UNIVERSITY OF KWAZULU-NATAL

MODELING THE BURDEN OF DISEASE FOR CATTLE

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Abstract

Summary measures of human population health (SMPH) represents approaches to measuring the burden of disease. These approaches are divided into two classes: health expectancies and health gaps. A health gap model approach called disability adjusted life years (DALYs) was proposed by the World Health Organization (WHO) to assess the burden of disease on human populations. DALYs are the sum of the years of life lost due to premature mortality (YLL) and years of life lost due to disability (YLD).

WHO pointed out that DALYs could be adapted to assess the burden of the disease on animal populations. However, to date, little has been done in this regard. This motivated our study which is focused on cattle (cows, oxen and bulls). Using the DALYs approach, we formulated a productivity adjusted life years (PALYs) approach for cattle populations. We used it to assess the burden of ticks and tick-borne diseases (T and TBDs) for cattle populations in 20 villages in the Eastern Cape Province, South Africa. This is the first time that such an approach has been taken to assess the burden of disease on animals, in particular, for cattle.

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I, Omran A. M. Salih

Student Number: 213513306

declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.

2. This thesis has not been submitted for any degree or examination at any other university.

3. This thesis does not contain other people's data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

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   i. Their words have been re-written but the general information attributed to them has been referenced.

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Student Declaration

I declare that the contents of this dissertation are original except where due reference has been made. It has not been submitted before for any degree to any other institution.

Omran Salih

August 2014

Dedication

To

My parents:

A. M. Salih and Mona

Acknowledgments

First and foremost, I am always indebted to ALLAH, the most gracious and the most merciful for unlimited blessings on me. I am truly indebted and thankful to my supervisors for directing my thesis and pushing me to work hard. This thesis would not have been possible without their kind support and guidance. I will remain grateful to them for ever.

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Contents

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Abbreviations and Definitions

SMPH: Summary measures of population health.

SMPH are used to represent methods of measuring the burden of disease in a population by collecting information from mortality and morbidity data [26].

DALY: Disability adjusted life years.

DALY combine time lived with a disability and the time lost due to premature mortality in case of human [3].

YLD: Year of life lost due to disability.

YLD is the component of the DALY that measures lost years of healthy life through living in health states of less than full health [3].

YLL: Year of life lost due to premature mortality.

YLL is the component of the DALY that measures years of life lost due to premature mortality [3].

PALY: Productivity adjusted life year.

PALY combine time lived with a disability and the time lost due to premature mortality in case of animals [33].

WHO: World health organization.

GBD: Global burden of disease.

NBD: National burden of disease.

Chapter 1

Introduction

1.1 Importance of Human Health

People desire to maintain a healthy life style therefore, they will try all sorts of ways to remain healthy. To improve their healthy life style, people work as either individuals or in groups at various levels such as families, work groups, associations, communities and nations. They engage in a wide range of activities that they believe will contribute positively to their healthy life. People also try to avoid activities or situations that they see as potentially negative to their health [13].

Population health is the health outcome of a group of individuals, including the distribution of such outcomes within the group [24]. Population health is one of the most important advances in thinking about global development because it has a considerable effect on economic performance [24]. Although the impact of individuals health levels on their performance and incomes are easily noticeable and widely acknowledged, the outcome of population health for the well-being and for economic performance (at the macro level) of individuals, families, and communities are hard to measure and rather, have been neglected.

The significance of a healthy population to the economic sector can not be understated because it's effects are clear. Economic evidence shows that a 10% improvement in life expectancy at birth is associated with a rise in economic growth of some $0.3\% - 0.4\%$ a year [12]. This emphasises the connection between health performance and economic performance. Countries with ailing health find it difficult to achieve continued growth while wealthier countries tend to have health population for a start. Poverty stricken societies tend to have low life expectancies because their infant population is more susceptible to malnourishment and mortality.

There are many problems in the world affecting the economic sector, culture sector and human health [2]. One of these problems is burden of disease. Lower life expectancy demotivates adult literacy which further curtails productivity. Easily transformable human diseases like malaria and sleeping sickness also hinder development of the economic sectors on which many countries rely. Population health is basically about measuring health outcomes and their determinants and using these measures to coordinate the efforts of public health communities. As a result most nations in the world are working to measure burden of the disease. The burden of disease can be defined as "the strain that a particular disease process has in a particular area as measured by cost, mortality, and morbidity" [30]. The World Health Organization (WHO) quantifies burden of disease by using summary measures of population health (SMPH) [35].

1.2   Measuring Impact of Human Health

SMPH take into account both non-fatal health outcomes and mortality. This is represented as a single number and then used as a yardstick to determine the health of a particular population. The task of developing a SMPH has a long history [44, 47, 17] with much work conducted by members of the Reseau de Esperance de Vie en Sante

(REVES) [50, 10]. SMPH has many applications which include the active life expectancy (ALE) [18] done in the United States of America, quality adjusted life years (QALYs) by the global burden of disease (GBD) [45], the disability free life expectancy (DFE) [7, 36], and the disability adjusted life years (DALYs). DALYs are widely used by the GBD study [29, 30, 34] and the national burden of disease studies (NBD) [30, 21, 8].

Summary Measures of Population Health

Summary measures of population health are used to represent methods of measuring the burden of disease in a population by collecting information from mortality and morbidity data. In the last decade, many indicators were been designed to adjust mortality to reflect the impact of disability or morbidity [26]. These measures fall into two classes: health expectancy (HE) and health gaps (HG).

HE is a measure of improvement in the quality of life and can be divided into five classes:

 (i) Disability-adjusted life expectancy (DALE).

 (ii) Healthy adjusted life expectancy (HALE).

(iii) Quality adjusted life expectancy (QALE).

(iv) Disability-free life expectancy (DFLE).

 (v) Active life expectancy (ALE).

HG measure the difference between the actual health in comparison with the "ideal" health state and is classified into four categories namely:

 (i) Potential years of life lost (PYLL).
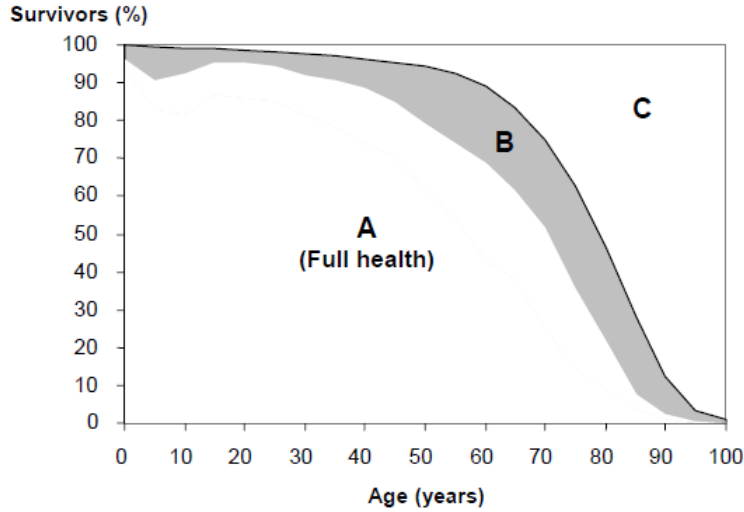
Figure 1.1: Typology of summary measures of population [25]

(ii) Healthy years of life lost (HYLL).

(iii) Disability adjusted life years (DALY).

(iv) Quality adjusted life years (QALY).

Figure 1.1 represents a typology of SMPH. It is evident that there are three areas A, B, and C. The curve is the survivorship for a hypothetical group of people of a particular age x in perfect health. Area A represents the life time of those who lived in perfect health conditions, area B represents the life time of those who lived in poor health conditions and area C represents the time lost due to premature mortality. The area under the survivorship curve represents the total life expectancy (LE) at birth which is given by

$$LE = A + B, \tag{1.1}$$

where A is time lived in perfect health and B is time lived in poor health.

The HEs are measures that take into account both the time lived in perfect health and the time lived in a health state that is less than perfect health or ideal health.

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The health expectancy is determined by

$$HE = A + f(B), \qquad (1.2)$$

where A is time lived in perfect health, B is time lived in poor health (less than perfect health) and $f(B)$ is a function that assigns weights to years lived in sub-perfect health (perfect health has a weight of 1).

HGs are measures that take into account the difference between the actual health of a population and stated standards for population health. The health gaps are given by

$$HG = C + g(B), \qquad (1.3)$$

where B is time lived in poor health, C is time lost due to mortality (premature death) and $g(B)$ is a function that assigns weights to health states lived during time B, but where a weight of 1 equals to time lived in a health state equivalent to death). For a detailed explanation of SMPH, the reader is referred to [5, 32, 43, 40].

1.3   Importance of Cattle Health

Cattle play an important role in human health and well-being because they are sources of income, meat, employment, milk, draught power and a measurement of wealth [24]. In Africa, cattle also have social importance which include status symbolism and uses during religious-practices [48]. However, meat, milk and hide production remain the main outputs of cattle production. In South Africa these contribute $25\% - 30\%$ of all agricultural outputs [28]. For rural farmers, cattle production is also important for crop production through provision of draught power and manure. Cattle also contribute to subsistence, nutrition, income generation, assets, security, social and cultural functions [48]. One of the crucial functions of cattle in some rural areas is provision draught of

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power. Thus cattle production in a rural set up is critical and contributes to multiple livelihood objectives and offers pathways out of poverty.

Diseases of cattle are a threat to animal production which in turn reduce incomes of farmers thus hampering their health and economic well-being. As such, adequate animal health control, which raises cattle production, will uplift the livelihoods of communities. Tick-borne diseases are one broad group of diseases which have serious impact on cattle production in the tropical regions, with their impact being influenced by the production system as well as the agro-ecological setting. In rural Eastern Cape of South Africa, cattle farming is severely hampered by tick-borne diseases; with anaplasmosis (gall-sickness), babesiosis (red water) and ehrlichia (heart water) being considered among the most serious [27].

1.4   Social and Economic Impact of Cattle Diseases

The social and economic burden of a disease generally refers to the effect a disease has on society measured in terms of mortality, morbidity, financial cost, or other indicators [49]. These measurable quantities enable assessment of the impact of any disease. The most important metric used to assess the impact of the disease is the financial cost therefore, it's impact in resource poor communities ought to be extended to cover indirect consequences that affect human health like malnutrition and financial hardships. Cattle provides both direct and indirect benefits to resource poor communities. Such benefits include direct source of food like milk and meat; their use in agriculture (both as a source of draught power and manure), as a reservoir of wealth and as a valuable cultural benefit. In high income communities, cattle are mainly treated as a sources of pride, food and a financial asset. Therefore, when cattle loss occurs due to disease, the impact cuts across all societal levels and as such it's direct costs need to be estimated using market prices. The indirect costs associated with cattle loss are more difficult

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to estimate even though their impact may seem to be more important than the direct financial costs [37].

To estimate the economic and social values of burden of tick-borne diseases, certain methods ought to be sought for to combine the adverse effects of the diseases on the community and reduced productivity in cattle in conjunction with the low levels of human well-being and productivity. Direct costs to human health include the costs of death, sickness and injury and the costs of treating the disease. Indirect costs include the loss of wages to workers who are sick and the reduced productivity of workers who may have sub-clinical effect of disease. The various methods for measuring the cost or impact of ticks and tick-borne diseases are discussed in Chapter 3.

1.5   Measuring Impact of Cattle Health

Currently, there are no standard mathematical methods to measure and assess the impact of cattle or animal health on productivity. The most common methods are statistical, and the acceptable procedure is data collection about a specific disease and then followed by modeling using preferred statistical techniques [1, 24]. Using such techniques (least squares regressions) requires large data sets so as to obtain realistic conclusion. More to that, the results obtained via regression analysis are heavily dependent on the respective formulated form, if the error term is inadequately interpreted. This gives varying calculations that are dependent on how the regression is initially set up. In some cases (corrected least squares regressions), the results are affected by outliers, since the "best" performer along any dimension serves as the anchor for the estimate.

It is this that motivated us to develop mathematical models for our study rather than statistical ones. We modified DALYs model to measure productivity adjusted life

years (PALYs) and then assessed the burden of disease for livestock. This measure of cattle population health combines mortality and morbidity into one unit to measure the impact of a disease on communities. The reason for using the DALYs approach to formulate a PALYs approach for cattle populations is because the DALYs model is widely used in human health assessment to successfully give realistic results. Thus we expect our new model to give realistic results compared to other statistical methods.

1.6 Summary

Studies on the burden of disease have been implemented in many countries using a SMHP approach [25, 22]. These measures were adapted by the WHO to assess the burden of disease on human population and to help policy makers take proper decisions [16]. However many studies prior to this work that have used SMPH technique have dealt only with the human population and neglected the impact of disease spread in the animal population as well as the social and cultural values of livestock to the rural and resources-poor communities in Africa. The main objective of this study is to use SMPH technique to assess the burden of tick-borne diseases in cattle population resource-poor communities of the Eastern Cape, South Africa.

1.7 Outline

The objectives of this study include, but are limited to

- understanding DALYs model for human population,

- adapting DALYs model to PALYs model for cattle population,

- using PALYs model to assess the burden of tick-borne disease(s) on cattle popu-

lation in resource-poor communities of the Eastern Cape Province, South Africa.

For the methodology, we used a questionnaire to collect our sample data. We preferred this type of data collection because the responses are gathered in a standard way, so it is more objective and also allows for quick collection of information from a large portion of the population. For our analysis, we entered the data in Excel and basic descriptive statistics performed therein. We used SPSS software to perform complex statistical analyses on the data and some of the results used as PALYs model parameters. The remaining data, for example the number of dead animals due to ticks and tick-borne diseases were used to test our model. There is some information that the farmers' responses were unclear because of insufficient knowledge or data; for example, at what age did the animals die because of ticks and tick-borne diseases. In that case, we used a survival distribution function to obtain a theoretical sample for this data as described in Chapter 4.

In Chapter 2, we review the DALYs model followed by discussion of how DALYs formula is built, and then apply it to a practical example. In Chapter 3, we build PALYs model from DALYs and discuss how it can be used to assess the burden of diseases in cattle populations. In addition, the effect of the parameters on the model behaviour is studied using a practical example. In Chapter 4, we apply this model to sample data collected from 20 villages of the Eastern Cape Province to assess the burden of ticks and tick-borne diseases and present a full discussion of our results.

Chapter 2

DALYs for Human Populations

2.1 Introduction

DALYs is a measure used to assess burden of disease on human populations as a single number by calculating years of life lost due to premature mortality and years of life lost because of disability [26]. It is the sum of the years of life lost due to premature mortality (YLL), and years of life lost due to disability (YLD) (in health state less than perfect health) or is the years of life lost due to a health condition. DALYs highlight the effective number of years lost due to disability and premature mortality. In studying DALYs, we aim to maximize the number of years lived in perfect health. DALYs can be expressed as follows:

$$\text{DALYs} = \text{YLD} + \text{YLL}. \tag{2.1}$$

2.2 Social Values with DALYs

All summary measures of population health involve explicit or implicit social value choices. In particular, the DALYs measure the gap between a population's actual health status and some 'ideal' or reference status. In developing the DALYs indicator [29] five value choices were identified that should be explicitly made:

1) How should we compare years of life lost through death with years lived with poor health or disability of various levels of severity?

2) How long 'should' people in good health expect to live?

3) Is a year of healthy life gained now worth more to society than a year of healthy life gained sometime in the future?

4) Are lost years of healthy life valued more at some ages than others? The GBD chose to value a year of life at young adult ages more than in old age or infancy.

5) Are all people equal? Do all people lose the same amount of health through death at a given age, even if there are variations in current life expectancies between population groups?

Health researchers have reached general agreement upon probable answers to these five questions that should be used as a bench mark for developing a measure of the burden of disease [31]. In the following sections, we discuss these issues.

2.3 Years of Life Lost Due to Disability

The number of years lost due to disability (YLD) for each disease is another class for the DALYs measure. YLD is assumed to be proportional to the average duration of

the disease (I), with the proportionality constant comprised of the number of incident cases (N) and the severity of the disease (D). The number of incident cases is necessary to obtain the YLD for a particular population (in the case of an individual $N = 1$). The severity of the disease D is important as the health of the population has a direct effect on the years lost; the healthier the population the fewer years lost. Putting this all together we obtain:

$$\text{YLD} = N \times I \times D. \tag{2.2}$$

Disability Weight

Disability weight is a measure that reflects the severity of the disease on the scale of 0 to 1 (with 0 representing perfect health and 1 representing death) in order to measure the time lived with a disability and assess disabilities in such a way that will promote health. By incorporating disability weight to our model, we intend to provide answers to the first question suggested by Murray (See §2.2.) [29]. Disability weight was defined, measured and valued in a clear framework that includes simplifying reality by the GBD [34]. These weights were adapted by the World Bank and WHO [54]. To give each disability or condition a specific number between zero and one, each disability weight was categorized into the six classes presented in Table 2.1.

Table 2.1 shows the disability weight distribution in six classes. Column 1 contains disability classes, column 2 contains description of each classes and column 3 contains disability weight for each class in a particular range. Each disability condition or disease was assigned to one of six classes. The classes are arranged in increasing order of severity from top to bottom. A disability within the same class is considered to have a similar effect outcome on an individual even though it may affect other functional capacities within the same individual.

Table 2.1: Definition of disability weight adapted by WHO [41]

Classes	Description	Disability Weight
1	Limited ability to perform at least one activity in one of the following areas: recreation, education, procreation or occupation on scale between	0 - 0.096
2	Limited ability to perform most activities in one of the following areas: recreation, education, procreation or occupation on scale	0.096 - 0.220
3	Limited ability to perform in two or more of the following areas: recreation, education, procreation or occupation on scale between	0.220 - 0.400
4	Limited ability to perform most activities in all of the following areas: recreation, education, procreation or occupation on scale between	0.400 - 0.600
5	Needs assistance with instrumental activities of daily living such as meal preparation, shopping or housework on scale between	0.600 - 0.810
6	Needs assistance with activities of daily living such as eating, personal or toilet use on scale between	0.810 - 0.920

2.4 Years of Life Lost Due to Premature Mortality

YLL is a function of death rates and the average duration of life lost due to a death at each age. As death rates are incidence rates, there is no obvious alternative for mortality other than the incidence approach. YLL for each premature death should

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be counted from birth until the maximum life span[1]. The maximum life span adapted by the WHO is that of Japan, because it has the highest life expectancy in the world; (80 years for men and 82.50 years for women) [3]. YLL for a given condition on a population basically corresponds to the product of the number of deaths and the standard life expectancy at the age at which death occurs. The basic formula for YLL is given by

$$\text{YLL} = N \times L, \tag{2.3}$$

where L is the standard life expectancy at age of death, and N is the number of deaths.

Life Expectancy

Life expectancy literally means the expected number of years that an individuals is supposed to leave to reach the maximum life span of a given population. By incorporating life expectancy in our model, we intend to provide answers to the second question suggested by Murray (See §2.2.). Life expectancy from birth to the age of one hundred years is tabulated in Table 2.2. Note that we have used the life expectancy set by WHO [3] as indicated at birth (i.e., at the age of zero in the table). The life expectancy for men and women is calculated separately because men on average live shorter than women: this is a *"biological difference in survival potential between males and females"* [21].

Table 2.2 shows the standard life expectancy for the human populations. Inferring from the table, it is clear that an infant who dies shortly after birth would lose all the years that he or she would have lived. On the other hand a man who dies at the age of 50 years would lose 30.99 years of his expected life while and a woman who dies at the same age would lose 33.99 years of her expected life.

_____

[1]Life span means the amount of time that a person or animal actually lives.

Example 2.4.1. If a man ($N = 1$) dies in an accident at the age of 30, the YLL is calculated as follows: the standard life expectancy at age 30 is $L = 50.51$ from Table 2.2. Using Eq.(2.3) we have

$$\text{YLL} = 1 \times 50.51 = 50.51 \, \text{years.}$$

Example 2.4.2 shows the basic procedure for calculating the DALYs.

Example 2.4.2. Suppose a woman aged 20 years suffers from moderate depression up to the age of 50 and passed away as a result [16]. We want to find out how many DALYs she has lost as a result.

To solve Example 2.4.2, firstly we have to find YLD. The average duration of disease is $50 - 20 = 30$ years, and disability weight for moderate depressive episode is 0.350 [29]. Substituting these two values in Eq.(2.2) we get

$$\text{YLD} = 1 \times 30 \times 0.350 = 10.50 \, \text{ years.}$$

Secondly we have to compute YLL. The standard life expectancy at age 50 is 33.99 years (from Table 2.2). Then using Eq.(2.3) we have

$$\text{YLL} = 1 \times 33.99 = 33.99 \, \text{years.}$$

Finally, YLD and the YLL are added up according to Eq.(2.1) to estimate DALYs for the woman as follows:

$$\text{DALYs} = 10.50 + 33.99 = 44.49 \, \text{years.}$$

Therefore the burden of disease in this case, in terms of DALYs, is 44.49 years.

Table 2.2: Standard life expectancy table created by WHO [55]

Age	Male	Female	Age	Male	Female	Age	Male	Famele	Age	Male	Famele
	Sex			Sex			Sex			Sex	
0	80.00	82.50	26	54.48	57.19	52	29.12	32.14	78	8.53	10.25
1	79.36	81.84	27	53.49	56.21	53	28.19	31.22	79	7.99	9.58
2	78.36	80.87	28	52.50	55.23	54	27.26	30.29	80	7.45	8.90
3	77.37	79.90	29	51.50	54.25	55	26.32	29.37	81	7.01	8.36
4	76.38	78.92	30	50.51	53.27	56	25.42	29.37	82	6.56	7.83
5	75.38	77.95	31	49.52	52.29	57	24.52	27.55	83	6.12	7.29
6	74.39	76.96	32	51.31	51.31	58	23.61	26.65	84	5.68	6.76
7	73.39	75.97	33	47.54	50.34	59	22.71	25.74	85	5.24	6.22
8	72.39	74.97	34	46.55	49.36	60	21.81	24.83	86	4.90	5.83
9	71.40	73.98	35	45.57	48.38	61	20.95	23.95	87	4.56	5.43
10	70.40	72.99	36	44.58	47.41	62	20.09	23.07	88	4.22	5.04
11	69.40	72.00	37	43.60	46.44	63	19.22	22.20	89	3.88	4.64
12	68.41	71.00	38	42.61	45.47	64	18.36	21.32	90	3.54	4.25
13	67.41	70.01	39	41.63	44.50	65	17.50	20.44	91	3.30	3.98
14	66.41	69.01	40	40.64	43.53	66	16.71	19.59	92	3.05	3.71
15	65.41	68.02	41	39.67	42.57	67	15.93	18.74	93	2.80	3.43
16	64.42	67.03	42	38.69	41.61	68	15.15	17.90	94	2.56	3.16
17	63.42	66.04	43	37.72	40.64	69	14.36	17.05	95	2.31	2.89
18	62.43	65.06	44	36.74	39.68	70	13.58	16.20	96	2.14	2.71
19	61.43	64.07	45	35.77	38.72	71	12.89	15.42	97	1.97	2.53
20	60.44	63.08	46	34.81	37.77	72	12.21	14.63	98	1.80	2.36
21	59.44	62.10	47	33.86	36.83	73	11.53	13.85	99	1.63	2.18
22	58.45	61.12	48	32.90	35.88	74	10.85	13.06	100	1.46	2.00
23	57.46	60.13	49	31.95	34.94	75	10.17	12.28			
24	56.46	59.15	50	30.99	33.99	76	9.62	11.60			
25	55.47	58.17	51	30.06	33.07	77	9.08	10.93			

2.5   Preference Time

DALYs are characterized by including two social values; disability weight and life expectancy, where disability weight reflects the severity of the disease burden. The standard life expectancy is captured in the YLL component (See §2.3.) and the severity of the disease burden is captured in the YLD component (See §2.4.) [26]. The other social values used in DALYs models are discounting and age weighting [3, 26, 33].

Discounting

Discounting means that the value of a healthy life year today is set higher than the value of future healthy life years. It is an economic concept that individuals prefer benefits now more than in the future. By incorporating discounting in our model, we intend to provide answers to the third question suggested by Murray (See §2.2.). For example, if an individual is offered 100 dollars today or 100 dollars next year, s/he will prefer 100 dollars today rather than in the future. This is because future dollars are valued lower than dollars today [42, 33]. Years of health life are similar to the value of a dollar, in the sense that a person will prefer years of healthy life now to years of healthy life in future. There is a big debate among economists, public health planners and medical ethicists about discounting because discounting future health affects both measurements of disease burden and estimates of the cost-effectiveness of an intervention [16].

Discounting of future benefits is commonly used in economic analysis and there are some specific consideration in applying discounting to the DALYs in measuring population health [29]:

1) To be consistent with measurement of health outcomes in cost-effective analyses.

2) To prevent giving excessive weight to deaths at younger ages (For example, without age weighting and discounting, a male death at age zero results in 44% more YLL, than a death at age 25 and 97% more than a death at age 40; with discounting at 3% an infant death results in only 12% and 29% more YLL than a death at age 25 and age 40, respectively).

3) The disease eradication/research paradox: assuming that investment in research or disease eradication has a non-zero chance of succeeding, without discounting, all current expenditure should be shifted to such investment because the future stream of benefits is infinite. This is a particular case of the excessive sacrifice argument.

In many health economic and other social policy analyses, 5% discount rate per annum was a standard for many years. Environmentalists and renewable energy analysts arguing in recent decades for the lowest discount rates for social decisions. A discount rate of 3% is used by both the world bank disease control priorities study and the GBD project. A 3% discount rate recommended to be used in health analysis by the US Panel on cost-effectiveness in health and medicine recently, to adjust both health outcomes and cost, even though the sensitivity of the results to the discount rate ought to be examined [29].

A continuous discounting function at any age x, is given by

$$G(x) = e^{-rx}, \tag{2.4}$$

where $r > 0$ is the discount rate. Figure 2.1 shows the discount function plotted for different rates. Further, it shows the effect of discounting on the number of years of life lost at various times in the future. In other word, it describes the weight placed on rewards received at different points in time.
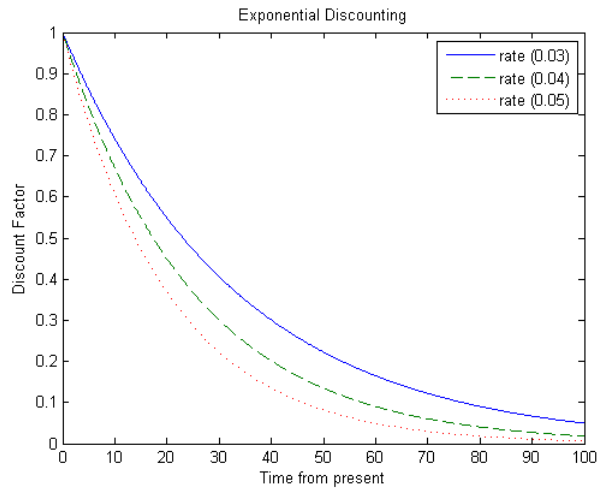
Figure 2.1: Effect of discounting

Age Weighting

Age weighting means that the life years of children and old people are counted less than other ages. By incorporating age-weighting in our model, we intend to provide answers to the fourth question suggested by Murray (See §2.2.). A high age weight for a particular age group does not mean that the time lived during that age is more important than the time lived during ages with less age weights but is rather indicative of the greater social value at that age [42, 33]. The function used to model the relative age weights is:

$$F(x) = Cxe^{-\beta x}, \tag{2.5}$$

where C and β are constants, x is age (years) and $F(x)$ is age weighted at age x. The GBD recommended that the values of $C = 0.1658$ and $\beta = 0.05$ be used for standard age weighting in NBD for comparison with other studies. They pointed that you are of course free to also compute burden with other age weights as relevant, and without age weighting [52]. As we can see in Figure 2.2 there are two figures with different age weighting scales; the first one is given by a different study [14]. The GBD researchers

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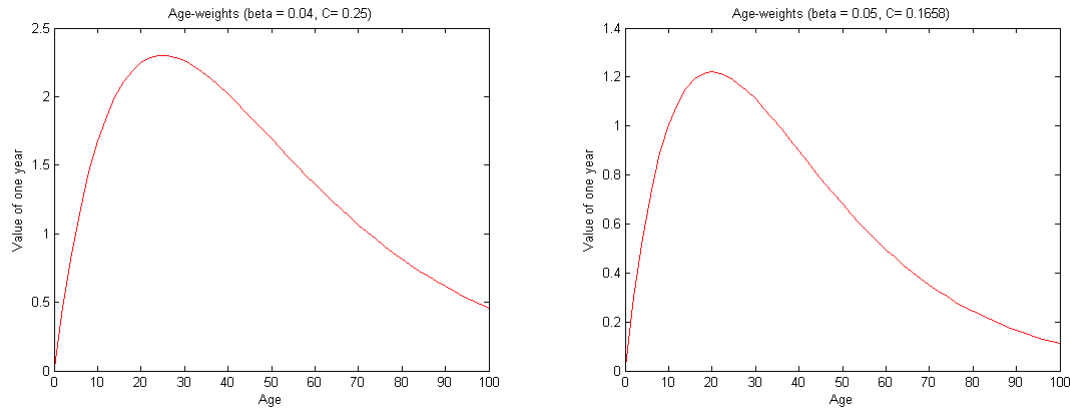
Figure 2.2: Age-weighting functions

therefore incorporated age-weighting into the DALYs. The underlying assumption is that the relative value of year of life increasing expeditiously from the time of birth to a peak value in the early twenties; therefore it declines steadily.

Further, Figure 2.2 shows the relative value assigned to each year of life in the calculation of disease burden [17]. In the first figure the relative value of a life year is below one for children under 5, and for persons older than 75 years of age. This implies that, in the calculations, a life year lost for children is given less weight than a life year lost for adults below 75 years. In the second figure the relative value of a life year is below one for children under 10, and for persons older than 40 years of age. This implies that, in the calculations, a life year lost for children is given less weight than a life year lost for adults below 40 years. An adjustment has been made which explicitly introduces a bias against children and the elderly. In a difference of age-weights, Murray [29] argues that there is a widespread preference for age weights in most cultures, and that on average, these preferences can be expressed as the function given in Eq.(2.5).

As a result the years of healthy life lived for children and older people are weighted less than other ages. The DALYs calculations give age weight on a scale ranging from

zero to 1.2 from birth up to 100 years according to the GBD study. (See Figure 2.2.).

Discounting future health is very important whenever we are studying populations of mixed age group. The impact that the death of an infant relative to the death of an adult is controlled by discounting. For example; a year old girl's demise results into a loss of 34 years of life well as the death of a 25 years-old woman's results into a loss of 33 years (this is when age weighting is incorporated also). Discounting also diminishes the impact of health interventions benefit is achievable only in the future. For example, vaccinating against hepatitis may prevent livers cancer among many cases but it's can only be realised after scores of years later.

The GBD study used the same standards of measure for all regions of the world. The same life expectancy is used as the 'ideal' standard for all population subgroups irrespective of whether the prevailing life expectancy differs from one region to another. Also the same disability weight is allocated to every individual suffering from the same disease and the value of a year of health life lost at any age is given equal weight (equal 'age weight'). This would provide answers to the fifth question suggested by Murray (See §2.2.).

2.6   Formulas for Calculating DALYs

When considering discounting and age weighting, DALYs could be discussed and calculated in the following ways:

1) Without age weighting and discounting (Basic formula).

2) With discounting.

3) With age weighting and discounting.

In §2.3 and §2.4 we have shown how to calculate DALYs without considering discounting and age weight in Eq.(2.2) and Eq.(2.3). In the subsections that follow we consider the DALYs model with discounting and age weighting and discounting.

2.6.1 DALYs Formula with Discounting

The YLD value of any disability with discounting, for a given number of incident cases[2] (N), is given by

$$\text{YLD} = N \times D \times G(x), \tag{2.6}$$

where D is the disability weight and $G(x)$ is the discount function.

A continuous discounting function at any age x, is given by

$$G(x) = e^{-rx}, \tag{2.7}$$

where r is the discount rate. Total discount (TD) in the continuous-time case is given by

$$\text{TD} = \int_a^{a+I} e^{-r(x-a)}dx, \tag{2.8}$$

where I is the average duration of disability in case of YLD or I is the standard life expectancy at the age of the death in case of YLL, r is the discount rate and a is the age of onset.

By substituting Eq.(2.8) in Eq.(2.6), the YLD becomes as

$$\text{YLD} = \int_a^{a+I} NDe^{-r(x-a)}dx, \tag{2.9}$$

from Eq. (2.9), we obtain

$$\text{YLD} = \frac{DN[1 - e^{-rI}]}{r}. \tag{2.10}$$

---

[2]The number of incident cases refers to the number of individuals in the population that are affected by the disease.

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To find the years of life lost due to premature mortality (YLL) formula, we set the disability weight (D) to one (because disability weight set equal to one in case of death) and replace the average duration of disability (I) with the standard life expectancy at age of death (L) and the number of incident cases (N) to the number of death in Eq.(2.10). Then the YLL becomes

$$\text{YLL} = \frac{N[1 - e^{-rL}]}{r},$$ (2.11)

where N is the number of deaths.

2.6.2   DALYs Formula Including Age Weight and Discounting

When considering age weight and discount function, the YLD value of any disability with weight at age x, and discounting, is given by

$$\text{YLD} = N \times D \times F(x) \times G(x),$$ (2.12)

where N is the number of incident cases, D is the disability weight, $F(x)$ is the age weight function and $G(x)$ is the discount function. The weight for any age x, is given by the age weight function in Eq.(2.5).

By combining Eq.(2.5), Eq.(2.8) and Eq.(2.12) we obtain the total of YLD in the continuous time as

$$\text{YLD} = \int_{a}^{a+I} NDCxe^{-\beta x}e^{-r(x-a)}dx.$$ (2.13)

Eq.(2.13) states that the YLD for the duration of life lost with disability starting from the age of onset is obtained via the product of disability weight, the integral of discount factor and age weight. Therefore Eq.(2.13) simplifies to

$$\text{YLD} = NDCe^{ra} \int_{a}^{a+I} xe^{-(r+\beta)x}dx.$$ (2.14)

By using integration by parts in Eq.(2.14), we obtain

$$\text{YLD} = NDCe^{ra} \left(\left[\frac{-x}{(r+\beta)}e^{-(r+\beta)x} - \frac{1}{(r+\beta)^2}e^{-(r+\beta)x} \right]_{a}^{a+I} \right),$$

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which can be simplified to give

$$\text{YLD} = \frac{NDCe^{-\beta a}}{(r+\beta)^2} \left[a(r+\beta) + 1 - e^{-(r+\beta)I} \left((a+I)(r+\beta) + 1 \right) \right], \tag{2.15}$$

where N is the number of incident cases, D is the disability weight, r is the discount rate, C and β are constant from the age weighing function, a the age of onset and I is the average duration of disability. Eq.(2.15) shows how to calculate years of life lost due to disability.

A formula for the YLL can be found by simply setting the disability weight, D, to 1 (representing death) and changing the average duration of disability (I) to standard life expectancy at age of death (L). Thus the YLL formula is:

$$\text{YLL} = \frac{NCe^{-\beta a}}{(r+\beta)^2} \left[a(r+\beta) + 1 - e^{-(r+\beta)L} \left((a+L)(r+\beta) + 1 \right) \right], \tag{2.16}$$

where N is the number of death, D is the disability weight, r is the discount rate, C and β are constants from the age weighing function, a age of death and L is the standard life expectancy at age of death. Eq.(2.16) shows how to calculate years of life lost due to premature mortality.

The general formula for YLD for a particular discount rate r and age-weighting parameters (C, β, K) is obtained by adding Eq.(2.10) and Eq.(2.15) to give

$$\text{YLD} = D \left(\frac{Ce^{-\beta a}}{(r+\beta)^2} \left[a(r+\beta) + 1 - e^{-(r+\beta)I} \left((a+I)(r+\beta) + 1 \right) \right] \right.$$
$$\left. + \frac{(1-K)[1-e^{-rI}]}{r} \right). \tag{2.17}$$

It is important to highlight the introduction of a normalization parameter K. This parameter enables distinction between a DALYs including an age weighting (K takes on a value one), and one that includes a non-age weighting function (K takes on a value of zero).

$$0 \leq K \leq 1.$$

In a similar manner, we also obtain the general formula for YLL by using Eq.(2.11) and Eq.(2.16) to obtain

$$
\begin{aligned}
\text{YLL} = \Bigg(& \frac{Ce^{-\beta a}}{(r+\beta)^2} \left[a(r+\beta) + 1 - e^{-(r+\beta)L} \left((a+L)(r+\beta) + 1 \right) \right] \\
& + \frac{(1-K)[1-e^{-rL}]}{r} \Bigg).
\end{aligned}
\tag{2.18}
$$

Here, K plays the same role as in (2.17).

2.7   Practical Example

The following example shows how to calculate DALYs, with and without treatment, highlighting the impact of varying the age weighting and discount rates.

Imagine a 35 year old woman suffers from bipolar depression for 10 years and dies from this condition. We wish to discover how many DALYs were lost as a result. Further we are interested in determining how many DALYs would have been averted if she underwent treatment.

To obtain the DALYs we need to estimate the YLD and YLL. We note that the disability weight for bipolar depression is 0.6 [29].

The YLD is obtained from Eq.(2.10) by substituting for the values of the average duration of the disease ($L = 10$), discount rate ($r = 0.03$) and disability weight ($D = 0.6$) in Eq.(2.10). We find that

$$
\text{YLD} = \frac{1 \times 0.6 \times \left[1 - e^{-0.03 \times 10} \right]}{0.03} = 5.1836 \text{ years.}
$$

The YLL is found by substituting the standard life expectancy at age 45 ($L = 38.72$ from Table 2.2) and discount rate ($r = 0.03$) in Eq.(2.11):

$$
\text{YLL} = \frac{1 \times \left[1 - e^{-0.03 \times 38.72} \right]}{0.03} = 22.90 \text{ years.}
$$

By using Eq.(2.1) the total DALYs lost without treatment is calculated as:

$$\text{DALYs without treatment} = 5.18 + 22.90 = 28.08 \text{ years.}$$

In order to determine how many DALYs would have been averted by treatment, it will be assumed that the woman received medication at age of 35 and did not die but lived up to her life expectancy at age of 35 years when she was diagnosed with the condition. With these assumptions the DALYs is calculated as follows, the Disability weight for the treated bipolar depression is given [29] as 0.302 (a fall of 0.298 from the untreated DALY weight). In terms of DALYs with treatment, only YLD is calculated because it is assumed that she has lived all her standard life expectancy at age 35.

The YLD is calculated from Eq.(2.10) with the following figures: $0.302, 48.38$ and 0.03 for the disability weight, duration of the disease and discount rate respectively;

$$\text{YLD} = \frac{0.302 \times [1 - e^{-0.03 \times 48.38}]}{0.03} = 7.71 \text{ years.}$$

Therefore the DALYs with treatment for her condition is 7.71. The total number of DALYs averted can then be obtained as the difference between DALYs without treatment and DALYs with treatment. Hence the DALYs averted is $28.04 - 7.71 = 20.33$ years.

When age weight is considered, Eq.(2.17) and Eq.(2.18) are used to calculate DALYs with and without treatment, respectively. The YLD is calculated by substituting the average duration of the disease $(L = 10)$, discount rate $(r = 0.03)$, disability weight $(D = 0.6)$, age weighing parameters $(C = 0.1658, \beta = 0.04)$, age weighting modulation constant $(K = 1)$, and age of onset of disability $(a = 35)$ into Eq.(2.17) to obtain $\text{YLD} = 6.95$ (the number of YLD without treatment lost because of the disability is 6.95 years).

The YLL is calculated by substituting the standard life expectancy at age 45 $(L = 38.72$ from Table 2.2), discount rate $(r = 0.03)$, age weighing parameters $(C =$

0.1658, $\beta = 0.04$), age weighting modulation constant ($K = 1$), and age of death ($a = 45$) into Eq.(2.18) to yield YLL = 25.76 (the number of YLL without treatment lost from age of 45, due to premature death therefore is 25.76).

By substituting years of life lost due to disability and years of life lost due to premature mortality in Eq.(2.1), the total DALYs lost without treatment is

$$\text{DALYs without treatment} = 6.95 + 25.76 = 32.71 \text{ years.}$$

Regarding DALYs with treatment, only YLD with treatment are calculated by changing disability weight for the treated form of the disease from 0.6 (without treatment) to 0.302 (with treatment) [29]. In this case she would have lived for her expected life at age 35 ($L = 48.38$). By substituting the values ($a = 35$, $L = 44.13$, $D = 0.302$, $\beta = 0.04$, $K = 1$, $C = 0.1658$, $r = 0.03$) into Eq.(2.17), we obtain that the number of DALYs lost with treatment is 8.13 years.

The total number of DALYs averted can be calculated as:

$$\text{DALYs averted} = 32.71 - 8.13 = 24.58.$$

The total number of DALYs averted if the woman underwent treatment is 24.58 years.

2.8 Summary

In this Chapter we discussed the concept of DALYs models by using years of life lost due to disability (YLD) and years of life lost due to premature mortality (YLL). It has been shown that there are three methods to calculate DALYs model: Basic formula in Eq.(2.3) and Eq.(2.2), DALYs with discounting in Eq.(2.10) and Eq.(2.11) and DALYs with both discounting and age weighting in Eq.(2.17) and Eq.(2.18). An example was also discussed to show how DALYs can be used to compare the expected gains to an individual for treatment versus no treatment.

Chapter 3

PALYs for Cattle Population

3.1   Introduction

The previous chapter discussed the DALYs model for human population according to WHO. This model can be adapted to animal population [41]. Our aim in this chapter is to reformulate the DALYs model for human population into a productivity adjusted life years (PALYs) model for cattle. The PALYs model will then be used to assess the burden of diseases on cattle production, particularly the burden of tick-borne diseases in the Eastern Cape Province, South Africa.

It is important to understand the evaluation of disease in a cattle population because their health poses both direct and indirect consequences on humans. To the best of our knowledge, the economic cost of cattle health and disease has not been determined yet. We wish to address this gap.

3.2   PALYs Concepts for Cattle

In constructing a PALYs model for cattle several aspects need to be readjusted or reconfigured from the DALYs model. In this Chapter we will describe the social and economic values underlying PALYs model. In rebuilding the PALYs model for cattle, the following four choices have to be redefined:

1) Standard life expectancy,

2) Disability weight,

3) Discounting,

4) Age weighting.

Attainment of these objectives was realized by making use of a carefully designed questionnaire targeting about 350 farmers around the Eastern Cape Province. The questionnaire (See Appendix A.2.) is designed in such a way that participants (who are involved in monitoring the cattle) are interviewed in their local language by a trained interpreter. The obtained information was analyzed to determine the importance of social, economic values and impact of the disease. This information was also used to calculate a standard life expectancy table for cattle (See §3.3.1.) and come up with definition of disability weight for cattle (See §3.3.2.) and the age weighting function (See §3.3.3.).

3.3   Data Collection

The social and economic values of cattle and economic impact of diseases on Nguni cattle production in Eastern Cape was examined using a probabilistic sampling method [20] (by this we mean any method of sampling that utilizes some form of random

selection). This is because such a technique provides greater external validity for our findings. Due to limited resources, simple random sample (a probability sampling technique) was used to select our samples [20]. A sample of 20 villages close to Mthatha was selected and 18 farmers from each village were interviewed.

The sample size of the farmers was calculated using sample size calculator software [23] based on the following assumption: population size of $75,000$ farmers, 95% confidence level. The Department of Agriculture in the Eastern Cape province helped facilitate the interactions with the identified farmers.

3.3.1 Data Analysis

The data was captured in Excel, and the basic descriptive statistics were preformed therein. The database was imported into the social package of statistical analyses (SPSS) software to perform complex statistical analyses. Results were presented in the form of PALY model parameters, such as life expectancy, disability weight and age weighting.

3.3.2 Life Expectancy

The term "life expectancy" is most often used in the context of human populations, but can also, used for plants or animals. Life expectancy for cattle is the expected number of years of life remaining at a given age. It is denoted by e_x where the subscript x denotes the current age of the animal in question since the life expectancy depends on the current age, x. The life expectancy is calculated according to a particular mortality experience. Because life expectancy is an average value, the actual ages of the members of a given cattle population may or may not significantly deviate from the expected life. In this section we have calculated standard life expectancy for cattle by using the

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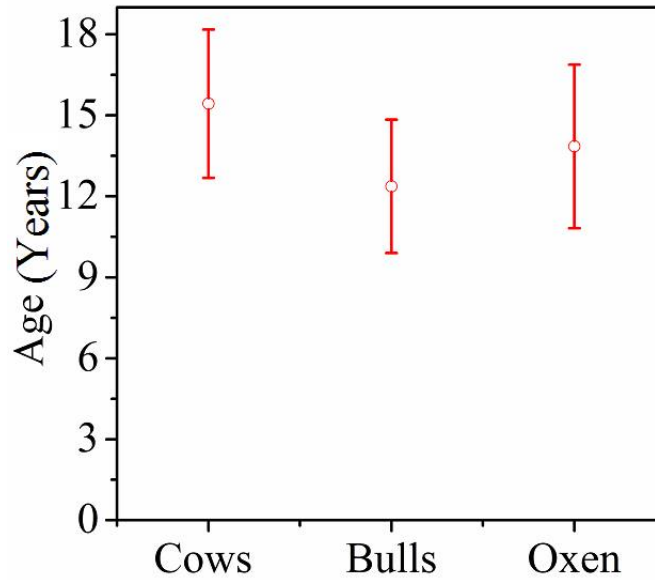
Figure 3.1: The life span for cattle (mean and standard deviation) based on a questionnaire in Eastern Cape Province, South Africa (2013)

following methods.

Calculating Life Expectancy for Cattle

There are two methods for calculating life expectancy for population [52]. The first method involves using the life span for cattle. We have used two questions from our questionnaire to estimate the life span for cattle population. Firstly, we asked farmers about the general condition of their animals (Appendix A.2 q.4). For this question we considered good and excellent condition only because a poor condition gives an unrealistic estimation. We also inquired about the longevity of their animals (Appendix A.2 q.5). Figure 3.1 represents their responses as the average life span for cattle. The average life span for cows, bulls and oxen are $15.43, 12.37$ and 13.85 years respectively. We will use the life span for cattle to calculate the life expectancy at

given age x, via

$$e_x = LS - x, \qquad\qquad (3.1)$$

where e_x is life expectancy for a member of the cattle population at age x and LS is its life span. For example if a bull is aged 5 years, then its life expectancy at age 5 years is 7.37 years.

Note that this method gives an estimation of life span which depends on the farmers' estimations. The disadvantage with this method is that large data sets are necessary in order to obtain reliable estimations. In our PALYs calculation, we have chosen a different method to calculate life expectancy that gives a more realistic result. This approach has been used in calculating life expectancy for human populations in many countries [55].

In this method of calculating life expectancy, the l_x table is used [52, 4] (See Table 3.1.). In this table, the following definitions are used

- x is age group $(x = 1, 2, \ldots, k)$.

- n_x is the number of cattle at age x which survive until the age x.

- d_x is the death rate, this refers to the number of cattle that die at age x. The death rate d_x is evaluated as follows

$$d_x = n_x - n_{x+1}; \quad \sum_{i=0}^{k} d_i = n_0.$$

  Note that the sum of $\sum_{i=0}^{k} d_i$ gives the number of cattle at birth which survive until the birth.

- l_x is the probability of cattle population that survives within age x (survivorship). This is given by

$$l_x = \frac{n_x}{n_0}.$$

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- q_x is the probability of dying within age x (e.g between ages x and $x+1$). This is given by

$$q_x = \frac{d_x}{n_x}; \quad q_{k-1} = 1.$$

- L_x is midpoint of probability of the cattle population that survives within age x (midpoint survivorship). That is,

$$L_x = \frac{(l_x + l_{x+1})}{2}.$$

Note that the sum of $\sum_{i=0}^{k} L_x$ gives the total probability of age groups lived by the entire study population.

- T_x is the total probability of age groups left to be survived by population who survive within age x,

$$T_x = T_{x-1} - L_{x-1}; \quad T_0 = \sum_{i=0}^{k} L_x.$$

- e_x, defined as the expectancy at age x is given by the following equation

$$e_x = \frac{T_x}{l_x}; \quad e_{k-1} = \frac{1}{2}.$$

The calculation of the standard life expectancy using the l_x table requires knowing the number of dead animals in each age of life, for example determining how many animals died just after birth. We obtained this information by inquiring as to the total animals lost in a year (Appendix A.2 q.20) and then the age of death (Appendix A.2 q.21). The first question was answered well; the responses resulted in 116, 124, 86, for cows, oxen and bulls respectively. However, the second question was answered vaguely. We decided to estimate the number of the animals (cows, bulls, oxen) that died at each age theoretically, using a survival distribution function [9].

Table 3.1 illustrates the steps taken in calculating the standard life expectancy of the cattle population (cows) from mortality data. In Table 3.2, we only quote the

Table 3.1: Standard life expectancy for cattle (Cows)

x	n_x	$d_x = n_x - n_{x+1}$	$l_x = \frac{n_x}{n_0}$	$q_x = \frac{d_x}{n_x}$	$L_x = \frac{(l_x + l_{x+1})}{2}$	$T_x = T_{x-1} - L_{x-1}$	$e_x = \frac{T_x}{l_x}$
0	116	5	1.00	0.04	0.98	12.83	12.83
1	111	5	0.96	0.05	0.94	11.85	12.38
2	106	5	0.91	0.05	0.89	10.91	11.94
3	101	4	0.87	0.04	0.85	10.02	11.51
4	97	5	0.84	0.05	0.81	9.17	10.96
5	92	5	0.79	0.05	0.77	8.35	10.53
6	87	5	0.75	0.06	0.73	7.58	10.11
7	82	5	0.71	0.06	0.69	6.85	9.70
8	77	5	0.66	0.06	0.64	6.17	9.29
9	72	4	0.62	0.06	0.60	5.53	8.90
10	68	4	0.59	0.06	0.57	4.92	8.22
11	64	4	0.55	0.06	0.53	4.35	7.89
12	60	5	0.52	0.08	0.50	3.82	7.38
13	55	2	0.47	0.04	0.47	3.32	7.01
14	53	5	0.46	0.09	0.44	2.86	6.25
15	48	4	0.41	0.08	0.40	2.42	5.85
16	44	4	0.38	0.09	0.36	2.03	5.34
17	40	3	0.34	0.08	0.33	1.66	4.83
18	37	3	0.32	0.08	0.31	1.33	4.18
19	34	4	0.29	0.12	0.28	1.03	3.50
20	30	5	0.26	0.17	0.24	0.75	2.90
21	25	5	0.22	0.20	0.19	0.51	2.38
22	20	3	0.17	0.15	0.16	0.32	1.85
23	17	7	0.15	0.41	0.12	0.16	1.09
24	10	10	0.09	1.00	0.04	0.04	0.50
25	0	0	0.00	0.00	0.00	0.00	0.00
$\sum$		116	13.33		12.83		

Table 3.2: Standard life expectancy for cattle (Oxen, Bulls)

Age x	Standard life expectancy (Oxen)	Standard life expectancy (Bulls)
0	13.15	12.34
1	12.59	11.64
2	12.02	11.09
3	11.45	10.53
4	10.78	9.96
5	10.19	9.39
6	9.59	8.82
7	8.98	8.23
8	8.36	7.79
9	7.74	7.35
10	7.02	6.92
11	6.65	6.50
12	6.23	6.10
13	5.59	5.72
14	5.08	5.38
15	4.41	4.70
16	3.93	4.17
17	3.62	3.80
18	3.40	3.30
19	3.13	3.00
20	2.61	2.83
21	2.35	2.30
22	1.97	1.75
23	1.33	1.17
24	0.50	0.50

standard life expectancy for bulls and oxen. For example if a bull aged 5 years, then its life expectancy at age 5 years is 9.39 years (See Table 3.2.). It is interesting to note that the standard life expectancy for cattle using the l_x table is greater than using statistical estimation based on the farmers' response.

3.3.3   Disability Weight

Disability defined as some form of inability to perform everyday tasks in a way that is usual for cattle. Disability weight is a weight function that reflects the severity of a cattle disease between 0 (perfect health) and 1 (equivalent to death). Each disability condition is assigned a number between 0 and 1 depending on the severity of the disease. Disability health outcomes of cattle diseases differ from each other in their causes, nature and the impact on the individual cattle. There is need to define and quantify disability in a framework that is both simple and clear to effectively put a measure on the duration of time lived with a disability. This assessment aids policy makers in making an all encompassing health policy.

We derived the definition of the disability weight for cattle from their social and economic values. This is because the sole purpose for keeping cattle is the benefits that humans derive from them. Therefore, we have formulated a definition of disability weight for cattle so that people can give each disease a specific number between 0 and 1. In this procedure, we ensure that any condition or disease that causes pain is weighted between 0 (perfect health) and 1 (equivalent to death). These weights are then grouped into four levels as illustrated in the third column of Table 3.3.

According to this data, we will be able to weigh the severity of a set of indicator disabling conditions, such as mastitis, rabies, anthrax and any condition that causes pain. We grouped these weights into four levels according to outcome of the impact of the disease. In level 1, we have perfect health. Level 2 has weights between 0.01 –

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0.33, level 3 is weighted between 0.34 – 0.66 and level 4 has weights between 0.67 – 0.99. If there is change of any of these parameters (milk production, drought power, etc.), then the disability weight should be changed. For example, assume that a dairy cow gets sick with a disease and the pain condition changes its milk production from 6 liters per day to 3 liters per day. Then the disability weight for this condition should be between 0.34 and 0.66.

We have used two questions from our questionnaire to incorporate disability weight for cattle population. We have chosen six parameters that we will use to evaluate the impact or severity of the disease on cattle. The parameters we considered are beef production, milk production, draught power, social status, dowry payment and cultural ceremonies. We asked farmers why they kept animals (Appendix A.2 q.2) and what was the impact of the diseases on cattle with respect to the six parameters (Appendix A.2 q.3, 12). These responses, taken together with other published data [24], enabled us to classify the impact of the diseases. The first question allowed us to find out the purpose of keeping the cattle with reference to our parameters and the second question revealed the impact of the disease in each parameter. Table 3.3 gives the general classification that we adopted as regards to how the disease affects the productivity derived from cattle.

For example, from questionnaire, a healthy fat animal was considered the most ideal for dowry. Among the factors cited as reducing value of animals for dowry, disease and deterioration in condition were prominent. A disease free animal but in poor condition was more acceptable compared to a diseased animal. These were put in disability weight category 2 and 3 respectively. A diseased animal with poor body condition was the least acceptable for dowry thus we put it into category 4 for the disability weight scale. From the literature [11], optimal beef productivity required a weight of 500 – 600 kg for oxen. This was classified as level 1 and the disability weight was 0. Based on this, a loss of 100 kg resulted in the animal dropping a level on the disability weight
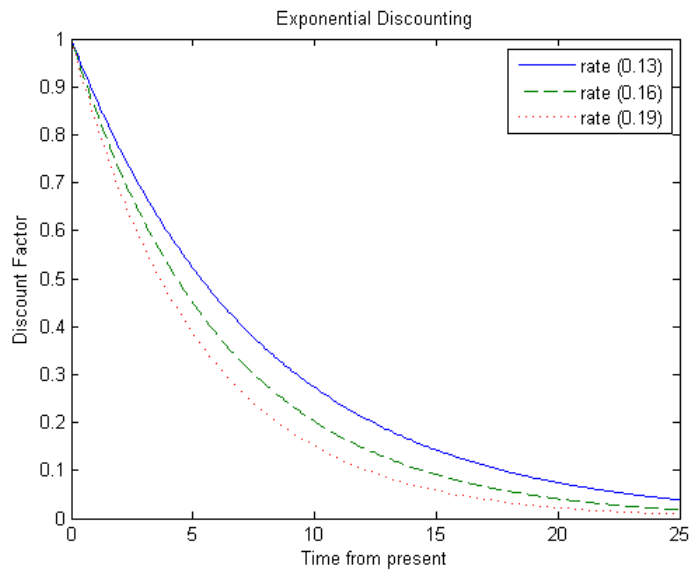
Figure 3.2: Effect of discounting

scale to level 2. Subsequent lowering of levels of disability weight were also by 100 kg weight increments.

3.3.4 Discounting

In this study, we will use the same discount function (exponential decay) used in the DALYs model for human population. However, we have to change the discount rate to be able to get the same effect of discounting in the number of years of life lost at a different time in the future.

Figure 3.2 shows the effect of discounting in the value of a year of life lost at different times in the future for cattle. For the purpose of calculation, the PALYs formulae for cattle uses a continuous function given by Eq.(2.4).

Table 3.3: Definition of disability weight (D_w) for cattle based on a questionnaire in Eastern Cape Province, South Africa (2013)

Levels	Description	D_w
1	1. Beef production [(500 − 600kg for oxen), (300 − 516kg for bulls), (320 − 440 kg for cows)]. 2. Milk production [5 − 6 litres per day]. 3. Draught power [3 − 5hrs for cows, 5 − 6hrs for oxen]. 4. Social status [acceptable]. 5. Dowry payment [acceptable]. 6. Cultural ceremonies [acceptable].	0
2	1. Beef production [(400 − 499kg for oxen), (260 − 299kg for bulls), (280 − 319kg for cows)]. 2. Milk production [3.5 − 4.9 litres per day]. 3. Draught power [2 − 3hrs for cows, 3 − 4hrs for oxen]. 4. Social status [not very acceptable for reason of loss of condition]. 5. Dowry payment [not very acceptable for reason of loss of condition]. 6. Cultural ceremonies [not very acceptable for reason of loss of condition].	0.01 − 0.33
3	1. Beef production [(300 − 399kg for oxen), (220 − 259kg for bulls), (200 − 239kg for cows)]. 2. Milk production [2 − 3.4 litres per day]. 3. Draught power [1 − 2hrs for cows, 2 − 3hrs for oxen]. 4. Social status [not acceptable for reason of being diseased]. 5. Dowry payment [not acceptable for reason of being diseased]. 6. Cultural ceremonies [not very acceptable for reason of being diseased].	0.34 − 0.66
4	1. Beef Production [(200 − 299kg For Oxen), (180 − 219kg For Bulls), (240 − 279kg For Cows)]. 2. Milk Production [1 − 1.9 litres per day]. 3. Draught Power [0 − 1hrs For Cows, 1 − 2hrs For Oxen]. 4. Social Status [not Acceptable For Reason Of Being Thin And Diseased]. 5. Dowry Payment [not Acceptable For Reason Of Being Thin And Diseased]. 6. Cultural Ceremonies [not Very Acceptable For Reason Of Being Thin And Diseased].	0.67 − 0.99
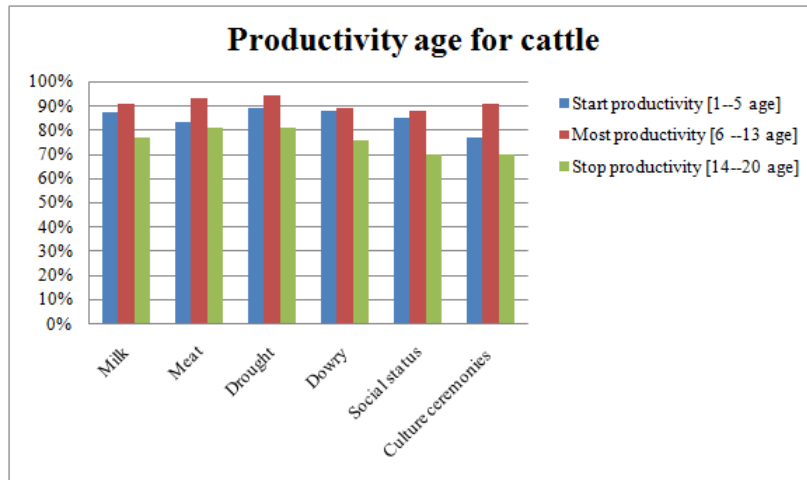
Figure 3.3: Productivity age for cattle based on a questionnaire in Eastern Cape Province, South Africa (2013)

3.3.5 Age-Weighting

Here we wished to determine the age at which cattle start and stop being useful. We asked farmers the age at which animals become productive in terms of meat, milk, draught power, social status, dowry and culture ceremonies (Appendix A.2 q.6, 7). Figure 3.3 represents their responses as a percentage of age productivity. This data shows the age of productivity of years of life for different types of products. For example, the percentage of cattle which start milk production between ages 1 to 5 is 87% and that of meat is 91%. According to our data it is clear that as a particular member of a cattle population grows towards the productive age, its life becomes more valuable (the age weight increase) until it reaches its maximum at the expected age of maximum productivity. Then as it gets older, its life gradually loses value (See Figure 3.4.).

Age weighting means that the life years of cattle are counted differently because cattle are more productive at a particular age than others. In this study, age-weight is based on the questionnaire which has indicated that there is a broad variation in

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economic and social values of cattle at different ages. The impact of lost years of a healthy life varies significantly with cattle ages; for instance lost years of healthy life during the productivity ages has a greater negative impact compared with lost years of healthy life during the very early age or late age. According to our data, we value years of healthy life lived during productive ages over early and late ages. This choice is very reasonable and it is made based on economic and social values. Using Figure 3.3 we require an age weighting curve as indicated in Figure 3.4. The relative value of a life year is below 0.8 for age under 5 as well as for cattle older than 13 years of age. This implies that, in the calculations, the value of a life year lost is weighted the same in both regions. The preference of productive ages shown by the function plotted in Figure 3.4 can be expressed mathematically as

$$R(x) = \beta_1 \, x \, e^{-\beta_2 \, x^2}, \tag{3.2}$$

where x is the age of the cattle, while β_1 and β_2 are parameters of the age weighting function. Fixing the maximum of $R(x) = 1$ (because we choose to take our age-weighting scale from zero to one) yields

$$\beta_1 = \sqrt{2\beta_2} \, e^{1/2}, \qquad \beta_2 > 0.$$

In the above equation, β_1 determines the importance of age-weights and is chosen arbitrarily; β_2 is an adjustment constant, chosen so that the introduction of age-weights does not alter the total number of years of life lost. The value of $\beta_1 = 0.2332$ and $\beta_2 = 0.01$ used in our PALY calculation.

3.4   Calculating PALYs for Cattle

PALYs for a disease or health condition are calculated as the sum of the years of life lost due to premature mortality YLL in the cattle population and the equivalent 'healthy'
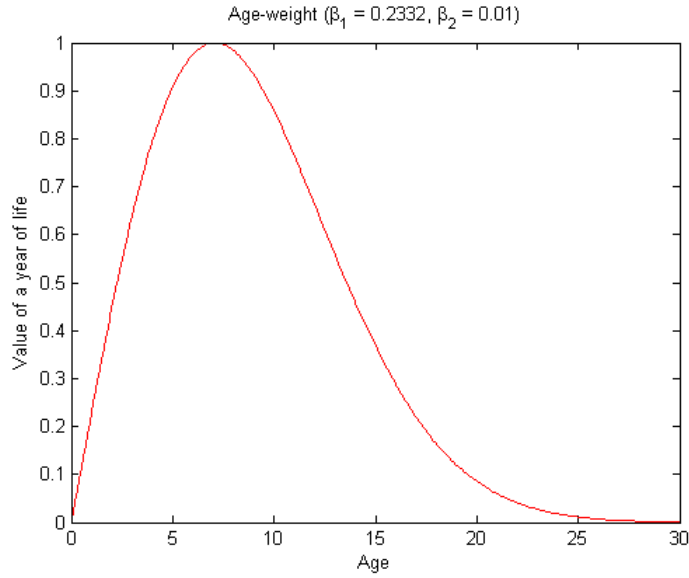
Figure 3.4: Values of productivity for cattle in different age groups based on a questionnaire in Eastern Cape Province, South Africa (2013)

years lost due to disability YLD for incident cases of the health condition:

$$\text{PALYs for cattle} = \text{YLL for cattle} + \text{YLD for cattle}. \tag{3.3}$$

The YLD and YLL can be calculated using three methods. These include without age weighting and discounting, discounting only and both discounting and age weighting.

3.4.1   Basic Formulas for YLD and YLL

The basic formula for YLD (without age weighting and discounting) is basically the product of the number of disability cases, the average duration of the disease and the disability weight. This translates to

$$\text{YLD for cattle} = N_i \times D_w \times I, \tag{3.4}$$

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where N_i is the number of incident cases, D_w is the disability weight, and I is the average duration of disability.

The basic formula for YLL (without age weighting and discounting) is defined as the product of the number of deaths and the standard life expectancy at the age of mortality. This becomes

$$\text{YLL for cattle} = N_d \times L, \tag{3.5}$$

where N_d is the number of deaths and L is the standard life expectancy at age of death. Note that both formulae do not change whether we refer to humans or animals. However, the parameters values are different.

We present the basic procedure for calculating PALYs for cattle by using a suitable example.

Example 3.4.1. Assume that, at the age of 8, a cow gets sick with red-water disease which disables it for a certain period of time but after treatment it is in remission for 2 years. After 2 years it suffers from an onset of the same disease which disables it substantially and it dies as a result at age 10.

We wish to calculate the PALYs for this cow. In order to do this we need to calculate the YLD and YLL. YLD: Assume that its disability is weighted as 0.4320 (disability weight for red-water). Since it lasts for 2 years $(10 - 8 \text{ years})$

$$\text{YLD for cattle} = 1 \times 2 \times 0.4320 = 0.86 \, \text{years} \, (\approx 9 \, \text{months}).$$

YLL: From Table 3.1, the cow that dies at age of 10 loses 8.22 years of expected life. Using Eq.(3.3), the PALYs for the cow in question becomes

$$\text{PALYs for cow} = 0.86 + 8.22 = 9.08 \, \text{years}.$$

In this case, the number of PALYs lost due to the burden of disease is 9.08 years. This is the total productive time lost due to disability and premature death.

3.4.2 YLD and YLL with Discounting

The second method for calculating YLD and YLL considers the discount function. We obtain the formula for YLD by multiplying Eq.(2.4) and Eq.(3.4):

$$\text{YLD for cattle} = N_i \times D_w \times I \times G(x), \tag{3.6}$$

where $G(x)$ is the discounting function. The total discounting in the continuous-time case is given by

$$\text{TD} = \int_{a_i}^{a_i+I} e^{-r(x-a_i)} dx, \tag{3.7}$$

where a_i is the age of onset. By substituting Eq.(3.7) into Eq.(3.6), the total YLD in the continuous-time case becomes

$$\text{YLD for cattle} = \int_{a_i}^{a_i+I} N_i D_w e^{-r(x-a_i)} dx, \tag{3.8}$$

which evaluates to

$$\text{YLD for cattle} = \frac{N_i D_w [1 - e^{-rI}]}{r}, \tag{3.9}$$

where r is the discount rate.

Similarly, to find a formula for the years of life lost due to premature mortality YLL, we can simply modify Eq.(3.9) by setting the disability weight to 1 ($D_w = 1$) and replacing the average duration of disease (I) by the standard life expectancy at the age of death (L). The YLL formula is then

$$\text{YLL for cattle} = \frac{N_d [1 - e^{-rL}]}{r}, \tag{3.10}$$

where N_d is the number of death.

We revert to Example 3.4.1 this time taking discounting into account. First we shall calculate YLD for the cow:

$$\text{YLD} = \frac{1 \times 0.4320 \times [1 - e^{-(0.13 \times 2)}]}{0.13} = 0.76 \text{ years.}$$

In terms of YLL for the cow, we substitute standard life expectancy for cow at age 10 from Table 3.1 ($L = 8.22$) to obtain

$$\text{YLL} = \frac{1 \times [1 - e^{-(0.13 \times 8.22)}]}{0.13} = 5.05 \text{ years.}$$

Finally the YLD and the YLL are summed up according to Eq.(3.3) to obtain

$$\text{PALYs} = 0.76 + 5.05 = 5.81 \text{ years.}$$

The burden of disease in this case in terms of PALYs is 5.81 years. Taking discounting into consideration has reduced the productive time lost due to disability and premature death from 9.08 years to only 5.81 years.

3.4.3 YLD and YLL with Discounting and Age-Weighting

The YLD value of any disability weight (D_w) with discounting function, age-weighting function and number of disease cases (N_i), is given as:

$$\text{YLD for cattle} = N_i \times D_w \times G(x) \times R(x), \tag{3.11}$$

where $G(x)$ is the discounting function and $R(x)$ is the age-weighting function.

To calculate the YLD that accounts for the duration of life lost due to disability, duration from the age of onset, we simply integrate the disability weight times the age weight and discount function over the expected period of the disability. By substituting Eq.(3.7) and Eq.(3.2) into Eq.(3.11), we yield

$$\text{YLD for cattle} = \int_{a_i}^{a_i+I} N_i D_w \beta_1 x e^{-\beta x^2} e^{-r(x-a_i)} dx, \tag{3.12}$$

where I is average duration of disability and a_i is the age of onset. Eq.(3.12) can be

evaluated as

$$\text{YLD for cattle} = N_i \, D_w \, \beta_1 \, e^{a_i r} \left[\sqrt{\pi} r e^{\frac{r^2}{4\beta_2}} \left(-\frac{\text{erf}\left(\frac{2\beta_2(a_i+I)+r}{2\sqrt{\beta_2}}\right) + \text{erf}\left(\frac{2\beta_2 a_i + r}{2\sqrt{\beta_2}}\right)}{4\sqrt{\beta_2^3}} \right) \right.$$

$$\left. + \left(\frac{-e^{-(a_i+I)(\beta_2(a_i+I)+r)} + e^{-a_i(\beta_2 a_i + r)}}{2\beta_2} \right) \right], \tag{3.13}$$

where N_i is the number of incident cases, D_w is the disability weight, I is the average duration of disability, r is the discount rate, a_i is the age of onset and erf is the error function. Typical values of β_1 and β_2 are 0.2332 and 0.01 respectively.

Similarly, by replacing the duration of disease (I) with the standard life expectancy (L), the age onset (a_i) with the age of death (a_d), and setting the disability weight to one in Eq.(3.13), we obtain the YLL formula as

$$\text{YLL for cattle} = N_d \, \beta_1 \, e^{a_d r} \left[\sqrt{\pi} \, r e^{\frac{r^2}{4\beta_2}} \left(-\frac{\text{erf}\left(\frac{2\beta_2(a_d+L)+r}{2\sqrt{\beta_2}}\right) + \text{erf}\left(\frac{2\beta_2 a_d + r}{2\sqrt{\beta_2}}\right)}{4\sqrt{\beta_2^3}} \right) \right.$$

$$\left. + \left(\frac{-e^{-(a_d+L)(\beta_2(a_d+L)+r)} + e^{-a_d(\beta_2 a_d + r)}}{2\beta_2} \right) \right], \tag{3.14}$$

where N_d is the number of deaths, a_d is the age of death, L is the standard life expectancy at age of death.

Now we return to Example 3.4.1 to calculate PALYs considering age weighting and discounting.

YLD: By substituting the values $a_i = 8$, $I = 2$, $r = 0.13$, $D_w = 0.432$ and $N_i = 1$

into Eq.(3.13), the YLD is

$$\text{YLD for the cow} = 0.20 \left(-0.25 \times \frac{\text{erf}\left(\frac{2\times 0.01\times (8+2)+0.13}{2\sqrt{0.01}} \right) + \text{erf}\left(\frac{2\times 0.01\times 8+0.13}{2\sqrt{0.01}} \right)}{4\sqrt{0.01^3}} \right)$$

$$+ 0.20 \left(\frac{-e^{-(8+2)(0.01\times(8+2)+0.13)} + e^{-8(0.01\times 8+0.13)}}{2 \times 0.01} \right)$$

$$= 1.49 \text{ years.}$$

Similarly, YLL is calculated by substituting $a_d = 10$, $L = 8.22$, $r = 0.13$ and $N_d = 1$ into Eq. (3.14) to yield

$$\text{YLL for the cow} = 0.60 \left(-0.133 \times \frac{\text{erf}\left(\frac{2\times 0.01(10+8.22)+0.13}{2\sqrt{0.01}} \right) + \text{erf}\left(\frac{2\times 0.01\times 10+0.13}{2\sqrt{0.01}} \right)}{4\sqrt{0.01^3}} \right)$$

$$+ 0.60 \left(\frac{-e^{-(10+8.22)(0.01\times(10+8.22)+0.13)} + e^{-10\times(0.01\times 10+0.13)}}{2 \times 0.01} \right)$$

$$= 6.51 \text{ years.}$$

By using Eq.(3.3), the number of PALYs for the cow is

$$\text{PALYs for the cow} = 1.49 + 6.51 = 8.00 \text{ years.}$$

Taking both age weighting and discounting into account has resulted into the productive time lost due to disability and premature death to now lie somewhere inbetween the previous two values (Table 3.4.).

3.5 Summary

In this chapter, we calculated the standard life expectancy for cattle and defined the disability weight for cattle diseases. In addition, we shed light on the age weighting

Table 3.4: Summary of results Example 3.4.1

Scenario	Age weighting	Discount rate	YLD	YLL	PALYs
PALYs [0; 0]	No	0	0.86	8.22	9.08
PALYs [0; 0.13]	No	0.13	0.76	5.05	5.81
PALYs [1; 0.13]	Yes	0.13	1.49	6.51	8.00

of cattle. Furthermore, we built a new model for cattle populations to assess to burden of diseases. We demonstrated the applicability of our model with a worked out example. The example clearly illustrated the value in incorporating age weighting and discounting into a realistic PALYs model.

Chapter 4

Results and Discussion

4.1 Introduction

In this Chapter, we will show how to calculate PALYs for a group of cows, oxen and bulls with different levels of disabilities. To assess the impact of ticks and tick-borne diseases (T and TBDs), we will apply the PALYs model for these animals taking into account discounting and age weighting (See Chapter 3.). We will also show how many PALYs can be averted when the ticks are controlled.

In the data collection, we found out the most common causes of cattle mortality (Appendix A.2 q.8). Figure 4.1 represents the responses as a percentage of the most common causes of cattle mortality. We found that the typical percentages are 32%, 24%, 22% and 21% of deaths were due to old age, disease, drought and theft respectively. According to the data, disease is the second most common cause of cattle mortality consistent with the findings of Mapiye [24]. Our application and analysis will use PALYs model to assess the burden of ticks and tick-borne diseases.

We also asked farmers to indicate the number of animals that died due to disease
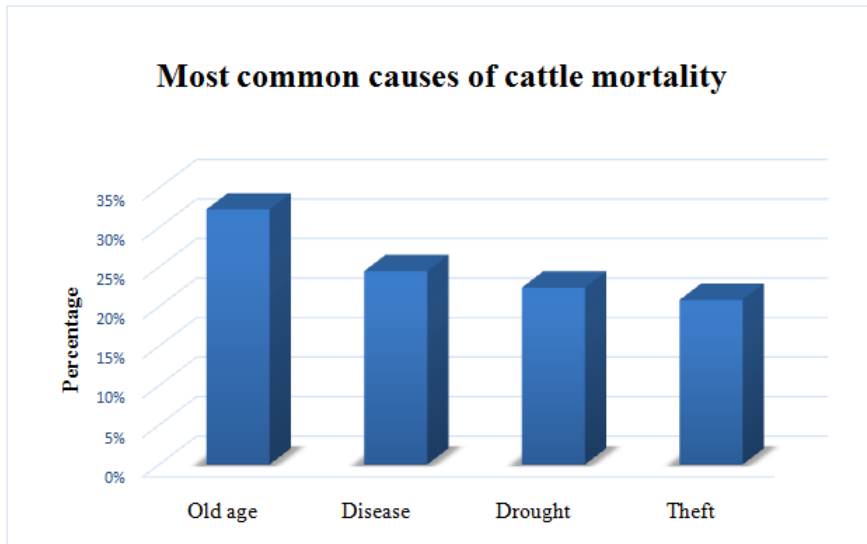
Figure 4.1: Most common causes of cattle mortality based on a questionnaire in Eastern Cape Province, South Africa (2013)

(Appendix A.2 q.22) and at what age this occurred (Appendix A.2 q.23). From the first question we found that a total of 116, 124, 86 deaths of cows, oxen, bulls occurred. However, the second set of responses were unclear. Again we decided to theoretically estimate the number of animals (cows, oxen and bulls) that died at various ages using a survival distribution function [9]. Table 4.1 contains sample data (the number of dead animals in each group). In the sections below, we will use our sample data in Table 4.1 to estimate PALYs for each of the animal population in this region. For each of the three animal types, the calculation will be divided into three tables according to severity of the disease (levels of disability weight, D_w) in each table.

The calculation of PALYs requires estimates for the average duration of disability and age of onset (the age specific incidence) in case of YLD. It also requires the age of death due to individual disease and standard life expectancy at age of death in case of YLL. The conceptual and computational details of how YLD and YLL for individual conditions are estimated have been presented in Chapter 3. To compute PALYs, we

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Table 4.1: The number of dead animals in each age-group based on a questionnaire in Eastern Cape Province, South Africa (2013)

Age group	Cows	Oxen	Bulls
0 - 4	6	6	4
5 - 9	17	19	13
10 - 14	23	25	17
15 - 19	29	31	22
20 +	41	43	31
Total	116	124	86

simply sum YLD and YLL together.

4.2   Calculation of PALYs for Cows: No controls

In this section, we will use our sample data in Table 4.1 to estimate PALYs for the cow population in this region at disability levels 2, 3 and 4. In the tables that follow:

- N_i - the number of cows infected by the disease in each group,

- a_i - average age of onset for group of animals (in this case cows),

- N_d - the number of death animals (in this case cows),

- a_d - age of death,

- L - standard life expectancy at age of death,

- D_w - disability weight,

Table 4.2: Calculation of PALYs for cows with $D_w = 0.33$

Age group	N_i	a_i	I	D_w	YLD	N_d	a_d	L	YLL	PALYs
0 - 4	6	2	1	0.33	4.18	6	3	11.51	71.14	75.32
5 - 9	17	7	1	0.33	11.77	17	8	9.29	141.41	153.18
10 - 15	23	12	1	0.33	10.88	23	13	7.01	92.94	103.82
16 - 20	29	18	1	0.33	7.75	29	19	3.50	20.51	28.26
20 +	41	20	1	0.33	2.06	41	21	1.50	7.56	9.62
Total	116				36.64	116			333.56	370.20

- I - duration of the disease.

In our calculations we assumed D_w and I to be constants for each animal type at a given level of disability. This is because, for D_w, we assume that all the animals are affected by the same disease, and in the case of I, that it is not easy for the farmer to estimate the average time an animal spends with the disease before it dies.

In Table 4.2 we calculate YLD, YLL and PALYs with $D_w = 0.33$. At this level, the number of years of life lived with disability is on average 0.32 years (approximately 3 months and 3 weeks). The years of life lost due to premature mortality is approximately 2.88 years (approximately 35 months). The number of PALYs lost for the 116 cows when in level 2 is 370.20 years. So on average, a farmer loses 3.18 years (approximately 38 months and 3 weeks) of productivity per cow due to fatality of the disease.

Table 4.3 shows the numbers of YLD, YLL and PALYs lost for the 116 cows when $D_w = 0.52$. At this level, the number of years of life lived with disability is on average 0.45 years (approximately 5 months and 2 weeks). The years of life lost due to premature mortality is approximately 2.88 years (approximately 35 months). The

Table 4.3: Calculation of PALYs for cows with $D_w = 0.52$

Age group	N_i	a_i	I	D_w	YLD	N_d	a_d	L	YLL	PALYs
0 - 4	6	2	1	0.52	6.08	6	3	11.51	71.14	77.22
5 - 9	17	7	1	0.52	17.48	17	8	9.29	141.41	158.89
10 - 14	23	12	1	0.52	16.16	23	13	7.01	92.94	109.10
15 - 19	29	18	1	0.52	7.06	29	19	3.50	20.51	27.57
20 +	41	20	1	0.52	5.20	41	21	1.50	7.56	12.76
Total	116				51.98	116			333.56	385.54

Table 4.4: Calculation of PALYs for cows with $D_w = 0.84$

Age group	N_i	a_i	I	D_w	YLD	N_d	a_d	L	YLL	PALYs
0 - 4	6	2	1	0.84	9.83	6	3	11.51	71.14	80.97
5 - 9	17	7	1	0.84	28.24	17	8	9.29	141.41	169.65
10 - 15	23	12	1	0.84	26.10	23	13	7.01	92.94	119.04
16 - 20	29	18	1	0.84	11.40	29	19	3.50	20.51	31.91
20 +	41	20	1	0.84	8.41	41	21	1.50	7.56	15.97
Total	116				83.98	116			333.56	417.54

number of PALYs lost for 116 cows is 385.54 years, therefore the average PALYs lost per cow is 3.33 years (approximately 40 months and 2 weeks).

Table 4.4 shows the calculation of PALYs lost for 116 cows when considering disability weight from level 4 ($D_w = 0.84$). At this level, the number of years of life lived with disability is on average 0.72 years (approximately 8 months and 3 weeks). The years of life lost due to premature mortality is approximately 2.88 years (approximately 35 months). The number of PALYs lost for 116 cows is 417.54 years, therefore

Table 4.5: Calculation PALYs for 116 cows with tick control

Age group	N_i	a_i	I	D_w	YLD	PALYs
0 - 4	6	2	11.94	0.10	6.17	6.17
5 - 9	17	7	9.70	0.10	13.96	13.96
10 - 15	23	12	7.38	0.10	10.51	10.51
16 - 20	29	18	4.80	0.10	4.06	4.06
20 +	41	20	2.90	0.10	2.83	2.83
Total	116				37.53	37.53

the average PALYs lost per cow is 3.60 years (approximately 43 months 3 weeks). This is equivalent to 23% of a cow's life expectancy at birth.

4.3 Calculation of PALYs for Cows: Tick control

So far we have calculated the PALYs lost for different D_ws without considering tick control. Now we would like to calculate the number of PALYs that would have been averted when tick control is considered leading to a reduction in TBDs, i.e., if the cows were medicated. In what follows we assume that the cows received treatment for their disease at the age of onset (a_i), and as a result did not die at the age of death (a_d), but lived for their expected life span at the age a_i (in the treated state). With these assumptions, the disability weight for the treated disease is 0.10. Now we only need to calculate YLD with treatment. This is achieved by changing the disability weight for the treated form of the disease from 0.33 or 0.52 or 0.84 (without treatment) to 0.10 (with treatment). In this case the cows (and the other animals in general) would have lived for their expected life at age of onset.

Table 4.6: Calculation PALYs averted per cow

D_w	PALYs (treatment)	PALYs (no treatment)	PALYs averted
0.35	3.18 yrs	0.32 yrs	2.86 yrs
0.52	3.31 yrs	0.32 yrs	2.99 yrs
0.84	3.56 yrs	0.32 yrs	3.34 yrs

Table 4.7: Calculation of PALYs for oxen with $D_w = 0.33$

Age group	N_i	a_i	I	D_w	YLD	N_d	a_d	L	YLL	PALYs
0 - 4	6	2	1	0.33	4.09	6	3	11.45	71	75.09
5 - 9	19	7	1	0.33	11.77	19	8	8.36	138	149.77
10 - 15	25	12	1	0.33	10.87	25	13	5.59	87.17	98.04
16 - 20	31	18	1	0.33	4.75	31	19	3.13	19.95	24.70
20 +	43	20	1	0.33	2.47	43	21	2.35	8.30	10.77
Total	124				33.95	124			324.24	358.37

Table 4.5 shows the PALYs calculations with tick control. The PALYs lost per cow during the treatment is 0.32 years (approximately 3 months and 26 days). In Table 4.6 we present the PALYs with and without treatment for the individual cattle (cow). In the last column we highlight the PALYs averted as a result of the tick control.

4.4 Calculation of PALYs for Oxen: No controls

In this section, our aim is to use sample data in Table 4.1 to estimate PALYs for the oxen population in this region beginning with levels 2, 3 and lastly 4.

Table 4.7 shows the numbers of YLD, YLL and PALYs lost for the 124 oxen when

Table 4.8: Calculation of PALYs for oxen with $D_w = 0.52$

Age group	N_i	a_i	I	D_w	YLD	N_d	a_d	L	YLL	PALYs
0 - 4	6	2	1	0.52	6.08	6	3	11.45	71	77.08
5 - 9	19	7	1	0.52	17.48	19	8	8.36	138	155.48
10 - 15	25	12	1	0.52	16.15	25	13	5.59	87.17	103.32
16 - 20	31	18	1	0.52	7.05	31	19	3.13	19.95	27.00
20 +	43	23	1	0.52	5.20	43	21	2.35	8.30	13.50
Total	124				51.96	124			324.42	376.38

$D_w = 0.33$. At this level, the number of years of life lived with disability is on average 0.27 years (approximately 3 months and a week). The years of life lost due to premature mortality is approximately 2.61 years (approximately 31 months and 2 weeks). The number of PALYs lost for the 124 oxen in level 2 is 358.37 years. So on average, a farmer loses 2.88 years (approximately 34 months and 3 weeks) of productivity per ox due to fatality of the disease.

Table 4.8 shows the numbers of YLD, YLL and PALYs lost for the 124 oxen when $D_w = 0.52$. At this level, the number of years of life lived with disability is on average 0.42 years (approximately 5 months). The years of life lost due to premature mortality is approximately 2.61 years (approximately 31 months and 2 weeks). The number of PALYs lost for the 124 oxen in level 3 is 376.38 years. So on average, a farmer loses 3 years (approximately 36 months and 2 weeks) of productivity per ox due to fatality of the disease.

Table 4.9 shows the numbers of YLD, YLL and PALYs lost for the 124 oxen when $D_w = 0.84$. At this level, the number of years of life lived with disability is on average 0.67 years (approximately 8 months). The years of life lost due to premature mortality

Table 4.9: Calculation of PALYs for oxen with $D_w = 0.84$

Age group	N_i	a_i	I	D_w	YLD	N_d	a_d	L	YLL	PALYs
0 - 4	6	2	1	0.84	9.83	6	3	11.45	71	80.83
5 - 9	19	7	1	0.84	28.24	19	8	8.36	138	166.24
10 - 15	25	12	1	0.84	26.10	25	13	5.59	87.17	113.27
16 - 20	31	18	1	0.84	11.40	31	19	3.13	19.95	31.35
20 +	43	20	1	0.84	8.41	43	21	2.35	8.30	16.71
Total	124				83.98	124			324.42	408.40

is approximately 2.61 years (approximately 31 months and 2 weeks). The number of PALYs lost for the 124 oxen in level 4 is 408.40 years. So on average, a farmer loses 3.29 years (approximately 39 months and 2 weeks) of productivity per ox due to fatality of the disease.

4.5 Calculation of PALYs for Oxen: Tick control

Here we would like to determine how many PALYs for 86 bulls will be averted when tick control is considered. Our calculation will be similar to §4.3.

Table 4.10 shows us the PALYs lost from 124 oxen with tick control. The PALYs lost per ox during the tick control is 0.29 years (approximately 3 months and 18 days). In Table 4.11 we present the PALYs with and without tick control for the individual cattle (ox). In the last column we highlight the PALYs averted as a result of the tick control.

Table 4.10: Calculation of PALYs for oxen with tick control

Age group	N_i	a_i	I	D_w	YLD	PALYs
0 - 4	6	2	12.02	0.10	6.20	6.20
5 - 9	19	7	8.98	0.10	14.95	14.95
10 - 15	25	12	6.23	0.10	11.48	11.48
16 - 20	31	18	3.40	0.10	2.81	2.81
20 +	43	20	2.61	0.10	1.65	1.65
Total	124					37.09

Table 4.11: Calculation of PALYs averted per ox

D_w	PALYs (no treatment)	PALYs (treatment)	PALYs averted
0.35	2.80 yrs	0.29 yrs	2.51 yrs
0.52	3 yrs	0.29 yrs	2.69 yrs
0.84	3.29 yrs	0.29 yrs	3 yrs

4.6 Calculation of PALYs for Bulls: No controls

In this section we will calculate the number of PALYs lost for 86 bulls. Our aim to determine how many PALYs are averted when considering treatment.

Table 4.12 shows the calculation of PALYs lost for 86 bulls when considering disability weight from level 2 ($D_w = 0.33$). At this level, the number of years of life lived with disability is on average 0.39 years (approximately 4 months and 3 weeks). The years of life lost due to premature mortality is approximately 3.72 years (approximately 44 months and 2 weeks). The number of PALYs lost for 86 bulls is 354.08 years , therefore the average PALYs lost per bulls is 4.11 years. So on average, a farmer loses

Table 4.12: Calculation of PALYs for bulls with $D_w = 0.33$

Age group	N_i	a_i	I	D_w	YLD	N_d	a_d	L	YLL	PALYs
0 - 4	4	2	1	0.33	4.09	4	3	10.53	69.48	73.57
5 - 9	13	7	1	0.33	11.77	13	8	7.79	134.85	146.62
10 - 15	17	12	1	0.33	10.87	17	13	5.72	87.85	98.72
16 - 20	22	18	1	0.33	4.75	22	19	3.00	19.64	24.39
20 +	30	20	1	0.33	2.47	30	21	2.30	8.31	10.78
Total	86				33.95	86			320.13	354.08

Table 4.13: Calculation of PALYs for bulls with $D_w = 0.52$

Age group	N_i	a_i	I	D_w	YLD	N_d	a_d	L	YLL	PALYs
0 - 4	4	2	1	0.52	6.08	4	3	10.53	69.48	75.56
5 - 9	13	7	1	0.52	17.48	13	8	7.79	134.85	152.33
10 - 15	17	12	1	0.52	16.15	17	13	5.72	87.85	104
16 - 20	22	18	1	0.52	7.05	22	19	3.00	19.64	26.69
20+	30	23	1	0.52	5.20	30	21	2.30	8.31	13.51
Total	86				51.96	86			320.13	372.09

4.11 years (approximately 49 months and 1 weeks) of productivity per bull due to fatality of the disease.

Table 4.12 shows the calculation of PALYs lost for 86 bulls when considering disability weight from level 3 ($D_w = 0.52$). At this level, the number of years of life lived with disability is on average 0.60 years (approximately 7 months). The years of life lost due to premature mortality is approximately 3.72 years (approximately 44 months and 2 weeks). The number of PALYs lost for 86 bulls is 372.09 years, therefore

Table 4.14: Calculation of PALYs for bulls with $D_w = 0.84$

Age group	N_i	a_i	I	D_w	YLD	N_d	a_d	L	YLL	PALYs
0 - 4	4	2	1	0.84	9.83	4	2	10.53	69.48	79.31
5 - 9	13	7	1	0.84	28.24	13	7	7.79	134.85	163.09
10 - 15	17	12	1	0.84	26.10	17	12	5.72	87.85	113.95
16 - 20	22	18	1	0.84	11.40	22	19	3.00	19.64	31.04
21 - 25	31	23	1	0.84	8.41	41	31	2.30	8.31	16.72
Total	86				83.98	86			320.13	404.11

the average PALYs lost per bulls is 4.33 years. So on average, a farmer loses 4.33 years (approximately 51 months and 2 weeks) of productivity per bull due to fatality of the disease.

Table 4.12 shows the calculation of PALYs lost for 86 bulls when considering disability weight from level 4 ($D_w = 0.84$). At this level, the number of years of life lived with disability is on average 0.98 years (approximately 11 months and 2 weeks). The years of life lost due to premature mortality is approximately 3.72 years (approximately 44 months and 2 weeks). The number of PALYs lost for 86 bulls is 372.09 years, therefore the average PALYs lost per bulls is 4.70 years (approximately 56 months). So on average, a farmer loses 4.70 years of productivity per bull due to fatality of the disease.

4.7 Calculation of PALYs for Bulls: Tick control

Here we also would like to determine how many PALYs for 86 bulls will be averted when tick control is considered. Our calculation will be similar to §4.3 and §4.5.

Table 4.15: Calculation of PALYs for bulls with Tick control

Age group	N_i	a_i	I	D_w	YLD	PALYs
0 - 4	4	2	11.09	0.10	7.19	7.19
5 - 9	13	7	8.23	0.10	14.90	14.90
10 - 15	17	12	6.10	0.10	11.59	11.59
16 - 20	22	18	3.30	0.10	2.60	2.60
20 +	30	20	2.83	0.10	1.71	1.71
Total						37.99

Table 4.16: Calculation of PALYs averted per bull

Disability Weight	PALYs (no treatment)	PALYs (treatment)	PALYs averted
0.35	4.11 yrs	0.44 yrs	3.67 yrs
0.52	4.33 yrs	0.44 yrs	3.89 yrs
0.84	4.69 yrs	0.44 yrs	4.25 yrs

Table 4.15 shows us the PALYs lost from 86 bulls when considering treatment. The PALYs lost per bull during the treatment is 0.44 years (approximately 5 months and a week). Table 4.16 shows us the PALYs averted calculation per bull in various levels of disability.

4.8 Discussion

From our analysis, approximately 26% of productivity years of a cow are lost due to burden of ticks and tick-borne diseases. However, introducing tick control reduces the loss to approximately 3% of their life expectancy productivity. Thus tick control will

save around 23% of years of productive life of cows. In case of oxen, approximately 23% of productivity years of oxen are lost due to burden of ticks and tick-borne diseases. However, introducing tick control reduces the loss to approximately 2% of their life expectancy productivity. Thus tick control will save around 21% of years of productive life of oxen. In case of bulls, approximately 35% of productivity years of bulls are lost due to burden of ticks and tick-borne diseases. However, introducing tick control reduces the loss to approximately 3% of their life expectancy productivity. Thus tick control will save around 32% of years of productive life of bulls. We hope encouraging the use of ticks and tick-borne control early enough will improve cattle productivity and hence welfare in rural communities.

In calculating PALYs for burden of ticks and tick-borne disease, we have seen that our calculations required many estimates associated with the PALYs calculation (e.g., the age at onset a_i, expected age of death with and without treatment a_d and the duration of the disability I) and assumptions (disability weight D_w with and without treatment, choice of age weight and at what rate, choice of discounting and at what rate r). All these decisions affect the difference in PALYs with and without treatment. Our application was also able to show the relative contribution of YLL and YLD to total PALYs. Presentation of the full calculation also allows others to insert alternative values to re-estimate PALYs. This would be particularly helpful if, for example, we wished to generalize the results to another setting where life expectancy differed, or where disability resulting from the condition was considered to be better or worse.

Chapter 5

Conclusion

In this thesis, we studied the general impact of burden of the diseases on human population and its measurement using DALYs model. We adapted the model to study the impact of the burden of disease on cattle populations. The importance of the social and economic values of human health and cattle health population were discussed.

We presented two models for assessment of the burden of diseases. The first model presented in Chapter 2, describes the dynamics of estimating years of life lost due to disability and premature mortality. We presented an example to show how DALYs could be calculated to assess burden of disease on human population. In Chapter 3, we formulated a relatively new model (PALYs) to assess the burden of diseases on cattle population. In Chapter 4, we applied the new model to specific data (we have designed a questionnaire to formulate our new model and to obtain data) to assess burden of ticks and tick-borne diseases on the cattle population in resource-poor communities in the province of Eastern Cape, South Africa.

Our study provides an illustration of methods for assessing productivity adjusted life years and for measuring the outcomes of health interventions in terms of PALYs. The calculation in different disease areas have shown that age of disease onset is an

important factor determining variation of number of PALYs averted. The pattern of variation is mostly dictated by the shape of the age weighting function. PALYs is decreased when disease starts in the very early years of life (or in the older ages of life) and is of short duration. It is increased when the disease starts in later years of life up to old ages. These conclusions are based on the use of the age weighting function originally proposed in this research (See chapter 3.). The results would have been different if we had made use of a different age weighting function.

This thesis illustrates calculation methods of assessing productivity adjusted life years for measuring outcomes of health problem in term of PALYs. This calculation is helpful in cost-effective analysis [16], in particular when researchers want to compare different programs for the same disease. The cost-effectiveness calculation is particularly useful when relating different programs that are focusing on the same disease or goal. We hope our analysis is helpful in aiding communities to determine the productivity of their cattle populations.

Appendices

Appendix A

Questionnaire Sheet

A.1   Consent Form

DEPARTMENT OF MATHEMATICS

UNIVERSITY OF KWAZULU-NATAL

COLLEGE OF AGRICULTURE, ENGINEERING AND SCIENCE

Name of Project: Modeling the Burden of Disease for Cattle.

CONSENT FORM

Name of Principal Investigator: Omran Salih.

Co-investigator: Dr S. Chitanga

Name of Organization: College of Agriculture, Engineering and Science.

Name of Sponsor: University of KwaZulu-Natal.

Introduction

I am a masters student at University of KwaZulu-Natal and I am conducting research

on the economic impact of cattle diseases in livestock communities in South Africa. In this research I will have discussions with you as a participant and explain to you the study. Once you have heard about the study you may then ask questions for clarifications.

After you have heard about the study, and if you agree to participate I will ask you to show your willingness before we can begin. If there is some information that you do not understand or do not feel comfortable with, please ask us to stop as we go through the information and we will take time to explain. If you have questions later, you can ask them from me or from the co-investigator.

Purpose

Cattle health has both direct and indirect impacts on human welfare. However, the economic cost of cattle health and disease has not been determined. The purpose of this project is to determine this and show the economic impact of cattle on communities.

Type of Research Intervention

We will be interviewing participants using a structured questionnaire.

Selection of Participants

You have been selected to participate in this study because you live in this area and you might have experienced economic impact of cattle diseases.

Voluntary Participation

You do not have to agree to participate in this study. You can choose to say no and any services that you and your family receive in this community will not change. You can ask as many questions as you like and I will take the time to answer them.

Project Procedure

This interview will be guided by me or co-investigator (Dr Chitanga). We will ensure that you are comfortable before we start the interview and we will answer all the questions that you might have regarding this study. Our questions will mainly be focusing

on your understanding of the social and economic impact of cattle disease, the most common diseases and the most common cause of mortality.

These questions do not contain any personal information related to participant. The information answered is confidential, and no one else except the researcher will be allowed to read the questionnaire. The questionnaires will be destroyed after writing of the final report.

Duration

I am asking you to participate in this activity which will take about 15 to 20 minutes. I will do this at times that are convenient to you.

Risks and/or discomfort

There is no risk to participate in this interview. However, the project involves collection of data on your basic knowledge about cattle of disease, social values and economic values.

Benefits

There will be no immediate and direct benefit to you, but your participation is likely to help us find out more about the impact of cattle disease and the general health and livelihoods of the community. The information will help other related stakeholders, policy makers and Ministers to meet your needs and those of the community where you live.

Re-imbursement

You will not be provided with any payment to participate in this study but your participation is likely to help us to understand the impact of cattle disease on the health of the people in this community to ensure better ways of addressing these environmental problems in the future.

Confidentiality

All data will be kept securely in the private office of the principle investigator and will not be given to anyone outside the study and your name will not be used in any data

collection form or report.

Sharing of Research Findings

Nothing that you tell us today will be shared with anybody outside the research team, and nothing will be attributed to you by name. I will also publish the results in order that other interested people may learn from our research.

Right to refuse or withdraw

Your participation in this project is completely voluntarily. If you don't like to give your opinion on certain issues and if you don't feel like answering questions during the interview you may feel completely free to refuse to answer. In case, you choose not to continue to be active in the project, you are free to withdraw from the collaboration at any time and it will not affect your position in the community or cause you to lose benefits you would otherwise be entitled to.

Who to contact

You have the rights and opportunity to ask any questions you might have regarding this study. You are free to contact the Principal Investigator Mr. Omran Salih College of Agriculture, engineering and science, University of KwaZulu-Natal omran@aims.ac.za or you may contact/call: 0610515048.

Certificate of consent

I have read the information provided above or it has been read to me in a language which I understand. I have had the opportunity to ask questions about the project and they have been answered to my satisfaction. I voluntarily agree to collaborate in this project.

Signature of the participant   Date

Signature of the researcher conducting the study   Date

Print name of witness for illiterates ....

participant...................

Signature of witness...................

Date........................

Statement by the researcher/person taking consent

I have accurately read out the information sheet to the participant, and to the best of my ability made sure that the person understands that questions will be asked about impact of cattle disease in the communities.

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by him/her have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

A copy of this Informed Consent Form has been provided to the participant

Print Name of Researcher/person taking the consent ....

An Informed Assent Form will .... OR will not .... be completed.

A.2   Questionnaire

Questionnaire number: .... Community name: ....

Enumerator name: .... Name of respondent:....................

Municipality name: .... Date:...

1. How many animals do you have?

Class	Cows	Oxen	Bulls
Number			

2. Why do you keep animals?

Monetary/Commercial value	Rank (5-highest & 1-least)	Social value	Rank (5-highest & 1-least)
Meat/Growth		Social status	
Milk		Dowry	
Drought power		Cultural ceremonies	
sale		Other (specify)	

3. What characteristics do you use to assess the general condition of your animals?

Characteristic	Rank/Importance in classification (5-high & 1-least)

4. What is the general condition of your animals?

Excellent	Good	Poor	very poor

5. How long do your animals usually live?

Class	Cows	Oxen	Bulls
Age			

6. At what age do animals become productive for each of the following product series, indicate the age when your animals start and, stop being useful. Also indicate that is most useful?

Monetary/Commercial value	Start	Most useful	Stop
Meat/Growth			
Milk			
Drought power			
sale			

7. At what age do animals become productive for each of the following product series, indicate the age when your animals start and, stop being useful. Also indicate that is most useful?

Social value	Start	Most useful	Stop
Social status			
Dowry			
Cultural ceremonies			
Others (specify)			

8. What are the most common causes of cattle mortality? (Rank 1-5 with 1-most important cause of mortality and 5-least important).

Class	Cows	Oxen	Bulls
Diseases			
Old age			
Lack of forage/Drought			
Theft			
Others (specify)			

9. What are the most common diseases in your area? List.

Disease	Rank (5 1 with 5-most common & 1-least common)
Red water	
Heart water	
Mastitis	
Lumpy skin	
Anthrax	
Others(specify)	

10. Are ticks common in your area? If yes during which months do you see them a lot? ....

11. Do ticks have any effect on your animals? If yes, go to number 12. ....

12. From the list of uses of your animals, how would you rank the impact of ticks on the uses of your animals? Effect (1-insignificant, 2-mild, 3-severe).

Monetary/Commercial value	Effect	Social value	Effect
Meat/Growth		Social status	
Milk		Dowry	
Drought power		Cultural ceremonies	
sale		Other (specify)	

13. Do you control ticks and tick-borne diseases on your animals? If yes, go to number 14. ....

14. What control measures do you use? ....

15. In a period of one year, how many animals do you treat against ticks and tick-borne diseases? ....

16. If you dont treat your sick animals, how long will they survive?

....

17. What is the cost of the control measures you use against ticks, in a period of one year?

....

18. Do you seek specialist advice for tick control or when animals are suffering from diseases caused by ticks? If yes, who do you consult and how much do you pay for the service?

....

19. What is the total amount of money you use in tick control?

....

20. How many animals do you lose in total in a period of one (1) year? and

Class	Cows	Oxen	Bulls
Number			

21 At what age?

Class	Cows	Oxen	Bulls
Age			

22. How many animals do you lose in a year due to diseases caused by ticks? and

Class	Cows	Oxen	Bulls
Number			

23. At what age?

Class	Cows	Oxen	Bulls
Age			

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