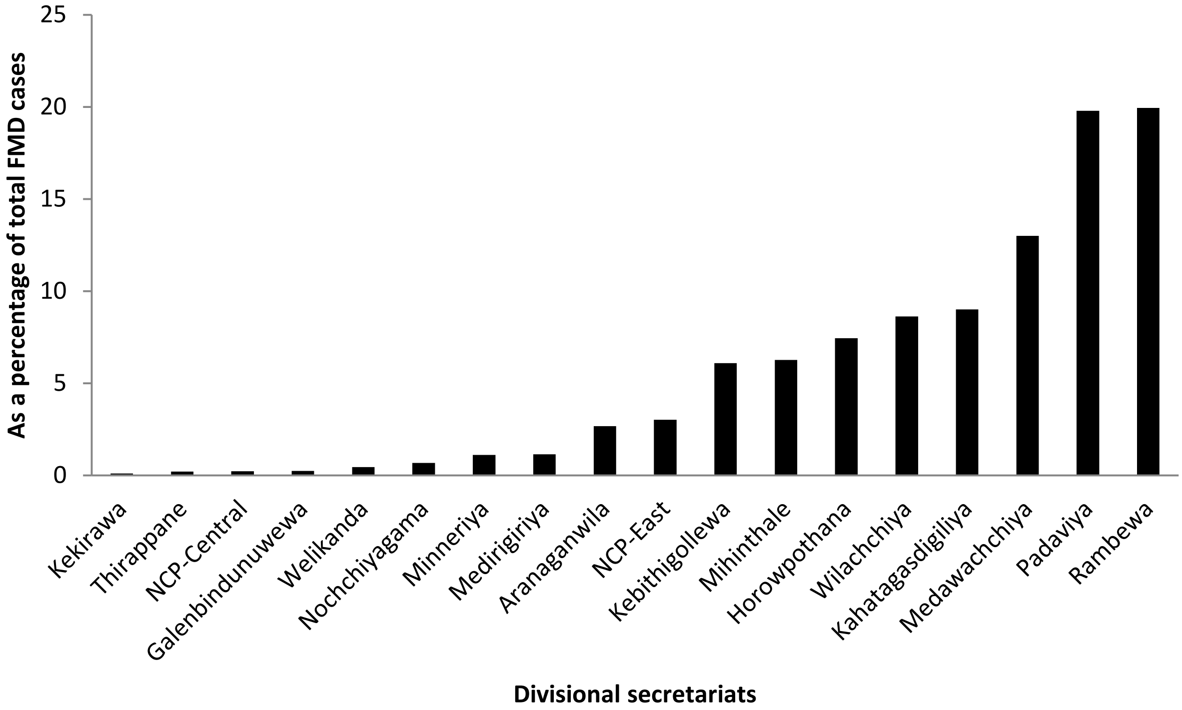

Figure 5.3 Distribution of FMD cases among divisional secretariats of North Central Province
Source: Department of Animal Production and Health, North Central Province

5.3.2 Data analysis

A- Questions to evaluate farmers' knowledge about FMD

Questions were asked to measure the farmers' knowledge about FMD. Respondents earned 1 point for each correct answer and maximum score was 15. The questions were composed to test the knowledge of FMD signs and symptoms, transmission, control, and immunity (Figure 5.4, see apedix a).

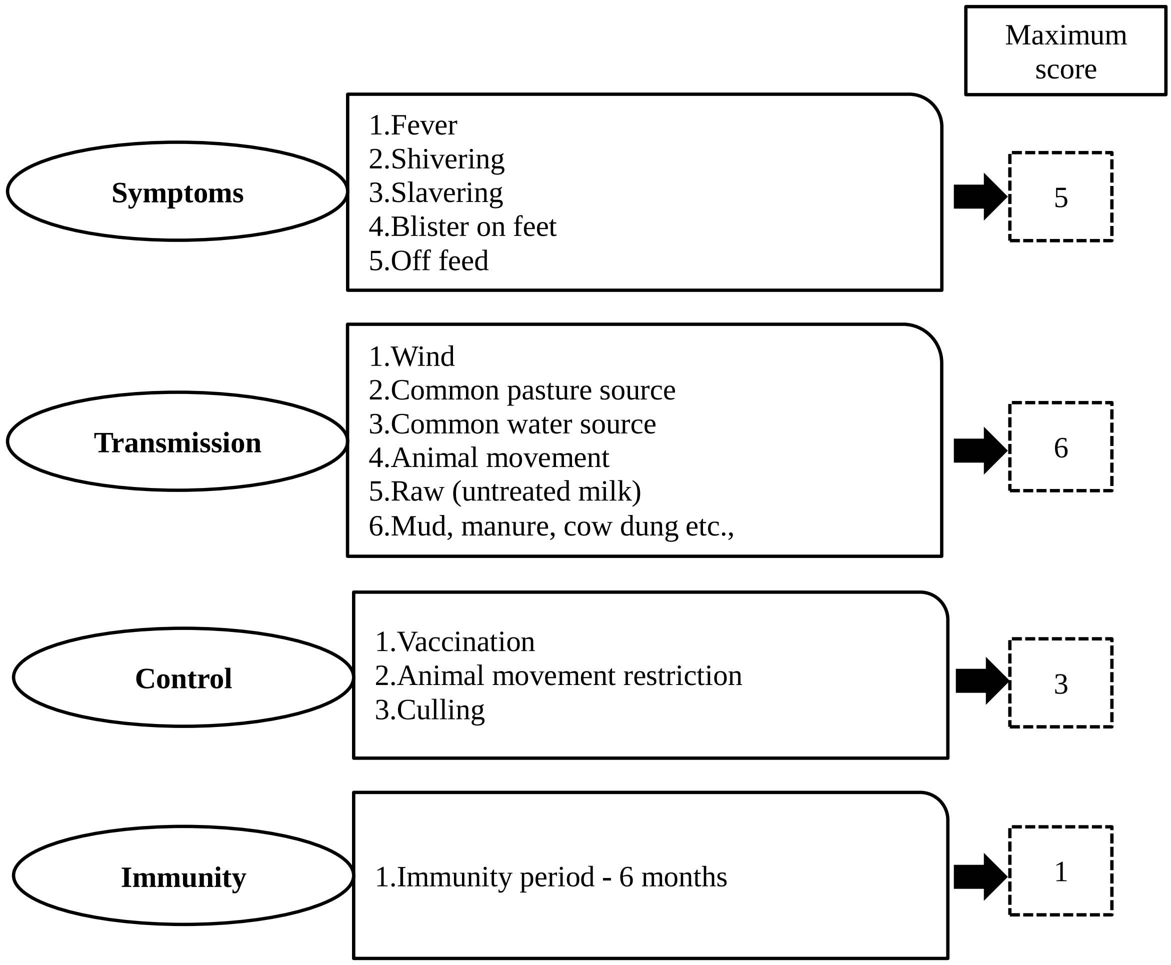

Figure 5.4 Questions and the given scores for correct answers

B- Item Count Technique (ICT) and Direct Questioning (DQ)

The item count technique (ICT) was introduced by Droitcour et al. (1991). This is an indirect questioning technique that is designed to elicit respondents' truthful answer to sensitive questions such as drug use, risky sexual behavior and racial prejudice. Estimation using the ICT is expected to be higher than that from conventional direct questioning (DQ). For example, Rayburn et al. (2003) reported that the ICT yielded a higher estimate of the base rate of "people who have had a physical fight with a person because he was a gay" than DQ. Similarly, LaBrie and Earlywine (2000) report a higher estimated percentage of "people having sex without a condom after drinking" from the ICT compared to DQ. A statistic test is needed to determine the difference between the two estimates from the two techniques. When the proportion of ICT which estimated from sub-sample A and sub-sample B is not statistically higher than the proportion of DQ which estimated from sub-sample C, it can be conclude that the behavior of interest is not considered as sensitive for respondents (Figure 5.5).

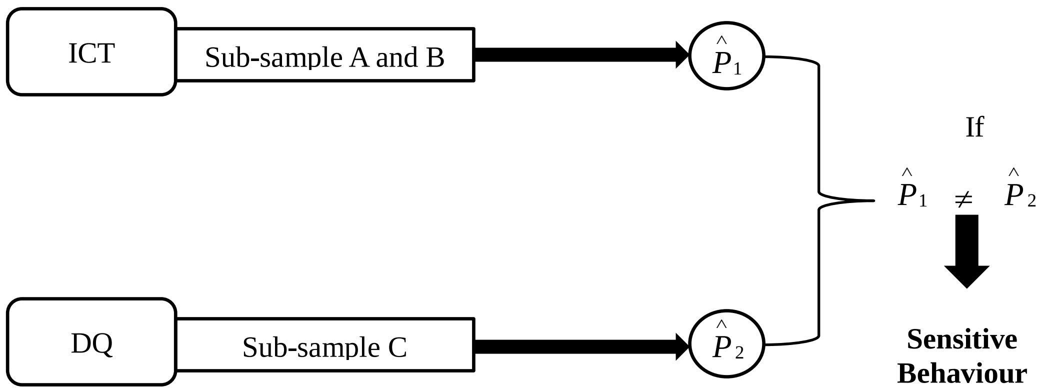

Figure 5.5 Analysis of sensitive behaviour

In this study, ICT technique was used to estimate the proportion of farmers who under-report, who sell infected animals, and who sell raw milk of FMD infected animals. These behaviours are assumed as sensitive behaviours because of the government law which prohibits it.

1. Item Count Technique (ICT)

The procedure in the present study was to randomly divide the sample into two same-size subsamples identified as Subsamples A and B. For example, the participants in Subsample A received a baseline list of statements, while those in Subsample B received the baseline list plus the sensitive statement, “If I suspect FMD in my animal, I will sell that animal soon”. The respondents were first told that the questionnaire was anonymous to encourage truthful answers, and then were asked to state the number of items that were true for them without mentioning which ones (see apendix b).

The baseline list consisted of five nonsensitive statements to ensure a higher estimate than would be obtained from a baseline list of fewer nonsensitive statements (Tsuchiya et al., 2007). Furthermore, the statements on the list were logically consistent with dairy farming and FMD (Droitcour et al., 1991). And finally, the statements were designed to obtain a negative correlation between responses in order to minimize the variance of responses for the baseline list (Glynn, 2013). The double-list technique was used in the present study to obtain a more accurate estimation (Droitcour et al., 1991). Two baseline lists are needed so that the sensitive statement can be presented to all respondents. The second baseline list Y was designed to be positively correlated to the first baseline list X to increase the certainty of the estimation (Glynn, 2013).

To illustrate the negative correlation between statements, for the first three statements in baseline list X, If the respondents have a bio-gas plant, he will count the first statement and, but will not count the second statement. Similarly, for the last two statements, if farmer have his own bull for breeding, he will count the fourth statement and, but not the fifth.

The proportion of the farmers’ under-reporting FMD suspect animals is given by the following equation.

$$\hat{P} = 1/2\left[\left(\overline{X}_{6B} - \overline{X}_{5A}\right) + \left(\overline{Y}_{6A} - \overline{Y}_{5B}\right)\right]$$

Where;

$\hat{P}$ is the proportion of farmers under-report FMD-suspect animals,

$\overline{X}_{6B}$ is the mean number of statements on “6-statement list X” counted by farmers in Subsample B,

$\overline{X}_{5A}$ is the mean number of statements on “5-statement list X” counted by farmers in Subsample A,

$\overline{Y}_{6A}$ is the mean number of statements on “6-statement list X” counted by farmers in Subsample A,

$\overline{Y}_{5B}$ is the mean number of statements on “5-statement list X” counted by farmers in Subsample B,

2. *Direct Questioning (DQ)*

In addition, another subsample of respondents, Subsample C, received a direct question to estimate the proportion of farmers who report FMD suspect animals to veterinary office. Anonymity was guaranteed to evoke truthful answers.

The question were

1. Do you immediately report if there is a FMD suspected animal to veterinary or local authority?
2. Do you immediately sell your live animal if it is suspected to be infected with FMD without informing anyone like veterinarian or local authority?
3. Do you sell milk of FMD infected animals?

The proportion of farmers' under-reporting, selling FMD infected animals and selling milk of FMD infected animals are obtained by dividing the number of yes response by the total number of DQ respondents.

Two hundred eighty four farmers were interviewed face-to-face in May 2014. (ICT respondents, 201; DQ respondents, 83). The sample was divided as indicate in Table 5.1 according to type of questionnaire. Both FMD infected and non-infected farmers were included as respondents to know whether they intend to report, sell meat and milk if their animal is suspected or obviously infected by FMD.

Table 5.1 Types of questionnaires and sample distribution

Types of questionnaire	Sample category	Size	Total sample
ICT	Sub-sample A	100	
	Sub-sample B	101	201
DQ	Sub-sample C	83	83

3. *Binominal test*

The binominal test is suitable to test the hypothesis that two proportions are equal. As used by Labrie and Earleywine (2000), the binominal test by Wilcox named *Twobinom was* employed to test the hypothesis that "estimation based on the ICT is equal to estimation based on DQ" since it is known to have better statistical properties than Fisher's exact test (Wilcox, 2005).

5.4 Results and discussion

5.4.1 FMD knowledge

A- Signs and symptoms

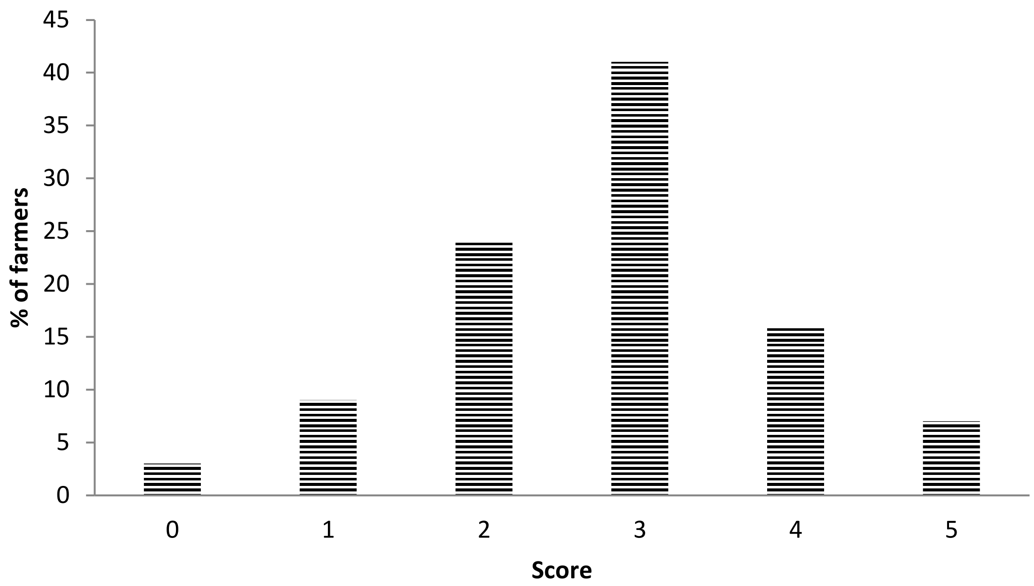

Figure 5.6 Distribution of knowledge scores on FMD signs and symptoms

In general, the clinical signs of FMD include a high fever for two or three days, mouth and foot blisters, shivering, slavering, and loss of appetite. According to the Figure 5.12, the majority (61%) of the farmers in the study area are able to identify the signs and symptoms of FMD infected animals. However, 3 % of the farmers are unable to identify any symptoms.

B- Routes of FMD transmission

The FMD has multiple known routes of transmission. These include under-report, animal movement, raw (untreated milk), grazing in common water and common pasture sources and mud, manure, cow dung etc. Figure 5.13 shows the distribution of knowledge scores related to FMD transmission routes. As indicated, 26 % of the farmers have received two (2) score level. Of the rest, 20% have received the one (1) score level and 17% of the farmers have not received any score at all. Therefore, overall knowledge about FMD transmission routes in Sri Lanka is poor.

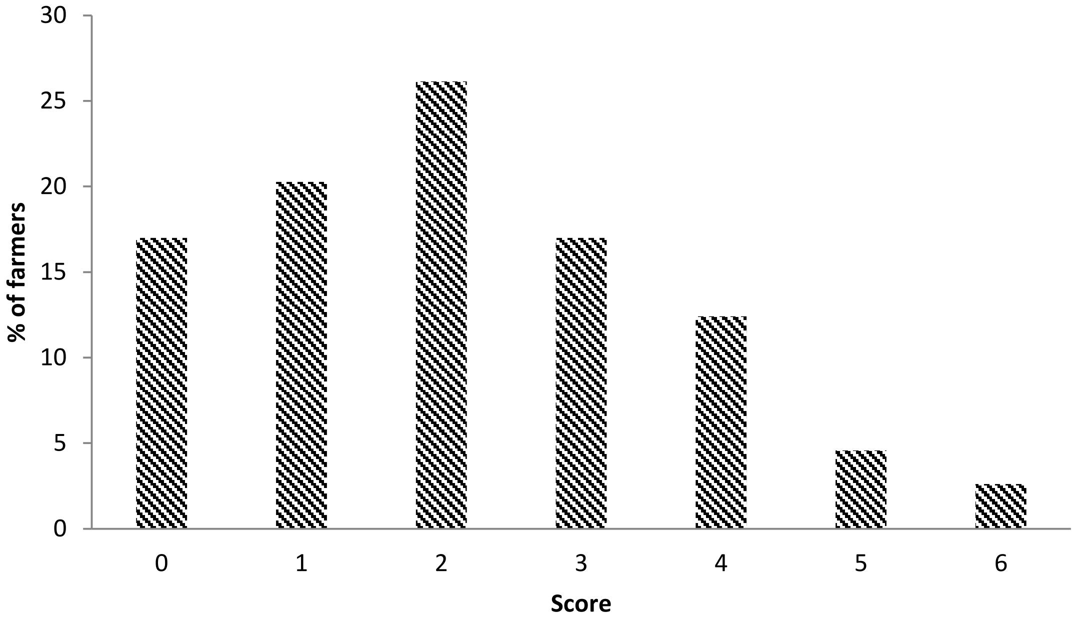

Figure 5.7 Distribution of knowledge scores on FMD transmission

C- FMD control

The basic principles that can be applied to control and eradication of FMD are:

- avoiding contact between infected and susceptible animals through livestock movement controls
- Reducing the number of infected or potentially infected animals in livestock populations through slaughter of infected or potentially infected animals and safe disposal of their carcasses by deep burial, and
- Reducing the number of susceptible animals through comprehensive vaccination programmes

According to the figure 5.14, a higher proportion of farmers (54%) have received the one (1) score level. A considerable percentage (17 %) of dairy farmers received a zero (0) score level. Thus, from the figure it is apparent from the figure that majority of the farmers (71 %) have very poor knowledge related to FMD control methods.

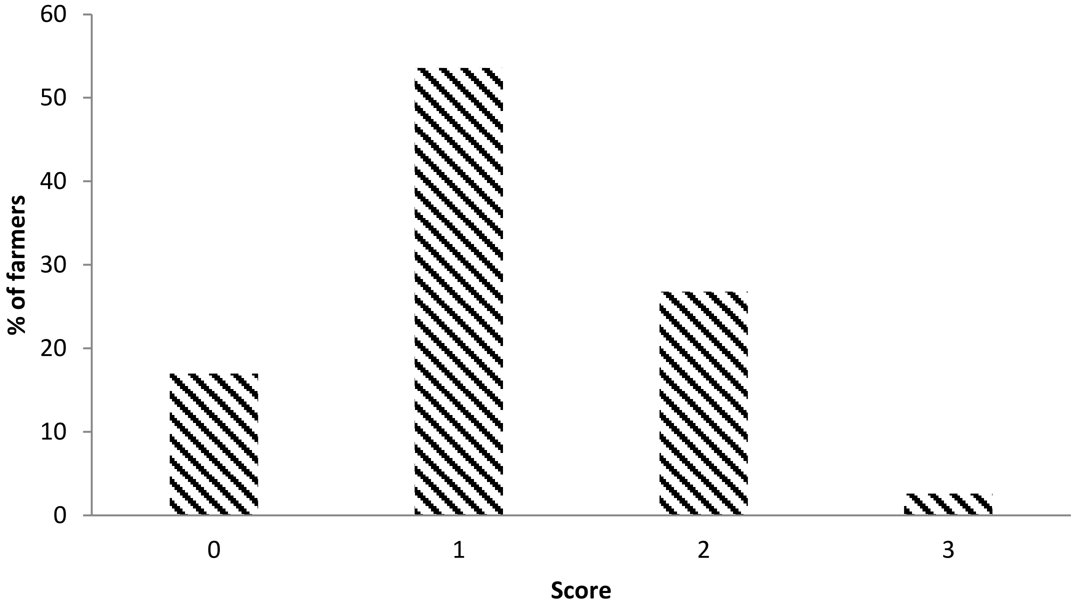

Figure 5.8 Distribution of knowledge scores on FMD Control

D- Immunity period of FMD vaccine

Vaccine provides immunity that protects animals from FMD disease without the risk of the infection. Knowledge related to the immunity period of FMD vaccine is necessary to receive vaccination at the correct time to avoid transmission of the infection.

Figure 5.15 shows the distribution of knowledge scores related to immunity period of FMD vaccine. From the figure it is clearly showed that majority of the farmers (89%) of the farmers don't know the immunity period of FMD vaccine.

Furthermore, figure 5.16 indicates the overall distribution of knowledge about FMD spread and control. Out of a total score (15), nearly 58% of the farmers have received less than six (6) score. In addition, 6% of the farmers have received zero (0) score and it suggest that don't know anything about FMD spread and control at all.

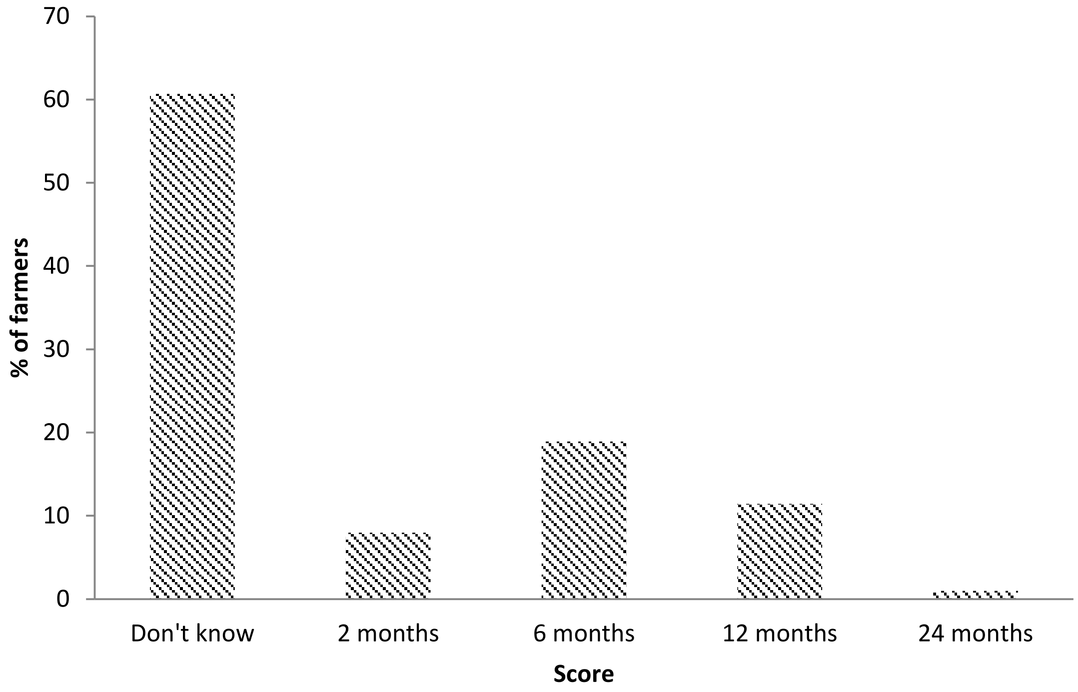

Figure 5.9 Distribution of knowledge scores on immunity period of FMD vaccine

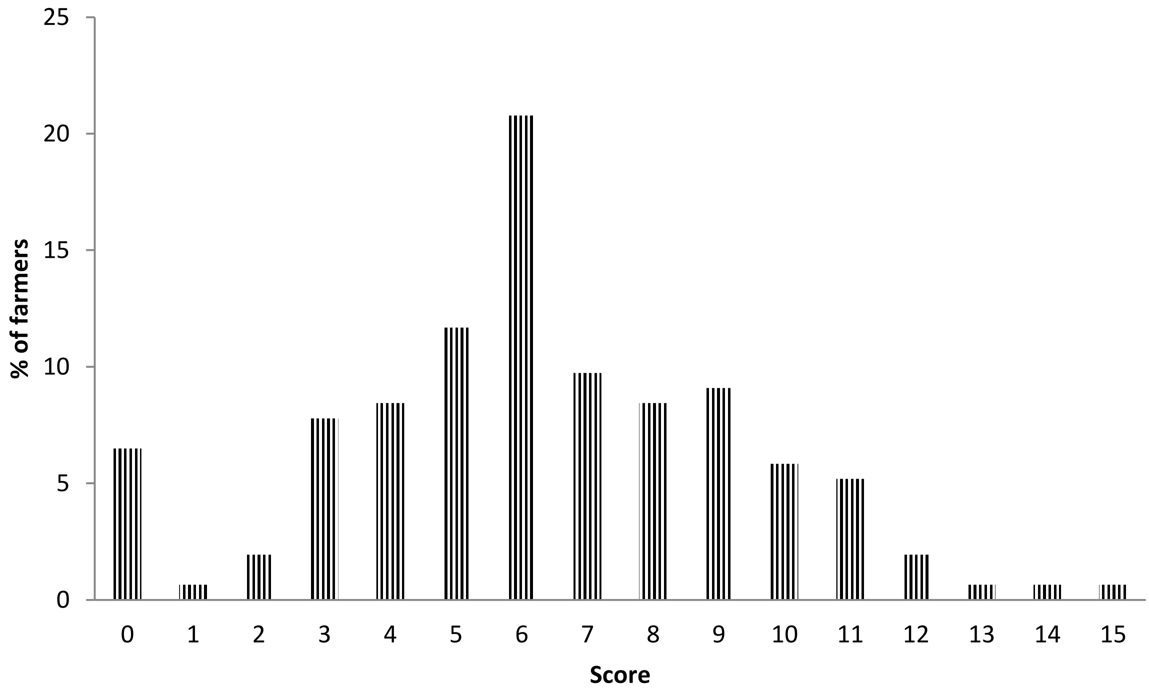

Figure 5.10 Overall distribution of knowledge about FMD spread and control

5.4.2 Farmers’ behaviour towards FMD spread from ICT and DQ

The estimates of the proportion of farmers who under-report animals suspected of infection with FMD and who sell FMD infected animals, from the ICT and DQ methods are shown in Table 5.2.

From the total sample, estimates of under-reporting based on the ICT are higher than those based on the DQ, and the difference is statistically significant at 1% level. Therefore, from the results it is clear that under-reporting is a sensitive behavior. Nearly, 23 % of the farmers are reluctant to report FMD infected animals.

Table 5.2 Distribution of behaviours

Type of Behaviour	ICT (%)	DQ (%)	Binomial test	Factor
Under-report of FMD infected animals	23.08	6.02	0.0008***	3.96
Sell FMD infected animals	10.88	4.82	0.1044	2.26
Sample size (n)	201	83		

Note: ***statistically significant at 1% level.

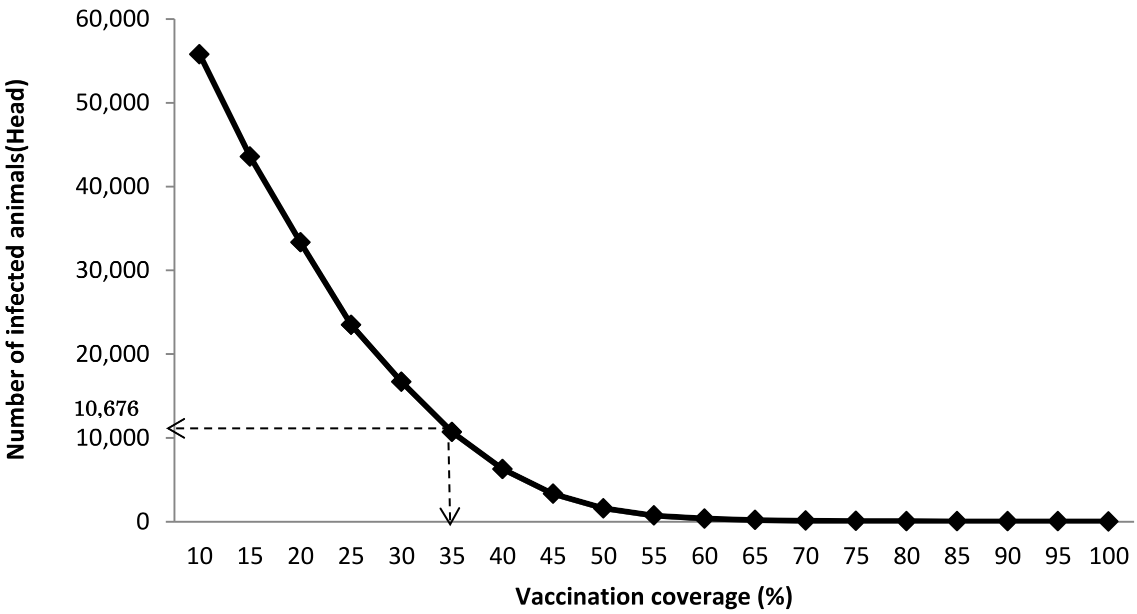

Figure 5.11 Number of infected animals, by FMD vaccination coverage

The 3.96 factor score shown in table 5.2 indicates that ICT respondents are 3.96 times more likely to under-reporting FMD suspected (or infected) animals than DQ respondents.

This study found the same results that found in chapter 4. The figure 5.17 shows the distribution of infected animals (infected compartments of the four SEIR compartments) through different FMD vaccination coverage (See chapter 4 for more details). The numbers of infected animals tend to decrease with increasing vaccination coverage. The number of infected animals was 10,676, corresponding to a vaccination coverage of 35 % (Under condition of 85 % vaccine efficacy). The actual reported cases were 8,384 during the same period and it suggests that there are under-report cases by – 21.5%[1].

In addition, estimates of selling FMD infected animals based on the ICT are higher than those based on the DQ estimates, but the difference is not statistically significant. Thus, it is apparent that selling FMD infected animals is non-sensitive behavior. In other words, farmers freely admit that they sell FMD infected animals despite the law that prohibits it. Moreover, approximately 10.88 % of farmers sell FMD infected animals without informing veterinarians of the infection. The present results identified two main types of risks for FMD transmission.

Two main types of risks were identified for FMD transmission.

1. Farmers did not report their FMD-infected cattle, because they want to keep secret.
2. Farmers sell their FMD-infected cattle, because they think it is a non-sensitive problem.

But, the meaning and control method is difference for each risk. Especially, farmers' knowledge level on the law is unknown. The control method is depending on the results. Therefore, next step of the study will be analysed the knowledge level and behaviour for FMD transmission.

5.4.3 High-level and low-level knowledge from ICT and DQ

The total sample was categorized into two samples based on their knowledge level of FMD transmission namely, high-level knowledge and low-level knowledge. According to the figure 5.7, the farmers who have received two (2) scores or less than two were grouped to low-level knowledge. On the other hand, respondents who have received three (3) or more than three were grouped to high-level knowledge.

Table 5.3 indicates the distribution of behaviors among high-level and low-level knowledge groups.

As indicated, under-reporting rate is significantly higher at 1% level among low-level knowledge group compared to high-level knowledge group. Furthermore, selling infected animals and selling raw milk from FMD infected animals also high among low-level knowledge group than high-level knowledge group. But, the differences are not statistically significant. Thus, results suggest that the low-level knowledge group contribute more for FMD transmission than high-level knowledge group.

Table 5.3Distribution of behaviors among high-level and low-level knowledge groups

Type of Behaviour	High Knowledge	Low Knowledge	Binomial test
Under-report of FMD infected animals	0.30	28.00	8.75E-05***
Sell FMD infected animals	10.94	13.14	0.7077
Sell raw milk from FMD infected animals	15.29	21.63	0.3399
Sample size	53	148	

Note: ***statistically significant at 1% level.

The estimates of the proportion of farmers who sell FMD infected animals among high-level and low-level knowledge groups, from the ICT and the DQ methods are shown in table 5.4.

Table 5.4 Selling FMD infected animals among high-level and low-level knowledge groups

Levels of Knowledge	ICT (%)	DQ (%)	Binomial test	Factor
High Knowledge	10.94 (53)	0.00 (55)	0.0120***	10.94
Low Knowledge	13.14 (148)	7.07 (99)	0.2150	18.59

Note: ***statistically significant at 1% level.
Sample size in parentheses.

From the total sample, estimates based on the ICT are higher among high knowledge group than those based on DQ. The difference is statistically significant at 1% level. The 10.94 factor score indicate in Table 5.4 suggests that ICT respondents are 10.94 times are more likely to admit to selling FMD infected animals. Therefore, from the results it is clear that selling FMD infected animals is a sensitive behavior among high-level knowledge group.

Additionally, estimates based on the ICT were not statistically higher than those based on DQ in the low-level knowledge group, indicating that there is no underestimation from DQ. In other words, low-level knowledge farmers freely admit that they sell FMD infected animals despite the law prohibits it. Approximately, 13.1 % of low-level knowledge farmers sell FMD infected animals without informing veterinarians of the FMD infection. Therefore, the punishment and checking system for selling FMD-infected animals should be more strictly regulated.

5.4.4 Trained and Untrained farmers knowledge and behaviours towards FMD

As indicated in figure 5.18, most of the farmers (56%) in the sample population have received any kind of training related to dairy farming. Around 44% of the farmers have not received any kind of training at all.

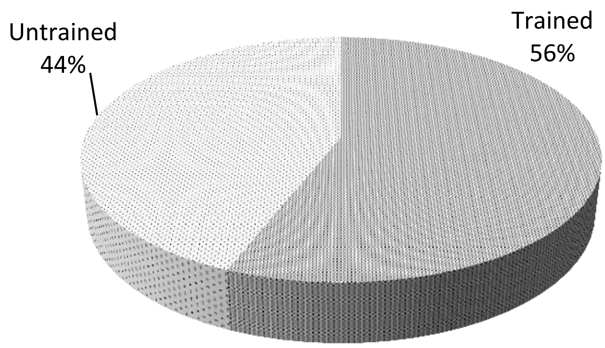

Figure 5.12 Distribution of training among farmers

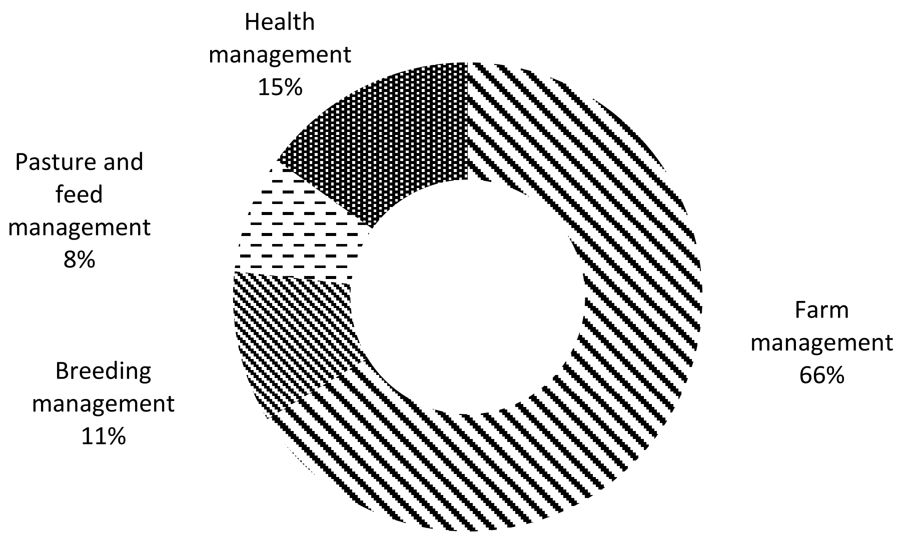

Figure 5.13 Distribution of type of training among farmers
Note: Farm management included training related to milk production, milking, shed construction etc,.

Furthermore, according to the figure 5.19, a higher proportion of farmers (66%) have received the training on farm management. A considerable percentage of farmers (11%) have received training on breeding management, particularly on Artificial insemination (AI). Of the rest, 8% have received the training on pasture and feed management and 15 % have joined the animal health management training. It is clearly evident in the above figure that proportion of the farmers have received training on animal health management is very low in the study area. Thus, training programs, particularly focusing on disease identification and health management should be conducted.

5.4.5 Willingness to accept for culling

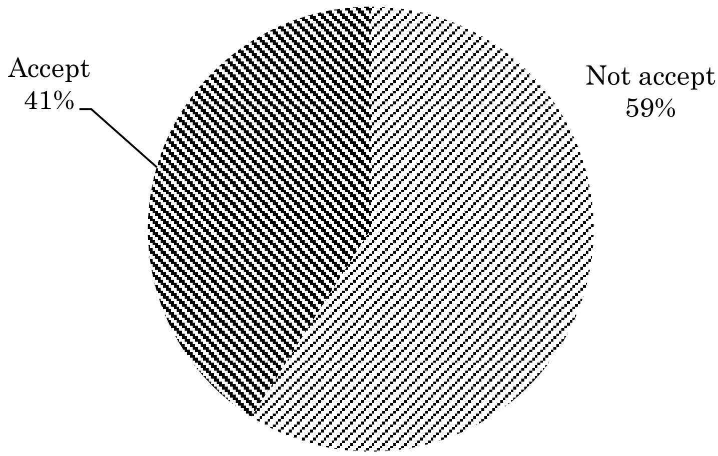

Figure 5.14 Willingness to accept compensation for culling

In addition to preventive vaccination and animal movement restriction, outbreaks of FMD can be controlled by stamping-out or (circle) culling. As indicated in figure 5.20, most of the farmers (59%) do not willing to accept any compensation for culling of FMD infected animals.

Sri Lanka is a Buddhist country and Buddhists and Hindus reject cattle slaughtering. A Buddhist monk in Sri Lanka Bowatte Indraratna thero set himself on fire in Kandy outside the Temple of the Sacred Tooth Relic demanding an end to cattle slaughter in May 2014. That was the Sri Lanka's first attempt at self-immolation by a monk. After that, Buddhist has organized many campaigns around the country to ban cattle slaughter in Sri Lanka. However, the government has so far disclosed no plans on banning the slaughter of cattle in the country. Therefore, most of the farmers in the sample reject cattle slaughtering and they are not willing to accept any value for culling. On the contrary, 41% of the respondents are willing accept compensation for culling FMD infected animals. The average willingness to accept value for culling was approximately Sri Lankan Rupee 75.7 per animal.

However, majority of the farmers do not willing to accept any amount, therefore, vaccination, animal movement control, and farmers knowledge on FMD spread and control play a big role in FMD eradication in the country.

5.5 Conclusion

Employing the knowledge questionnaire on FMD and Item Count Technique, the farmer's knowledge level and behavior towards FMD outbreak and its control were analyzed. From the knowledge related questionnaires, it is clearly indicated that, a higher proportion of farmers (63%) have very poor knowledge on routes of FMD transmission. In order to eradicate the FMD disease by 2020, there should be a mechanism to improve farmers' knowledge on FMD spread and control. Moreover, from the Item Count Technique results, it is clearly showed that approximately, 23 % of farmers were under-reporting if there is an FMD outbreak. Further, majority of farmers (63%) have poor knowledge level on routes of FMD transmission. The group of high-knowledge level and trained farmers indicates lower rates of under-reporting and selling infected animals and milk compared to the group of low-knowledge level and untrained farmers. Thus, farmer training programs to improve farmers' knowledge of FMD transmission and control are critical. Moreover, the regulations on infected animal and milk movements should be strictly enforced and farmers should be compensated for their early reporting to prevent transmission of FMD throughout the country.

<Notes>

1)

Number of infected animals from SEIR model estimation	=	10,676
Actual number of infected animals	=	8,384
Number of infected animals	=	10,676 - 8,384
Number of under-reported cases	=	2,292
	=	$\frac{2,292}{10,676} * 100$
	=	21.5 %

CHAPTER 6

Conclusion

Livestock, mainly cattle, buffaloes and goats form an integral part of the Sri Lankan rural economy. There is a strong symbiotic relationship between the crop and livestock species and exploiting the synergies of the both sub-sectors helps to improve the productivity of the agriculture economy of Sri Lanka. The agriculture sector contributes around 10.7 % of National Gross Domestic Production (GDP) and the livestock sector contributes around 7.4 % to the agricultural component (Central Bank of Sri Lanka, 2010).

Dairy sub sector is one of the most important of the agricultural sub sectors in Sri Lanka. This is mainly because of the influence it can make on the rural economy. The domestic milk production only constitutes of 28.6 % of the requirement and the rest is imported. The import bill on dairy commodities is around 37.8 billion Sri Lankan rupees (SLR) or approximately 20 million USD annually. Therefore, the government attention is most focused on the dairy sub sector to develop this sector into a ‘local industry’. The government policy on dairy development is aimed at producing country’s entire requirement of milk by the year 2020.

The dairy sub-sector has been stagnant over the past two decades due to various factors such as uncertainty, lack of reputation, severe land fragmentation, industrialization, attitudes, and economic and political factors (Livestock statistics, 2004). Additionally, lack of profitability is one of the main constraints in the milk production sector. Further, absence of proper technology, poor genetic merit of indigenous cattle and the unsatisfactory extension and the other supporting services, and the unavailability of proper and low cost input delivery system worsened the situation (Hitihamu et al., 2007).

The general purpose of this thesis was to economically and epidemiologically analyze the constraints and challenges of dairy farming systems to for future development in Sri Lanka. This will be done in the following manner:

6.1 Resource-use efficiency of dairy management systems in different agro-climatic zones

Demographic and socio-economic factors have significant impact on decision-making and dairy management practices. These factors will therefore affect the productivity and profitability of dairy herds and without having a good understanding of these factors it would very difficult to be involved in dairy business. There are main three agro-ecological zones in Sri Lanka. Resource availability, the management of the dairy farming system, and constraints and opportunities are significantly differs on the climatic zones. Additionally, each dairy farm and agro-climatic zone has its own unique ability to make decisions to produce a certain output given a set of inputs and technology. Thus, understanding technical efficiency, its measurement and determining factors, is of crucial importance in dairy production economics. However, no study to date has examined the technical efficiency of dairy farms in different agro-climatic zones in Sri Lanka. Studying of the factors that determine milk production and farm efficiency in each agro-climatic zone are important from a farmer's, as well as, from a policy point of view. Policy makers can use this knowledge to identify and target public interventions to improve farm productivity and income, while farmers can use this information to improve their performance, which ultimately leads towards self-sufficiency in milk production.

The first specific objective of this thesis was to examine the resource-use efficiency in dairy production systems in the Nuwara-eliya and Kurunegala districts, which are located in Up-country and Coconut Triangle in Sri Lanka. The stochastic production frontier model and Ordinary Least Squares (OLS) regression method were used to study the technical efficiencies and their determinant factors, respectively.

The findings showed that the mean technical efficiencies were 0.77 and 0.68 in Up-country and Coconut triangle, respectively. In addition, household size, feeding costs, and farmer-training were found to contribute positively to the technical efficiency, while the farmer's age and cattle diseases reduced the technical efficiencies in the studied regions. Therefore, the authorities should encourage the older dairy farmers to produce more efficiently by providing them with trainings and extension services on modern feed management technologies. From an economic efficiency point of view, the feed resources are under-utilized in the Coconut triangle, while over-utilized in the Up-country. Hence, in order to improve the dairy farming efficiency, the government should provide information on the prices and the availability of feed resources which can be purchased from different agro-climatic zones in Sri Lanka.

6.2 An Economic viability analysis of FMD vaccination programme

FMD has been a serious threat to the health of dairy cattle for centuries in Sri Lanka. The disease is endemic in the country particularly in the eastern part of Northern and Eastern province. Therefore, FMD has been ranked as the highest priority disease for control and eradication. Nevertheless, in Sri Lanka, currently there is no country-wide vaccination programme aimed to control FMD. The budget for FMD control and eradication has always been low and stagnant. It has remained around 20 million during the past fiscal years. In addition, there is an insufficient FMD vaccine production capacity and Sri Lanka spends a lot of country foreign exchange to import FMD vaccines. But sometimes these are produced for foreign strains of FMD viruses, and they are ineffective against the virus strain circulating in Sri Lanka. On the other hand, the economic return from the FMD vaccination at a dairy subsector level is unknown.

Thus, the second specific objective of this thesis was to evaluate the economic viability of current preventive vaccination program using integrated epidemiological and economic model. From the epidemiological model, it clearly showed that, current vaccination rate of 35 % is not sufficient to eradicate the FMD disease by 2020. In order to eradicate FMD, the current level of vaccination coverage required to be increased by 45 %. Moreover, from the economic model, it is clearly indicated that, every Sri Lankan Rupee 1 spent on biannual vaccination resulted in positive benefits of Sri Lankan Rupee 3.7. Nevertheless, FMD disease control is constrained by a low budget allocation and there is a shortfall from the actual allocation and the required allocation of 13.80 million Sri Lankan rupees. If the government can just allocate 0.025 % of additional budget annually for each province from the expenditure on agriculture and irrigation, it would generate 78.09 million Sri Lankan rupees additional benefits each year from FMD eradication. Therefore, preventive biannual vaccination is recommended for the dairy sector in Sri Lanka.

6.3 Farmers' knowledge and behaviour towards FMD outbreak

Vaccination alone is not sufficient to prevent FMD outbreak. Nevertheless, improving the farmer's knowledge on distinguishing FMD from other diseases, prompt reporting of any suspicion of FMD, as well as, restrict of all movements of animals or animal products are critical activities for an effective FMD response effort. Therefore, the third specific objective of this thesis was to analyze the farmers' knowledge level and behaviour towards FMD outbreak and its control.

ICT was used to estimate the proportion of farmers' "under-reporting" and selling FMD infected animals and milk during the outbreak. Moreover, knowledge questionnaire on FMD symptoms, transmission and, control were used to measure the farmer's knowledge level.

The results clearly showed that nearly, 23 % of farmers were under-reporting if there is an FMD outbreak. Further, majority of farmers (63%) have poor knowledge level on routes of FMD transmission. The group of high-knowledge level and trained farmers indicates lower rates of under-reporting and selling infected animals and milk compared to the group of low-knowledge level and untrained farmers. Thus, farmer training programs to improve farmers' knowledge of FMD transmission and control are critical. Moreover, the regulations on infected animal and milk movements should be strictly enforced and farmers should be compensated for their early reporting to prevent transmission of FMD throughout the country.

6.4 Constraints and Future Challenges

The general objective of this thesis was to economically and epidemiologically analyze the constraints and challenges of dairy farming systems to for future development in Sri Lanka.

This research study identified the main constraints and the future challenges for dairy development in Sri Lanka.

Unavailability of a better feeding pattern is one of the main constraints for higher milk production. Because of Land limitations due to population pressure, land segmentation and a small quantity of compound and coarse feed in the distribution system in Sri Lanka more than 90% of the farm herds are less than five cattle. Therefore, it is important to establish common pasture lands in prominent dairy production areas especially in the Up-country and Mid-country. Moreover, in order to have a long-term commitment to pasture management, "farmer management societies" will need to be established.

Moreover, poor and insufficient marketing options and long distance from farm gate to milk collecting center have a negative influence on milking frequency. As milking twice a day has been found to be low cost than once a day, it is important that efforts be made to increase milking frequencies through credit or subsidies for the purchase of milk storage and cooling facilities. Thus, the milk collecting network of the area needed to be strengthened through improvement of milk collection infrastructural facilities at the farmers door step and milk delivery to the collecting centers. And even if farmers can find an alternative sale for the milk, some processors or markets, don't conduct milk testing for milk quality and milk composition and they accept lower quality milk. Thus, farmers have low incentive to improve hygienic quality of milk. Therefore, the training and extension programs are need to improve the farmer awareness about clean milking, milk handling and storage practices. Additionally, in the study area the main problem is insufficient capacity of the milk collecting centers. Thus, improving the capacity of milk collecting and chilling center will be important in providing a continuous supply of milk in the future.

Additionally, Sri Lanka is a Buddhist country and Buddhists and Hindus reject cattle slaughtering. A Buddhist monk immolates himself to protest against the slaughter of cattle in Sri Lanka in 2013. That was the Sri Lanka's first attempt at self-immolation by a monk. After that, Buddhist has organized many campaigns around the country to ban cattle slaughter in Sri Lanka. Generally, cattle traders purchase animals in the FMD-affected areas for very low price and slaughter cattle transport to urban areas. Thereafter, infection is introduced into every Province. However, the government has so far disclosed no plans on banning the slaughter of cattle in the country. Therefore, most of the farmers in the sample reject cattle slaughtering and they are not willing to accept any value for culling. Therefore, vaccination and animal movement control methods are the reliable options for FMD control. However, results clearly showed that, current vaccination rate is not sufficient to eradicate the FMD disease by 2020. Thus, FMD-infected raw milk and animals movement controls are crucial.

The vaccine is free of charge and therefore, farmer participation for vaccination program is low. The proper mechanism should be developed to enhance the farmer participation rate for vaccination program.

Also, like in other developing countries poor awareness and knowledge of animal diseases is main constraint for FMD control and eradication. The results of this study showed that low-knowledge level farmers contributed significantly to spread the disease compared to high-knowledge level farmers. Furthermore, low-level knowledge farmers sell FMD infected animals without informing veterinarians of the FMD infection. Therefore, the punishment and checking system for selling FMD-infected animals should be more strictly regulated. Farmers' knowledge on FMD transmission and immunity are very low and the proportion of the farmers have received training on animal health management is very low in the study area. Thus, training programs, particularly focusing on disease identification and health management should be conducted. After completing the training exam can be administered to check the level of knowledge level.

Additionally, under-reporting of FMD-infected animals is one of the main risk factors for FMD transmission. Dairy is the main income source for the poor rural farmers, particularly in the dry zone of Sri Lanka. Farmers can not sell their milk and animals if consumers know that the farm is affected by FMD. Therefore, most of the farmers are considered 'under-reporting' as a sensitive behaviour. In order to overcome the obstacle, early reporting farmers could be compensated. Thus, reseracher should conduct a compensation survey to determine the level of compensation for early reporting.

Finally, in order to minimize the illigal animal movement between affected and non-affected areas establishment of check points and cattle trader associations are important.

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Appendices

A- Knowledge questions

The first question was related to farmers' knowledge of FMD signs and symptoms. Five correct answers were given and asked them to put ✓ or ✗ mark in the box. The maximum score is 4.

1. What are the clinical signs of FMD?

I.Fever ☐ II.Shivering ☐ III.Slavering ☐ IV.Blister on feet ☐ IV.Off feed ☐

The second questions was related to FMD transmission and asked farmers to select the correct answers. The highest possible score is 6.

2. What are the possible methods of FMD transmission?

I.Wind ☐ II.Common pasture source ☐ III.Common water source ☐ IV.Animal movement ☐ V.Milk and dairy products ☐ VI.Mud, manure, bedding and feed stuff ☐

The third question was about FMD control methods. The highest score is 3.

3. What are the methods of FMD control?

I.Vaccination ☐ II.Animal movement control ☐ III.Culling ☐

The last question was about immunity period of FMD vaccine. The duration of the immunity period is 6 months and maximum score is 1.

4. What is the duration of immunity period of the FMD vaccine?

I.2 months ☐ II.6 months ☐ III.12 months ☐ IV.24 months ☐

B- ICT statements

1. Questions for under-report (sub-sample A)

List X	List Y + Sensitive question
1. I have a bio-gas plant 2. I sell cow manure 3. I prefer to have female calves over bull calves 4. I have my own bull for breeding 5. I always use AI	1. I eat beef 2. I am a Buddhist 3. I sell bull calves 4. I feed coconut poonac to bull claves 5. I always separate FMD infected cattle from other healthy cattle 6. If I suspect FMD in my animals, I report quickly to veterinary office

2. Questions for under-report (sub-sample B)

List X + Sensitive question	List Y
1. I have a bio-gas plant 2. I sell cow manure 3. I prefer to have female calves over bull calves 4. I have my own bull for breeding 5. I always use AI 6. If I suspect FMD in my animals, I report quickly to veterinary office	1. I eat beef 2. I am a Buddhist 3. I sell bull calves 4. I feed coconut poonac to bull claves 5. I always separate FMD infected cattle from other healthy cattle

3. Questions for selling FMD-infected animals (sub-sample A)

List X	List Y + Sensitive question
1. I have a insurance for all animals 2. I always get the assistance of District Vet Surgeon in calf birth 3. If I want to use AI, I have to ask the assistance of LDI 4. I use chemicals acaricides for tick control at least once per every three months 5. Ticks are a big problem in my farm	1. I know the symptoms of FMD 2. I have enough money to buy cattle feed for all animals 3. I feed rice straw to cattle 4. I have a pasture land more than one acre 5. I don't have a grass cutter 6. If I suspect FMD in my animal, I will sell that animal soon

4. Questions for selling FMD-infected animals (sub-sample B)

List X + Sensitive question	List Y
1. I have a insurance for all animals 2. I always get the assistance of District Vet Surgeon in calf birth 3. If I want to use AI, I have to ask the assistance of LDI 4. I use chemicals acaricides for tick control at least once per every three months 5. Ticks are a big problem in my farm 6. If I suspect FMD in my animal, I will sell that animal soon	1. I know the symptoms of FMD 2. I have enough money to buy cattle feed for all animals 3. I feed rice straw to cattle 4. I have a pasture land more than one acre 5. I don't have a grass cutter

5. Questions for selling raw milk from FMD-infected animals (sub-sample A)

<u>List X</u>

1. I hire a labor for milking
2. My wife/husband helps me dairy farming
3. I give vitamins to cattle every day
4. I feed the calf colostrum after birth
5. I make milk toffee

<u>List Y + Sensitive question</u>

1. I milk once a day
2. I have a milking machine
3. FMD is a very big problem in this area
4. I wash udder and teats before milking
5. I use strip cup test to detect mastitis every day
6. <u>If sell the milk of FMD infected animals, because, if not it is a big income loss</u>

6. Questions for selling raw milk from FMD-infected animals (sub-sample B)

<u>List X + Sensitive question</u>

1. I hire a labor for milking
2. My wife/husband helps me in dairy farming
3. I give vitamins to cattle every day
4. I feed the calf colostrum after birth
5. I make milk toffee
6. <u>If sell the milk of FMD infected animals, because, if not it is a big income loss</u>

<u>List Y</u>

1. I milk once a day
2. I have a milking machine
3. FMD is a very big problem in this area
4. I wash udder and teats before milking
5. I use strip cup test to detect mastitis every day

要約

スリランカにおいて酪農部門は，畜産部門の中で最も重要なものとして考えられている．なぜなら，農村経済に大きな影響を及ぼすからである．一方で，国内の生乳生産量は 28.6%の需要を満たしているにすぎず，残りは輸入に依存しているのが現状である．酪農製品の輸入は，年間約 378 億ルピー，ドルにして 2,000 万ドルにのぼる．この状況から脱却するために，スリランカ政府は酪農部門を発展させ，2020 年までに国内需要に対応できるだけの生産力の拡大を目指すことを目標としている．

スリランカの畜産部門の発展には，低い収益性，不十分な飼料技術，FMD のような家畜感染症の存在などいくつかの阻害要因が存在する．本論文では，これらの阻害要因や対応措置の経済学的および疫学的分析を行い, 効率的な酪農生産システムを構築するための方策を検討することを主題におく．

酪農経営のタイプは，農場が位置している農気候区域に依存している．それぞれの農気候区域にある酪農場は，生産に対する意思決定に特徴を持っている．「Technical efficiency（技術的効率性）」は，意思決定の結果選択された投資と技術のセットから得られる最大可能産出量，つまり農場の能力を測るツールである．これにより, 各農気候区域の酪農経営において最も重要な経営システムとその規定要因を明らかにすることができるのである．また，各農気候区域における生乳生産と農場効率性を規定する要因は，農家側からだけでなく政策的観点からも研究される．この結果は，政策立案者が農場の生産性と収入を向上させるための政府介入策を特定し, 対象を見極めるための一助となるほか, 農家の生産能力を上昇させるための情報としても活用できるだろう．

主題に接近するための一つ目の目的は，スリランカの Up-country と Coconut Triangle に位置する Nuwara-eliya と Kurunegala 地方において, 酪農生産システムの資源利用効率性を算出することである. 技術的効率性とその決定要因を明らかにするために，確率的生産フロンティア分析と最小二乗法をそれぞれ用いた．分析の結果，技術的効率性の平均値は，Up-country と Coconut Triangle でそれぞれ 0.77 と 0.68 であった．また，農場の規模，飼料費用，農家トレーニングが技術的効率性に寄与し，農家の年齢と牛の疾病は技術的効率性を減少させることが明らかとなった．したがって，年配の酪農家へ対して近代的な飼料技術にトレーニングと普及サービスを提供することによってより効率的な生産が行えると推測される．経済効率性の観点からは，飼料資源が Coconut Triangle において過少利用されており, 逆に Up-country においては過剰利用されていた．以上から，酪農場の効率性を向上させるためには，スリランカの異なる農気候区域で購入できる飼料資源の価格および有効性に関する情報を, 政府が提供していくべきだと言える．

FMD はスリランカにおいて長い間，乳牛の健康にとって大きな脅威となっている．特に，北東部や東部の地方において風土病となっている．したがって，FMD はコントロールおよび撲滅が優先的に求められている疾病でもある. それにもかかわらず, スリランカでは，現在 FMD をコントロールするための全国的なワクネーションプログラムは存在していない．FMD のコントロールおよび撲滅に係る予算が常に不十分であるからである．加えて，FMD の国内ワクチン生産能力が不十分であり，スリランカは FMD ワクチンを輸入するために多くの国の外貨を費やしている．しかし，FMD ウィルスには多くの型があるため, スリランカでは十分な効果を持たない輸入ワクチンもある．一方で，FMD ワクチネーションによる酪農部門への経済的メリットについては明らかにされていないのが現状である．

主題に接近する二つ目の目的として，疫学と経済学の統合モデルを用いて予防的ワクチネーションプログラムの経済性を評価する．疫学的モデルから，現行のワクチネーション率である 35%では，2020 年までに FMD を撲滅することはできないことが明らかとなった．FMD の撲滅のためには，ワクチネーションカバー率を 45%まで上昇させる必要がある．また，経済学的モデルから，年 2 回のワクチネーションに係る費用 1 ルピー当たり便益は 3.7 ルピーであることが示された．一方，FMD 疾病対策は低予算にために制限されており，必要な予算は 1,380 ルピーと推計された．しかし，政府が農業と灌漑の費用から年間 0.025%の予算を各州に割り当て、予防的な年 2 回のワクチネーションがスリランカの酪農部門で実行できるのであれば，FMD 根絶による追加的な利益として毎年 7,809 万ルピーを生み出すことができると予測された．

ワクチネーションのみの対策は，FMD 発生の予防には不十分である．他の疾病から FMD を見分けるための農家知識の向上や，疑わしい FMD 感染家畜の早期報告と同時に家畜および畜産生産物の移動制限を行うことが，FMD に対応するために重要な活動である．したがって，三つ目の目的は，農家の知識レベルおよび FMD 発生とそのコントロールに対する農家行動を分析することである．農家の「未報告」の割合と FMD 感染牛および生乳の販売行動の割合を評価するために Item Count Technique を用いた．また，農家の知識レベルを測るために，FMD の症状，伝播，コントロールに関する設問を設計した．分析の結果から，23%の農家が，FMD が発生しても獣医事務所に報告をしないということ，多くの農家（63%）は FMD の伝播経路に関する知識が不足していたことが明らかとなった．さらに，高い知識を有しているグループとトレーニングを受けている農家は，それ以外のグループに比べて未報告や感染家畜および生乳の販売割合が低いことが示された．したがって，FMD の伝播とコントロールに関する農家知識の向上を図るために農家のトレーニングプログラムが重要である．また，感染家畜と生乳の移動制限は厳しく取り締まるべきであり，農家は FMD の全国な蔓延を防ぐために迅速に報告を行うべきであり、そのための政府による監視も強めるべきである。

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