Food and Agriculture Organization of the United Nations

AFRICA SUSTAINABLE LIVESTOCK 2050

The monetary impact of zoonotic diseases on society

ETHIOPIA

Evidence from four zoonoses

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ASL 2050

The monetary impact of zoonotic diseases on society in Ethiopia: Evidence from four zoonoses

1. Introduction

In Ethiopia, population growth, urbanization and gains in real per capita income will result in increased consumption of animal source foods. This will provide incentives for livestock producers and other actors along the value chain to rapidly expand and improve their businesses to satisfy the growing consumers' demand (FAO, 2017a). In a rapidly changing environment, returns on investments are often uncertain: competitive, economic, operational, legal, financial, fiscal, reputational and other risks will affect the profitability of livestock farming. Some livestock farmers and enterprises will succeed, expand and thrive; while others will fail and exit the livestock business altogether.

As livestock is a private business, the key role for the government of Ethiopia is to ensure that policies - largely implemented through public investments, laws and regulations - support a smooth and socially desirable transformation of the sector in the coming years. This is easier said than done because livestock, though a private business, also have broader, often negative, impacts on society. For example, grasslands degradation, microbiological water pollution, excess greenhouse gas emissions, animal epidemics and zoonotic diseases, are all consequences of inappropriate livestock farming practices that reduce societal welfare.

Zoonotic diseases, which jump the animal-human species barrier, are a major threat for society: they can both affect entire sectors of the livestock industry and reduce human capital. For example, it is estimated that avian influenza, at its peak, reduced chicken meat production by over one third in China (Huang *et al.,* 2017), and that the 2009 swine flu pandemic, which originated in Mexico, infected over 100 million people with a death toll of about 20 000 (Nathason, 2016). Given the current zoonotic disease information system, the Ministry of Livestock and Fishery and Ministry of Health find it challenging to generate accurate estimates of the incidence and prevalence of zoonoses, assess their impact on society, and measure the benefits of programmes and investments for their prevention, management and control (FAO, 2017c). In brief, the Ministries have difficulties in allocating public resources to tackle zoonotic diseases efficiently.

The Africa Sustainable Livestock 2050 initiative (ASL2050), under the guidance of a National Steering Committee comprising representatives of the Ministry of Livestock and Fishery; the Ministry of Health; the Ministry of Environment, Forest, and Climate Change; the Ministry of Agriculture and Natural Resources; and the Ministry of Culture and Tourism, has designed and implemented an expert elicitation protocol to assemble information on selected zoonoses and on antimicrobial resistance. The protocol was designed to gather the data needed for measuring the impact of zoonoses on society in monetary terms, thereby providing the government with a key piece of information for allocating taxpayers' money efficiently. Because three quarters of newly emerging infectious diseases in humans have a zoonotic origin and because the anticipated growth of Ethiopia will modify the drivers influencing the emergence and re-emergence of zoonotic pathogens, the value of accessing information for measuring the costs and benefits of preventing, managing and controlling zoonoses cannot be overstated.

This brief presents the results of the ASL2050 expert elicitation protocol on zoonotic diseases, as validated by stakeholders. As it was the first time an expert elicitation protocol on zoonotic diseases was implemented in Ethiopia and attaching monetary values to some variables rests on numerous assumptions, results are not cast in stone. What matters, however, is that stakeholders have used a One Health approach to experiment with a new methodology to look at zoonotic diseases – a methodology that they may or may not scale up or replicate – to provide decision-makers with information on how to best allocate admittedly scarce public resources.

2. An expert elicitation protocol for assembling information on zoonoses and AMR

When there is insufficient or unreliable data, or when data is either too costly or physically impossible to gather, expert elicitations are a promising tool to obtain good quality information. They are a scientific consensus methodology to get experts' judgements on the distribution of variables and parameters of interest, including those whose value is either unknown or uncertain. An important feature of expert elicitation is that experts not only provide information on the unmeasured, but can also suggest values that differ from those in the scientific literature or from official statistics (the official knowns), for example if they believe some causal linkages are underestimated or some issues underreported. The public sector, but more frequently private parties, have used expert elicitations for a multitude of purposes, such as to investigate the nature and extent of climate change; the cost and performance of alternative energy technologies; and the health impact of air pollution (Morgan, 2014). The World Health Organization has used an expert elicitation to estimate the global burden of foodborne diseases (WHO, 2015).

In Ethiopia, the current information system does not provide the government with sufficient information on the incidence, prevalence and impact of zoonoses on society, thereby making it challenging to measure the returns on investments aimed at their prevention, management and control. The Africa Sustainable Livestock 2050 initiative (ASL2050) has therefore designed and implemented an expert elicitation protocol to assemble information on selected zoonoses and antimicrobial resistance. The objective was to gather the data needed to measure the impact of zoonoses on society in monetary terms. It is the collection and dissemination of evidence relating to the economic cost of diseases that, coupled with information about the cost of alternative interventions for disease control and management, should guide decisions in the allocation of taxpayers' money.

- As it was the first time an expert elicitation protocol on zoonoses was implemented in Ethiopia, the protocol focuses on two livestock commodities, four zoonoses, and antimicrobial resistance. The two livestock commodities are cattle dairy and beef, while the four zoonoses are bovine tuberculosis, brucellosis, salmonellosis and anthrax (FAO, 2017b, c). These were selected because of their relevance not only for Ethiopia but also for other ASL2050 countries implementing the protocol, including Burkina Faso, Egypt, Kenya, Nigeria and Uganda, which will facilitate cross-learning.
- For animals and for each zoonosis, the protocol includes questions on the number of cases; number of deaths; number of salvage slaughtered; number of culls; number of carcasses condemned; production lost due to morbidity; and underreporting. Questions were asked by the different cattle production systems, including dairy commercial, feedlot, urban/peri-urban (dairy and beef), mixed crop-livestock, and pastoral/agro-pastoral systems as defined and quantified by stakeholders using available data and information (FAO, 2017c).
- For humans and for each zoonosis, the protocol includes questions on the number of cases; the average age of the person affected; the number of deaths; and the number of working days lost per case. Questions were asked by different category of people, including livestock keepers and consumers.
- The protocol did not collect price data, necessary to estimate the monetary values of the cost of any disease. For livestock, we sourced price data for live animals and animal products from the Central Statistical Agency, the Ethiopian Customs and Revenue Authority, and Bureau of Trade of Addis Ababa City Administration. For humans, we estimated the yearly value of statistical life to proxy the willingness to pay (WTP) for a so-called disability-adjusted life year (DALY), which is the amount citizens are willing to pay for ensuring one year of healthy life (box 1). The WTP for a DALY allows

the cost associated with mortality and morbidity to be straightforwardly calculated, as detailed in the next section.

- For antimicrobial resistance, the protocol includes four questions: on the proportion of cattle farms using antibiotics, by production system; on trends on use of antibiotics in cattle farms, by production system; on trends in antimicrobial resistance in humans; and on experts' concerns about antimicrobial resistance in humans.

Box 1. The willingness to pay for a disability-adjusted life year
To estimate the social cost of the disease, we estimate the Disability-Adjusted Life Years (DALY), a method used by the World Health Organization (WHO) to quantify the burden of disease from mortality and morbidity[1]. One DALY can be interpreted as one year of healthy life lost. It is a health gap measure that combines both time lost due to premature mortality and the time spent in sickness. For each disease, a disability weight is attached to the DALY, which measures the severity of a disease during sickness. We calculate the willingness to pay of a DALY to arrive at its value in monetary terms. We start from the yearly value of a statistical life calculated for the United States. The value of a statistical life has been calculated at USD 9.5 million by the US Department of Human and Health Services and at USD 9.6 million by the US Department of Transportation (DOT, 2016), and is used to value the reduction of fatalities and injuries. To translate the latter into a yearly value, we use the OECD's discounting approach (Quinet *et al.*, 2013): $$VSL = \sum_{t=0}^{T} VSLY * (1+\delta)^{(-t)}$$ where VSL is the value of statistical life, VSLY the yearly value, t is a discrete variable going from the present (0) to the expected end of the individual's life (T) and δ is the discount rate. Using a discount rate of 3 percent (ERG, 2014) and the expected life span of 79 years (World Bank, 2017), we calculate around 400 000 USD as a yearly value of a statistical life in the US, that will represent society's willingness to pay for a healthy year of life or for a DALY. To translate this value in the Ethiopian context, we use the benefit transfer methodology presented in Hammit and Robinson (2011), which takes into account the differences in real GDP per capita, as measured in purchasing power parity (PPP) and the elasticity of the willingess to pay for risk reduction with respect to income: $$VSLY_{Country} = VSLY_{US} * \left(\frac{GDP\ per\ capita\ in\ PPP_{Country}}{GDP\ per\ capita\ in\ PPP_{US}}\right)^{elasticity}$$

We used a snowball sampling approach to identify the experts to interview, with representatives of the ASL2050 Steering Committee initially suggesting names of renowned national experts, including two animal and two human health experts for each zoonotic disease. We then asked these experts to recommend additional experts to interview, and so on. When this snowball approach occasionally interrupted, the ASL2050 National Focal Point retook the expert unveiling process. The final sample comprised 42 experts, including 28 animal health experts and 14 human health experts. The sample is biased towards animal health experts, one of the reasons being that there are few human doctors with expertise in the selected zoonotic diseases. However, animal health experts were often able to respond to human health questions as, being specialised in zoonotic diseases, they typically operate at the interface

[1] http://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/

between animal and human health. We conducted the interviews in September and October 2017, analysed the data in November and validated the results with stakeholders in January 2018.

3. Livestock and public health monetary impact calculation: methodology

The monetary impact of the priority zoonotic diseases on society is determined as the sum of the losses in value (USD) due to morbidity and mortality in infected animals and humans over the period of one year as follows:

Livestock and Public Health USD Impact
=
Value of animals lost
+
Value of production decrease in infected animals
+
Social cost of mortality in humans
+
Social cost of morbidity in humans

The methodology used to calculate the value of the different variables in the equations is briefly discussed below both for animals and humans. Detailed explanation and data sources are described in the Annexes.

3.1 Cattle

In cattle systems, an infected animal will either die, be culled or salvage slaughtered or survive but suffer from production decrease. Both the value of the animals lost as well as the decreased production should be estimated to calculate the total loss due to occurrence of a disease in animals. Figure 1 depicts a flowchart that highlights the different cattle-related variables the protocol data allows estimating, including the value of animals lost due to the disease (in red) and the value of production decrease in survivors (in dark orange). The cost of treating sick animals are not accounted for as data on farmers' expenses on veterinary goods and services by disease are not available. However, a small proportion of farmers have usually access to animal health services and their expenses on veterinary services are typically negligible (CAHI, 2015; MAAIF, 2016). The value of animals lost is calculated as the sum of:

- the number of animal deaths multiplied by the farm-gate price of an adult animal;
- the number of carcasses fully condemned multiplied by the farm-gate price of an adult animal;
- the number of unborn calves, due to fertility reduction in survivors, multiplied by the farm-gate price of a young animal.

The value of production decrease in survivors is calculated as the sum of:

- the number of carcasses partially or not condemned animals multiplied by the farm-gate price of an adult animal discounted by 50 percent;
- The number of lost lactation periods – which is equal to the number of unborn calves, or the number of cows infected by the disease and affected by fertility loss – multiplied by the average litre per lactation and by the market price of one litre of milk;
- The number of cows infected by the disease and not affected by fertility loss, multiplied by the average reduction in lactation milk production in litres and by the market price of one lit. of milk;
- The number of survivors multiplied by the average dressed weight lost and by the market price of one kg of beef.

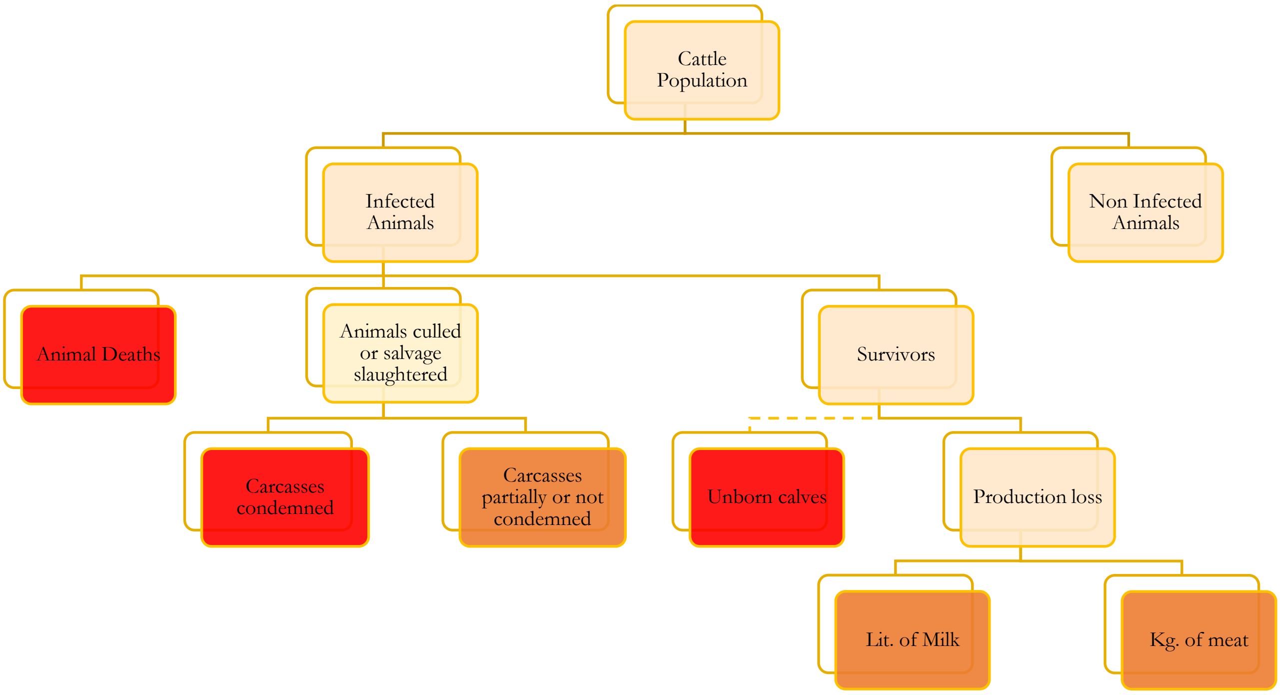

Figure 1. Cattle-related variables in the USD loss calculation

3.2. Humans

Zoonoses are transmitted from animals to humans through direct and indirect contact, vectors and food consumption. Different categories of people, therefore, face different risks of contracting zoonotic diseases[2]. To estimate the impact of morbidity and mortality of zoonses in humans, we have split the population at risk in three broad groups: (i) non-livestock keepers and non consumers of animal source foods; (ii) non-livestock keepers and consumers of animal source foods; (iii) livestock keepers and consumers of animal source foods.

Figure 2 depicts a flowchart that highlights the different human-related variables the protocol data allows estimating, including the number of infected people, as well as survivors and deaths, by category of people. We assume there are no infections among the non-livestock keepers and non-consumers of animal source foods.

[2] Occupations at higher risk of infection include also veterinarians, culling personnel, slaughterhouse workers and all that are in direct contact with live animals and animal material. It is however not possible to obtain good information on the number of such workers, let alone knowing how many of them are already included in the other two categories. We assume that the majority are already living in a livestock keeping household or are consumers of animal source foods.

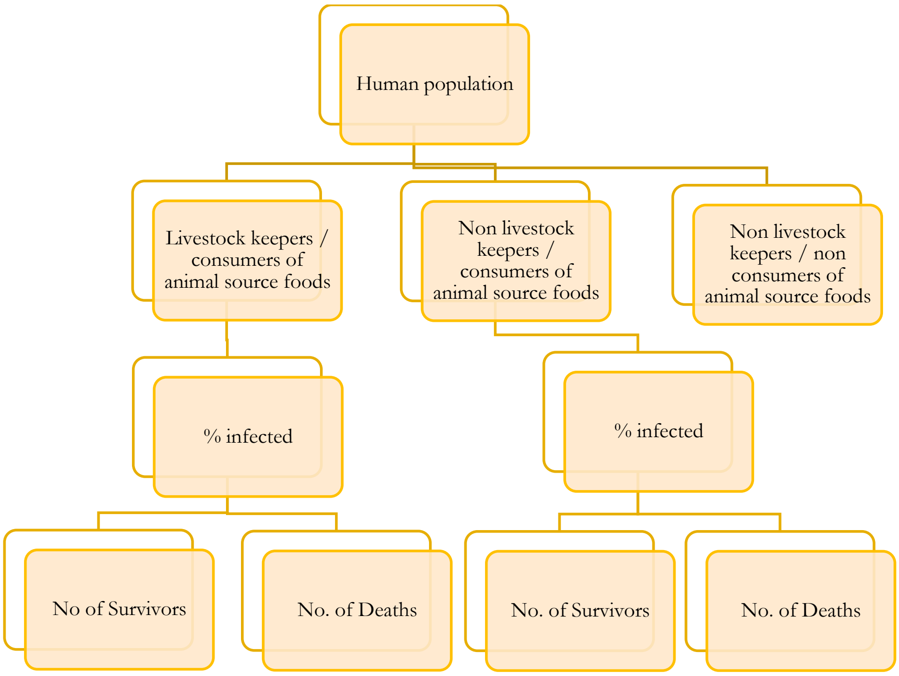

Figure 2. *Human related variables in the USD loss calculation*

The economic cost of the zoonotic disease is calculated as the sum of:

- The total number of survivors multiplied by the average number of working days lost (proxy for duration of the disease) expressed in years and the DALY disability weight measuring the severity of the disease[3] and by the society's willingness to pay for one year of healthy life.
- The total number of deaths multiplied by the average number of years of life lost – given by the difference between life expectancy and average age at infection – and society's willingness to pay for one year of healthy life.

4. Livestock and public health monetary impact calculation: results

4.1. Data validation

We validated the collected data through a three-step process. First, we generated summary statistics for the key variables to estimate and reviewed them with members of the ASL2050 Steering Committee. Second, for those variables whose values were implausible, we consulted relevant literature. Finally, we presented the summary statistics and literature review at a workshop involving protocol respondents to arrive at consensus on measures of central tendency. Table 1 presents the reference population, prevalence and fatality rate data that were used to calculate the monetary impact of the selected zoonoses on society.

[3] A DALY disability weight measures the severity of a disease and can take values from 0 to 1, zero meaning completely healthy and 1 meaning death. DALY weights by disease are provided by the WHO Global Burden of Disease.

Table 1. Key protocol-variables underpinning the USD loss calculation

	Total population		
	Cattle	Humans (101 407 000)	
		Cattle keepers	Consumers[4]
	56 682 162	70 072 237	15 109 643
Brucellosis			
Total number of cases per annum	672 594	114 387	11 332
Prevalence (cases/total population)	1.11%	0.163%	0.075%
Fatality per annum	56 652	1 521	755
Fatality rate (deaths/cases)	9.03%	1.3%	6.67%
Bovine TB			
Total number of cases per annum	3 052 600	3 929	907
Prevalence (cases/total population)	5.39%	0.006%	0.006%
Fatality per annum	319 295	761	151
Fatality rate (deaths/cases)	10.46%	19.4%	16.67%
Anthrax			
Total number of cases per annum	266 136	10 279	1 209
Prevalence (cases/total population)	0.47%	0.015%	0.008%
Fatality per annum	214 723	5 354	151
Fatality rate (deaths/cases)	80.68%	52.1%	12.50%
Salmonellosis			
Total number of cases per annum	757 551	47 834	12 088
Prevalence (cases/total population)	1.34%	0.068%	0.080%
Fatality per annum	328 611	1 675	151
Fatality rate (deaths/cases)	43.38%	3.5%	1.25%

4.2. Results

4.2.1 Brucellosis

Brucellosis in Cattle

Table 2 shows the economic impact of brucellosis measured as value of animals lost and value of production lost by production system. Brucellosis causes an estimated economic loss of 377.93 million USD per annum (expressed as PPP) in cattle despite the perceived low prevalence. The mixed crop-livestock and urban/peri-urban production systems suffer the most compared to the other production systems. The economic losses caused by the disease appear to be due more to reduced or foregone production rather than death of the infected animals. Total loss expressed as percentage of contribution of livestock to GDP and as percentage of total GDP are 1.96 percent and 0.21 percent, respectively.

Table 2. Prevalence of brucellosis and estimates of its economic costs by production system

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	TOTAL
Estimated prevalence	1.50%	0.50%	2.00%	1.00%	1.20%	1.11%
Value of animals lost (million USD PPP)	8.19	-	14.50	30.50	5.55	58.74
Value of production lost (million USD PPP)	61.46	0.28	100.73	137.24	19.42	319.18
TOTAL (million USD PPP)	69.65	0.28	115.22	167.79	24.97	377.93
Total loss, percent of livestock share in GDP[5]	0.36	0.001	0.60	0.87	0.13	1.96
Total loss, percent of GDP[6]	0.04	0.000	0.06	0.09	0.01	0.21

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

[4] Excluding cattle keepers
[5] Contribution of livestock to GDP (PPP): $19.23 billion. (Source: Own calculation based on Behnke & Metaferia, 2011).
[6] The GDP (PPP) was $177.95 billion (2016 estimate). (Source: The World Bank. Available at: https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD?locations=ET)

Table 3 below shows the same estimates by case and as percentage of the farm-gate price of a healthy animal. The loss per case can be higher than the price of an animal if the average value of production loss per head (unborn calves, milk production loss, and meat production loss) is higher than the average value of an animal. In most cases, losses are not merely due to death of the infected animals but also to impaired production/reproduction, foregone production, and producers' or government's decision to salvage slaughter or cull other animals out of precaution.

The average total loss per case (PPP) and loss per case estimated as a percentage of farm-gate price of a healthy animal[7] are estimated to be USD 1 458.64 and 47.98 percent of the value of a healthy animal, respectively. Highest total losses per case happen in the intensive/semi-intensive production systems (dairy commercial, feedlot, and urban/peri-urban) compared to the extensive systems.

Table 3. Estimates of value lost per case due to brucellosis by production system

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	AVERAGE
Value of animals lost per case (USD PPP)	379.80	-	190.64	70.05	58.88	139.87
Value of production lost per case (USD PPP)	2 848.51	1 899.02	1 325.23	315.22	205.83	1 318.76
TOTAL loss per case (USD PPP)	3 228.31	1 899.02	1 515.87	385.27	264.71	1 458.64
Loss per case, percent of price of healthy animal	56.67	50.00	40.43	55.00	37.79	47.98

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Brucellosis in Human Beings

As described above, the social cost of the disease is estimated as the sum of the cost of mortality and cost of morbidity. In particular, we estimate the impact of the disease for two sub-groups: cattle keepers who are in frequent contact with the animals and are also potentially consuming cattle source products, and individuals who are not livestock keepers but might be infected largely through consumption. Results are shown in Table 4 for the total population group and per case. In 2017 in Ethiopia 1 521 cattle keepers died of Brucellosis, on average at age of 23.60 yrs. According to the World Bank, the expected life span of an individual in the country is 65 yrs., meaning we account for 1 521 deaths * (65-23.60) years lost all together. Hence the total social cost of brucellosis among livestock keepers in Ethiopia is estimated at 150 700 768 USD (PPP), valuing the loss of one year at 2 100 USD (the yearly value of statistical life calculated for Ethiopia). It is 74 719 967 USD among consumers.

To put these numbers in context, Table 4 also shows the results as a percentage of GDP. This comparison should be regarded with caution: the GDP is an annual value, whereas mortality costs include the individual's future years remaining up to the expected end of his life. The total social cost of brucellosis, 225 420 735 USD (PPP), is equivalent to about 0.13 percent of the national GDP.

Table 4. Estimates of the annual public health costs of brucellosis in Ethiopia

	Livestock keepers	**Consumers**	**Total**
Years of life lost due to mortality (YLL)	71 060.96	35 515	106 576.17
Years lost due to morbidity (YLD)	701.32	65.72	767.04
DALYs (YLL + YLD)	71 762.27	35 580.94	107 343.21
Willingness to pay for one year of healthy life (USD PPP)	2 100	2 100	2 100
Total social cost (USD PPP)	150 700 768	74 719 967	225 420 735
Total social cost as percent of GDP (USD PPP)	0.09	0.04	0.13

Cost of Brucellosis in animals and humans in 2017

[7] The average price of a healthy adult animal differs by production system

To compare the cost of a zoonotic disease in animals and humans, we must address the fact that mortality costs consider the "loss" of future years as described above, whereas all other estimates refer to losses encountered in the reference year.

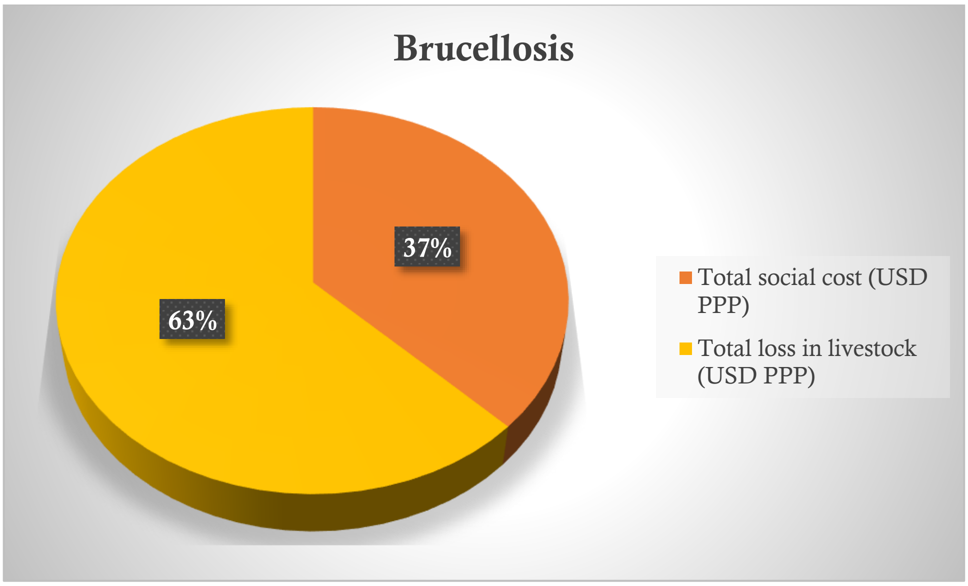

Figure 3. *USD cost of brucellosis in humans and animals (percent)*

Table 5 presents the value of the public health costs of brucellosis for livestock keepers versus the costs for the different cattle production systems whereas Figure 3 shows the relative weight of total costs in humans (including consumers) and animals. The disease causes the highest losses in the mixed crop-livestock production system both in terms of social cost and losses due to animal mortality and foregone production. The loss in animals in the urban/peri-urban production system is also very high compared to dairy commercial and pastoral/agro-pastoral systems. The total social cost of brucellosis is relatively low among livestock keepers in the dairy commercial and urban/peri-urban production systems.

Table 5. Annual costs of brucellosis in humans and cattle in different production systems

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Total
Animals (USD PPP)	69 656 069	282 310	115 229 873	167 797 959	24 968 335	377 934 546
Livestock keepers (USD PPP)	4 211 414	-	5 882 896	115 241 687	25 364 770	150 700 768

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

4.2.2 Bovine TB

Bovine TB in Cattle

Table 6 shows the value of animals lost and the value of production lost due to bovine tuberculosis by production system. There is high prevalence of the disease in the dairy commercial and urban/peri-urban production systems that usually keep exotic, grade or crossbred animals. Bovine tuberculosis causes significant economic losses both in terms of animals lost and foregone production. The highest loss is due to reduced and foregone production rather than to mortality. Total economic losses in the urban/peri-urban and dairy commercial systems are estimated at USD 1.5 and 1.2 billion (PPP), respectively, and ~USD 3.5 billion overall. This is a huge economic loss representing about 18 percent of the contribution of livestock to GDP and 1.96 percent of total GDP (PPP).

Table 6. Prevalence of bovine tuberculosis and estimates of its economic costs

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	TOTAL
Estimated prevalence	30.00%	3.00%	20.00%	4.00%	1.50%	5.39%
Value of animals lost (million USD PPP)	292.64	225.85	358.28	244.60	22.02	917.78
Value of production lost (million USD PPP)	930.71	0.55	1 142.60	446.56	41.30	2 561.74
TOTAL (million USD PPP)	1 223.36	0.78	1 500.87	691.18	63.32	3 479.52
Total loss, percent of livestock share in GDP	6.36	0.004	7.80	3.59	0.33	18.09
Total loss, percent of GDP	0.69	0.000	0.84	0.39	0.04	1.96

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Table 7 shows estimates of losses by case and as percentage of the farm-gate price of a healthy animal. Here too, total losses per case (USD PPP) are highest in the intensive systems of dairy commercial and urban/peri-urban cattle production amounting to 2 834.93 and 1 974.43 dollars PPP, respectively. Again, most of the losses are due to impaired and/or foregone production. The highest loss expressed as percentage of farm-gate price of a healthy animal (76.67 percent) is encountered in the pastoral production system. The overall loss per case is roughly 52 percent of the value of a healthy animal.

Table 7. Estimates of values lost per case due to bovine tuberculosis by production system

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	AVERAGE
Value of animals lost per case (USD PPP)	678.15	253.20	471.33	140.41	186.80	345.98
Value of production lost per case (USD PPP)	2 156.77	621.62	1 503.10	256.34	350.25	977.62
TOTAL loss per case (USD PPP)	2 834.93	874.82	1 974.43	396.75	537.05	1 323.60
Loss per case, percent of price of healthy animal	49.76	23.03	52.66	56.64	76.67	51.75

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Bovine Tuberculosis in Human Beings

Table 8 gives estimates of the public health cost of bovine tuberculosis in Ethiopia. The estimated total public health costs (USD PPP) of the disease among livestock keepers in all production systems and consumers are USD 74 740 696 and 12 781 597, respectively. This amounts to 0.05 percent of total GDP.

Table 8. Estimates of the annual public health costs of bovine tuberculosis in Ethiopia

	Livestock keepers	Consumers	Total
Years of life lost due to mortality (YLL)	35 530.48	6 045.37	41 575.85
Years lost due to morbidity (YLD)	60.33	41.11	101.44
DALYs (YLL + YLD)	35 590.81	6 086.47	41 677.28
Willingness to pay for one year of healthy life (USD PPP)	2 100	2 100	2 100
Total social cost (USD PPP)	74 740 696	12 781 597	87 522 293
Total social cost as percent of GDP (USD PPP)	0.04	0.01	0.05

Cost of Bovine Tuberculosis in Animals and Humans in 2017

Table 9 compares the public health costs of bovine tuberculosis in livestock keepers to costs for the cattle sector by production system. Urban/peri-urban and commercial dairy sectors suffer the most in terms of loss incurred due to death of animals, reduced and foregone production amounting to USD 1 500 876 724 and 1 223 364 444 (PPP), respectively. The public health costs are higher in mixed crop-livestock and pastoral/agro-pastoral cattle production systems, largely due to their sheer sizes. Figure 4 presents the shares of the monetary costs of bovine tuberculosis in animals and humans (livestock keepers and consumers). The estimated monetary cost of the disease in animals accounts for 98 percent of the total loss caused by the disease.

Table 9. Annual costs of bovine tuberculosis in humans and cattle in different production systems

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Total
Animals (USD PPP)	1 223 364 444	780 309	1 500 876 724	691 183 046	63 321 549	3 479 526 073
Livestock keepers (USD PPP)	2 090 959	-	2 903 802	57 155 167	12 590 767	74 740 696

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

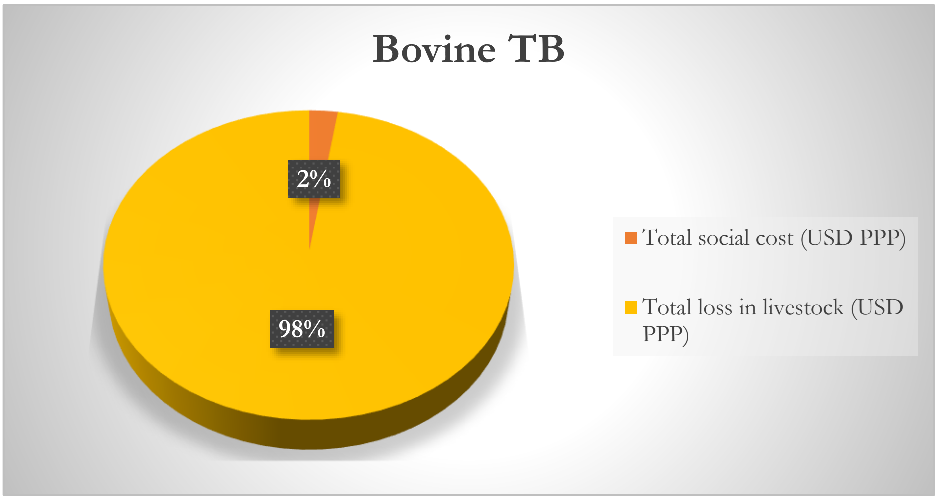

Figure 4. *USD cost (percent) of bovine tuberculosis in cattle and humans*

4.2.3 Anthrax

Anthrax in Cattle

Table 10 shows the value of animals lost and the value of production lost by production system. Even though the overall prevalence of anthrax based on expert opinions is generally low, the total economic cost of the disease reaches USD 162.86 million (PPP) of which two-third is from the mixed-crop livestock system. Much of the loss (~90 percent) is attributed to immediate death of the affected animals. The total losses as percent of contribution of livestock to GDP and total GDP are 0.85 percent and 0.09 percent, respectively.

Table 10. Prevalence of anthrax and estimates of its economic costs

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	TOTAL
Estimated prevalence	0.10%	0.10%	0.20%	0.50%	0.50%	0.47%
Value of animals lost (million USD PPP)	8.19	0.11	28.50	91.52	16.51	144.85
Value of production lost (million USD PPP)	-	-	-	15.25	2.75	18.00
TOTAL (million USD PPP)	8.19	0.11	28.50	106.78	19.27	162.86
Total loss, percent of livestock share in GDP	0.04	0.001	0.15	0.56	0.10	0.85
Total loss, percent of GDP	0.005	0.000	0.02	0.06	0.01	0.09

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Table 11. Estimates of value lost per case due to anthrax by production system

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Average
Value of animals lost per case (PPP)	5 697.01	3 798.05	3 749.56	420.30	420.30	2 817.04
Value of production lost per case (USD PPP)	-	-	-	70	70	28.02
TOTAL loss per case (USD PPP)	5 697.01	3 798.05	3 749.56	770.55	770.55	2 845.06
Loss per case, percent of price of healthy animal	100	100	100	70	70	88

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Table 11 shows losses per case of anthrax and as percent of the farm-gate price of healthy animal. In the intensive/semi-intensive systems, occurrence of the disease entails total loss of the value of the infected animals. Some fraction of the value is recovered in the form of salvage slaughtering among livestock keepers in the mixed crop-livestock and pastoral/agro-pastoral production systems.

Anthrax in Human Beings

The social costs of anthrax measured as DALYs are 187 596.58 and 6 045.57 among livestock keepers and consumers, respectively, whereas the corresponding monetary costs (USD PPP) are 393 952 817 and 12 695 693 USD among the two risk groups, respectively (Table 12). Overall, the total social cost of anthrax is 406 648 510 USD (PPP) amounting to 0.23 percent of GDP (PPP).

Table 12. Estimates of the annual public health costs of anthrax in Ethiopia

	Livestock keepers	Consumers	Total
Years of life lost due to mortality (YLL)	187 595.65	6 045.37	193 641.02
Years lost due to morbidity (YLD)	0.93	0.20	1.13
DALYs (YLL + YLD)	187 596.58	6 045.57	193 642.15
Willingness to pay for one year of healthy life (USD PPP)	2 100	2 100	2 100
Total social cost (USD PPP)	393 952 817	12 695 693	406 648 510
Total social cost as percent of GDP (USD PPP)	0.22	0.01	0.23

Cost of Anthrax in Animals and Humans in 2017

Table 13. Annual costs of anthrax in humans and cattle in different production systems

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Total
Animals (USD PPP)	8 194 832	112 924	28 502 608	106 780 519	19 271 776	162 862 659
Livestock keepers (USD PPP)	2 385 745	-	7 604 710	339 974 415	43 987 947	393 952 817

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Table 13 compares the total public health and livestock-related monetary costs (USD PPP) caused by anthrax. These social costs are the highest in the mixed crop-livestock system followed by the pastoral/agro-pastoral system. Comparing the total public health costs (in both livestock keepers and consumers) to the value of loss in animals shows that more than two-thirds of the economic impact of anthrax is on public health (Figure 5).

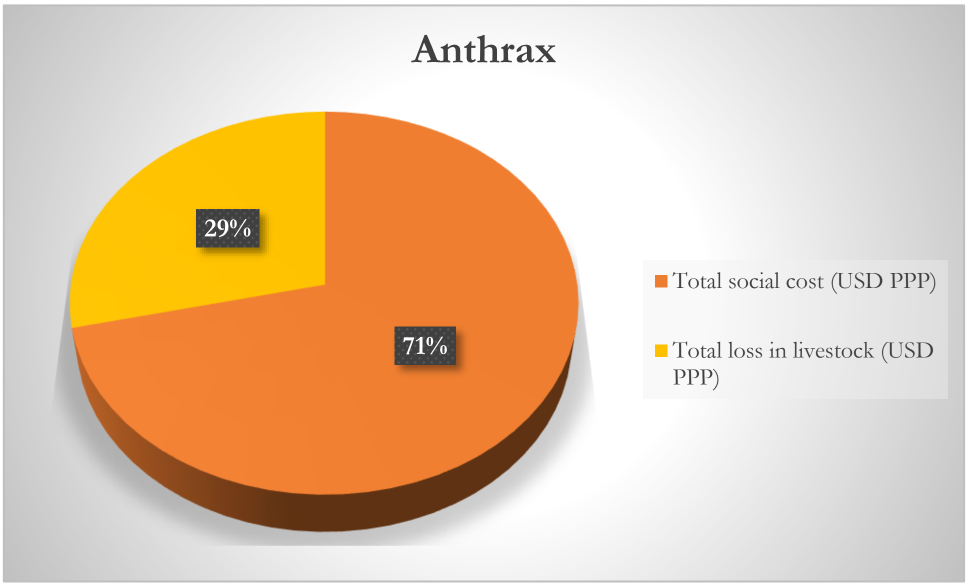

Figure 5. *USD cost (percent) of anthrax in humans and animals*

4.2.4. Salmonellosis

Salmonellosis in Cattle

The estimated prevalence of salmonellosis is relatively high in the commercial dairy and urban/peri-urban production systems whereas it is low in the mixed crop-livestock production system. The value of animals lost and the value of production lost due to salmonellosis are thus different in the different production systems as indicated in Table 14. The total economic impacts of the disease, in fact, is highest in the urban/peri-urban and the mixed crop-livestock systems at ~242 and ~229 million USD (PPP), respectively. The total loss as percentage of the contribution of livestock to GDP and total GDP are 3.29 percent and 0.36 percent, respectively.

Table 14. Prevalence of salmonellosis and estimates of its economic costs

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	TOTAL
Estimated prevalence	3.50%	1.50%	3.00%	1.00%	2.00%	1.34%
Value of animals lost (million USD PPP)	82.33	0.56	214.11	152.14	27.61	477.17
Value of production lost (million USD PPP)	21.45	0.36	27.83	76.27	29.58	155.50
TOTAL (million USD PPP)	103.78	0.92	241.95	228.81	57.19	632.68
Total loss, percent of livestock share in GDP	0.54	0.005	1.26	1.19	0.30	3.29
Total loss, percent of GDP	0.06	0.001	0.14	0.13	0.03	0.36

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

The value of animals lost, value of production lost, and the total loss as percentage of the farm-gate price of a healthy animal expressed on per case basis are given in Table 15. The economic cost of salmonellosis due to mortality is significantly higher than the loss due to impaired production and reproduction across all production systems except in the pastoral/agro-pastoral system where the impact due to animal death and impaired and/or foregone production are comparable. The total losses per case in the intensive systems are similar (USD PPP 2 121.98, 2 078.08, and 2 061.47 for urban/peri-urban, feedlot and dairy commercial systems, respectively). In the mixed crop-livestock system, three-quarters of the value of infected animals (as percentage of farm-gate price of a healthy animal) is lost. On the other hand, a little more than a third of the animals' value is lost in the dairy commercial system. Overall, salmonellosis causes about 55 percent loss in the value of sick animals across all production systems.

Table 15. Estimates of value lost per case due to salmonellosis by production system

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Average
Value of animals lost per case (USD PPP)	1 635.32	1 266.02	1 877.83	350.25	175.67	1 061.02
Value of production lost per case (USD PPP)	426.15	812.07	244.15	175.12	188.17	369.13
TOTAL loss per case (USD PPP)	2 061.47	2 078.08	2 121.98	525.37	363.84	1 430.15
Loss per case, percent of price of healthy animal	36.19	54.71	56.59	75.00	51.94	54.89

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Salmonellosis in Human Beings

The public health cost of salmonellosis among livestock keepers and consumers is estimated to be USD (PPP) 161 033 995 and 10 503 000, respectively (Table 16). The total public health cost of salmonellosis, 171 536 995 USD (PPP), is equivalent to 0.10 percent of the national GDP.

Table 16. Estimates of the annual public health costs of salmonellosis in Ethiopia

	Livestock keepers	Consumers	Total
Years of life lost due to mortality (YLL)	76 629.74	4 987.69	81 617.43
Years lost due to morbidity (YLD)	53.11	13.74	66.85
DALYs (YLL + YLD)	76 682.85	5 001.43	81 684.28
Willingness to pay for one year of healthy life (USD PPP)	2 100	2 100	2 100
Total social cost (USD PPP)	161 033 995	10 503 000	171 536 995
Total social cost as percent of GDP (USD PPP)	0.09	0.01	0.10

Cost of Salmonellosis in Animals and Humans in 2017

Table 17 compares the total cost (USD PPP) of salmonellosis in humans and animals. The public health costs of the disease in humans and losses in animals are the highest in the mixed crop-livestock systems followed by the pastoral/agro-pastoral systems. These costs are relatively low for the urban/peri-urban and dairy commercial systems. They were inestimable for the feedlot system. Much of the total cost of salmonellosis, about four-fifths of all costs, is due to its negative impacts on cattle production and productivity rather than on public health (Figure 6).

Table 17. Annual costs of salmonellosis in humans and cattle in different production systems

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Total
Animals (USD PPP)	103 785 702	926 787	241 956 389	228 815 398	57 198 313	632 682 589
Livestock keepers (USD PPP)	4 178 398	-	8 697 139	114 206 417	33 952 041	161 033 995

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

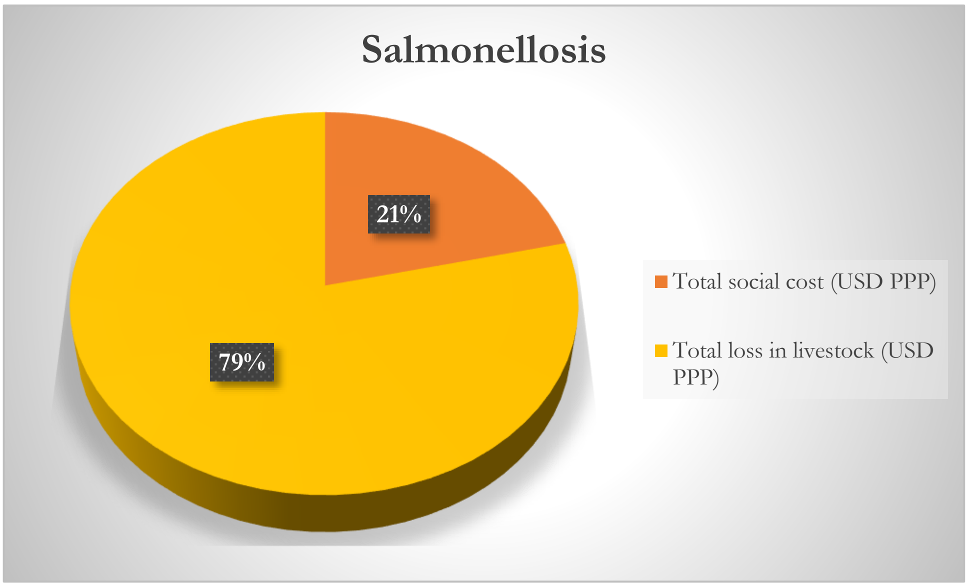

Figure 6. *USD cost (percent) of salmonellosis in animals and humans*

4.3. Discussion

Prevalence and Fatality

Prevalence estimates of the four zoonotic diseases in animals along the different production systems are generally within previously reported levels. Prevalence estimates abound for brucellosis and bovine tuberculosis. They are scant for anthrax and salmonellosis in animals, though estimates for salmonellosis in cattle products (mainly milk and meat) are numerous.

The overall brucellosis prevalence estimate of 1.11 percent in the current study is lower than many reports coming from any of the production systems. Asmare *et al.* (2014) reported a prevalence of 4 percent (ranging between 1.5 percent and 10 percent) for intensive dairy production systems. For mixed crop-livestock system, brucellosis prevalence estimates vary widely with ranges between 0 percent and 50 percent and average of 7.2 percent (Megersa *et al.*, 2012; Girma, 2011; Tadesse, 2016; Jergefa *et al.*, 2009; Tolosa *et al.*, 2010). In pastoral/agro-pastoral system, the reported average prevalence is 7.2 percent ranging between 0 percent and 22 percent (Dinka and Chala, 2009; Megersa *et al.*, 2011; Tadesse, 2016; Tschopp *et al.*, 2015). Estimates of cattle seroprevalence in the world range between 3 and 15 percent (Bosilkovski, 2015).

The overall prevalence level of 5.39 percent for bovine tuberculosis found in this study is in line with the national estimate of 5.8 percent (Sibhat *et al.*, 2017) though available estimates vary widely. In the urban/peri-urban dairy systems, prevalence level ranging from 8.14 to 30 percent was reported (Ameni *et al.*, 2003b; Firdessa *et al.*, 2012; Dissaa *et al.*, 2016). Bovine tuberculosis is also widely prevalent in the traditional production systems of mixed crop-livestock with values ranging between 1.6 percent and 22.2 percent (Tschopp *et al.*, 2013; Tschopp *et al.*, 2015; Voldermeier *et al.*, 2012) and pastoral/agro-pastoral with values from 0.6 to 4.4 percent (Tschopp *et al.*, 2010; Gumi *et al.*, 2011). It should be noted that clinical signs of tuberculosis in cattle are variable depending on the location and extent of the lesions. Even with advanced disease, visible signs are frequently absent. General findings include anorexia, dyspnea, weight loss, weakness, and low-grade fluctuating fever. Often the main sign of tuberculosis is emaciation, despite adequate nutrition and care (Salman and Steneroden, 2015). Thus, the reported prevalence rates are possibly an under estimation of the true disease prevalence.

The overall prevalence of anthrax found in this study (0.47 percent) is possibly on the low side but overall consistent with the available evidence. Published literatures do not report on anthrax prevalence; however, estimates calculated from case reports to the Disease Outbreak and Vaccination Reporting (DOVAR) database of the Ministry of Livestock and Fisheries do not markedly differ from the current estimates except for feedlot where it is somewhat higher (4.28 percent vs. 0.10 percent). At the same time, available sources indicate high fatality rates (~32 percent) among herds affected by anthrax outbreaks which is consistent with the findings presented in this study (MoA, 2010, MoA, 2012; Bahiru *et al.*, 2016). In cattle, anthrax usually manifests as peracute or acute disease; the peracute form typically occurs at the beginning of an outbreak and animals are found dead without premonitory signs, the acute form also runs a short course of about 48 h with severe depression, lethargy, abortion and fever (Salman and Steneroden, 2015). In Ethiopia, anthrax is probably underreported in both humans and animal populations due to under-diagnosis and lack of effective reporting and alerting system. Salman and Steneroden (2015) contend that this is the reality at a global level too.

Prevalence estimates of salmonellosis in the present study are slightly higher in the intensive dairy systems (3 percent to 3.5 percent) than in other production systems, as would be expected, and are in agreement with few available literatures that reported prevalence levels ranging from 0 to 5 percent (Bekele and

Ashenafi, 2010; Eguale *et al.*, 2016). Dailey (2011) did not identify any salmonella strains from samples originating from semi-intensive dairy system in the central highland. Alemayehu *et al.* (2003) reported prevalence of 0.6 to 3.1 percent for salmonellosis in feedlot systems. Reta *et al.* (2016) found a prevalence of 3.30 percent in the pastoral/agro-pastoral production system. Salmonella is often carried asymptomatically in cattle, but young, stressed or pregnant animals are the most susceptible to infection, which may result in enteritis and septicaemia (Spickler, 2005).

The overall animal fatality rates estimated in the present study were 9.03 percent, 10.46 percent, 80.68 percent and 43.38 percent for brucellosis, bovine tuberculosis, anthrax and salmonellosis, respectively. There is no much information on these zoonotic diseases and their effect in causing mortalities in cattle in Ethiopia. Exceptions include Ameni *et al.* (2010) who reported mortality rates of 0.6 to 4.4 percent in pastoral/agro-pastoral cattle production system due to bovine tuberculosis; Shiferaw (2004) who found a fatality of 7.7 percent in cattle kept in mixed crop-livestock system due to anthrax; and Pegram *et al.* (1981) who recorded a mortality of 6.76 percent in calves due to salmonellosis in a more likely mixed crop-livestock production system. The following fatality rates were reported for anthrax: 42.7 percent (OiE, 2017) and 33 percent (MoA, 2011).

Available literature and data on prevalence and mortality of zoonotic diseases in humans are very scarce, making it difficult to validate the results of this study. In the present study, the estimated prevalence of brucellosis is 0.16 and 0.08 percent in cattle keepers and consumers, respectively. The reviewed literature (Desta, 2016; Girma, 2012; G/Michael *et al.,* 2016; Haileselassie *et al.*, 2011; Pal *et al.*, 2017; Regassa *et al.*, 2009; Tadesse, 2016; Tibesso *et al.*, 2014; Tolosa, 2004; Tsegaye *et al.,* 2017; Wakene and Mamo, 2017; Workalemahu *et al.*, 2015; Yilma *et al.*, 2016) provides estimates on regions, zones, ecological zones or town areas, reporting prevalence rates with large variation between 0 and 34 percent, with the mode of most studies being 3 percent. It is not surprising that at the national level, we find a significantly lower prevalence, since most of the studies were conducted in areas where the risk of infection is high (e.g. commercial dairy farms or abattoirs).

Similarly, prevalence rates for bovine tuberculosis in humans are lower than those reported in the literature. For both cattle keepers and consumers, prevalence is 0.006 percent in this study. The findings of the literature (Ameni *et al.*, 2003; Ayele *et al.*, 2004; Bekele *et al.*, 2016; de Garine-Wichatitsky *et al.*, 2013; Endalew *et al.*, 2017; Gumi *et al.*, 2012; Gumi, 2013; Mengistu *et al.*, 2015; Müller *et al.*, 2013; Shitaye *et al.*, 2007; Tschopp *et al.*, 2010; Tschopp *et al.*, 2011; Tschopp *et al.*, 2012; Tschopp *et al.*, 2013) are varying between 0.41 and 24 percent, but are again based on different reference periods and small samples.

Prevalence rates of Salmonellosis in cattle keepers and consumers were estimated at 0.07 and 0.08 percent, respectively. Similar to the findings above, these rates are lower than the ones found in the literature, that range from 0.2 to 14.6 percent (Abebe *et al.*, 2014; Adimasu *et al.*, 2014; Beyene *et al.*, 2011; Mengistu *et al.*, 2014; Sibhat *et al.*, 2009; Tesfaw *et al.*, 2013).

The number of anthrax cases reported to the Ministry of Health were 575 and 848 cases in 2014 and 2015 respectively (MoH, 2015; 2016) with fatality rates of 1.22 and 5.90 percent, respectively during the two reporting years. Bahiru *et al.* (2016) found a fatality rate of 1.70 percent among anthrax patients nationally. On the other hand, Shiferaw (2004) reported a very high fatality rate of 50 percent for a single anthrax outbreak in northern part of the country. According to Grace *et al.* (2012), the total number of anthrax cases and deaths globally in unspecified year were 11 000 and 1 250, respectively, implying a fatality rate of 11.36 percent.

It is worth noting that prevalence of bovine tuberculosis, salmonellosis and brucellosis increases with the level of intensification. Moreover, bovine tuberculosis and salmonellosis, despite their economic and social impacts, were not among the five priory zoonotic diseases ranked for Ethiopia few years ago. The five priority zoonotic diseases in tier-one were rabies, anthrax, brucellosis, leptospirosis, and echinococcosis (Pieracci *et al.* 2016).

Economic Impacts in Animals

The studied zoonotic diseases cause significant losses in animal production and productivity. They cost the nation an estimated sum of 24.19 percent of the current contribution of livestock to GDP and 2.62 percent of the total GDP. In monetary terms, this is equivalent to USD PPP 4 653 005 867. Bovine tuberculosis alone is responsible for causing roughly 18 percent of the loss to livestock GDP or 1.96 percent to total GDP. These estimates are 3.29 percent and 0.36 percent for salmonellosis; 1.96 percent and 0.21 percent for brucellosis and 0.85 percent and 0.09 percent for anthrax, respectively. Costs of surveillance, prevention, and loss of access to markets were not considered in the present study.

Brucellosis has principal socio-economic and public health importance within countries and is considered significant in the international trade in animals and animal products (Neubauer, 2010). Brucellosis causes appreciable economic losses to the livestock industry and huge economic losses not only to dairy farmers but also to sheep, goat and pig farmers in infected areas, resulting from abortions, sterility, birth of weak offspring, decreased milk production, weight loss in animals, lameness, reduced breeding efficiency, veterinary attendance costs, the cost of culling and replacing animals, and vaccination costs (Nicoletti, 2010).

It is difficult to find information on economic losses due to zoonoses in the literature and official records. To put economic results in perspective, we thus compare the results of this study with those of Kenya and Uganda implemented with same methodology used here. We aggregate results by intensive and extensive systems to facilitate comparability. Table 18 and 19 present such results for brucellosis and bovine tuberculosis, respectively, as anthrax and salmonellosis in cattle were not investigated in Kenya and Uganda. The prevalence of Brucellosis and the total loss as share of GDP are lower in Ethiopia than the other two countries, even though fatality rates are higher. Bovine TB prevalence rates are higher in Ethiopian intensive systems compared to the other countries, and even though fatality is lower, the value of animal and production loss with respect to the cattle GDP is very high.

Table 18. Prevalence, fatality and cost of brucellosis in Ethiopia, Kenya and Uganda

Brucellosis	Prevalence		Fatality		Total animal and production loss as % of cattle GDP	
Production systems	Intensive	Extensive	Intensive	Extensive	Intensive	Extensive
Ethiopia	2%	1%	5%	10%	1%	1%
Kenya	4%	9%	2%	1%	3%	5%
Uganda (beef)	10%	10%	5%	5%	2%	9%

Table 19. Prevalence, fatality and cost of bovine tuberculosis in Ethiopia, Kenya and Uganda

Bovine TB	Prevalence		Fatality		Total animal and production loss as % of cattle GDP	
Production systems	Intensive	Extensive	Intensive	Extensive	Intensive	Extensive
Ethiopia	23%	4%	7%	13%	14%	4%
Kenya	1%	2%	21%	25%	2%	4%
Uganda (beef)	4%	4%	22%	22%	1%	10%

Public Health Impacts of the Zoonotic Diseases

The principal socio-economic effects of brucellosis in humans are reflected in medical care and reduced productivity (Nicoletti, 2010). The disease in humans is characterized with prolonged illness resulting in loss of vitality, loss of income and manpower, long-term treatment, and medical care costs. The impact of bovine tuberculosis can be severe when combined with immune system compromising disease conditions such as HIV that allow for co-infection and increased morbidity and mortality (Miller and Sweeney, 2013). Salmonella is a major cause of foodborne disease globally. The global burden of zoonotic disease from Salmonella is high (Miller and Sweeney, 2013). An estimated 93.8 million illnesses and 155 000 deaths result each year from non-typhoidal Salmonella, the clear majority of which are foodborne (Majowicz *et al.*, 2010). In the European Union alone over 100 000 human cases are reported each year with an estimated overall economic burden as high as 3 billion EUR a year (EFSA 2018). Salmonella strains that are resistant to a range of antimicrobials have emerged since the 1990s and are now a serious public health concern being 1 of 4 key global causes of diarrhoeal diseases (WHO 2018). Salmonella is most prevalent where livestock are farmed intensively (Leedom and Spickler, 2013). Transmission is generally through the faecal-oral route and humans generally contract salmonellosis through consumption of contaminated food including meat, eggs, and unpasteurized milk products. Less often Salmonella is transmitted through green vegetables contaminated by manure. Humans are much less susceptible to anthrax than herbivores. Infection occurs by contact to infected animals or contaminated animal products (WHO 2008; Hörmansdorfer, 2015). Thus, human anthrax is an occupational disease of farmers, veterinarians, butchers, slaughterhouse workers or workers in the fur, leather or wool industry, but also in transport or dock workers (Hörmansdorfer, 2015; Cook *et al.*, 2017).

Recent estimates of the burden of zoonotic disease indicate that zoonoses contribute to 26 % of the DALYs lost to infectious disease and 10 % of the total DALYs lost in low income countries, respectively, and to 1 % of DALYs lost to infectious disease and to 0.02 % of the total disease burden in high income countries (Grace *et al.* 2012). Particularly in low income countries, this burden is amplified by losses associated with malnutrition, also closely linked to zoonotic disease (Grace *et al.* 2012). The Global Burden of Disease dataset registered a total of 38 million DALYs in 2016 in Ethiopia (GBD, 2018). The sum of DALYs caused by the four diseases calculated in this study is 424 347, 1.1 percent of the total.

In Ethiopia, the total disability-adjusted life years lost due to brucellosis among livestock keepers and consumers are estimated at 71 762 and 35 581 DALYs, respectively. In monetary terms these losses are equivalent to USD PPP 225.42 million per annum or 0.13 percent of the total GDP. These estimates are 35 590 and 6 086 DALYs, 87.52 million USD and 0.05 percent of GDP for; 187 596 and 6 045 DALYs, 406.65 million USD and 0.23 percent of GDP for anthrax; 76 682 and 5 001 DALYs, 171.53 million USD and 0.10 percent of GDP for salmonellosis, in that order.

We compare results of brucellosis and bovine tuberculosis to Kenya and Uganda as presented in Tables 20 and 21. Prevalence is lower for brucellosis and similar for bovine tuberculosis in Ethiopia than in the other two countries. Fatality rates are much higher, suggesting that treatment might be less available than in the other two countries. The overall economic loss in terms of GDP is however much lower than in Kenya and Uganda.

Table 20. Prevalence, fatality and public health costs of brucellosis in Ethiopia, Kenya and Uganda

Brucellosis (Human)	Prevalence		Fatality		Total social cost as % of GDP
	Cattle keepers	Consumers	Cattle keepers	Consumers	All
Ethiopia	0.2%	0.1%	4%	7%	0.13%
Kenya	7%	0.5%	1%	0.4%	1.7%
Uganda (beef)	2.4%	0.1%	0.6%	1%	0.35%

Table 21. Prevalence, fatality and public health costs of bovine tuberculosis in Ethiopia, Kenya and Uganda

Bovine TB (Human)	Prevalence		Fatality		Total social cost as % of GDP
	Cattle keepers	Consumers	Cattle keepers	Consumers	All
Ethiopia	0.1%	0.1%	19%	20%	0.05%
Kenya	0.1%	0.03%	8.5%	5%	0.14%
Uganda (beef)	0.1%	0.1%	8%	6%	0.14%

5. Conclusion

Full assessment of the economic and social impacts of zoonotic diseases is challenging particularly where sources of reliable information and the means to acquire them are limited. In this study we attempted to assess the value of losses due to morbidity and mortality in animals and humans due to four zoonotic diseases in Ethiopia.

The increase of complexity of livestock production and the associated value chains has led to changes in the food systems, which in turn carry new challenges from zoonotic diseases in particular their impact, and the costs of surveillance, control and prevention. Direct losses to the animal and public health sectors, connected mainly to value losses due to morbidity and mortality in humans and animals, and indirect losses, such as the economic cost caused by the reaction to diseases and the limiting of its negative effects, all contribute to this negative impact. Morbidity and mortality of animals due to zoonotic diseases carry also other losses related to the wider social, cultural and economic value of animals and their health and welfare to people. In Ethiopia, cattle are the main source of livelihoods, income and employment, they provide draught power and organic fertilizer, and serve as a form of insurance and status to livestock keepers in the different production systems.

Ethiopia is particularly vulnerable to the impacts of zoonotic diseases due to the very close relationship and interaction between livestock and humans and since more than 80 percent of households in the country keep livestock. In mixed crop-livestock system, humans and livestock may dwell under the same roof. Several cattle farms, mainly dairy, are also found within urban settings – for instance, there were ~ 5 200 dairy farms in Addis Ababa city alone (Bogale *et al.,* 2014). Moreover, about 82 percent of the milk is supplied to consumers unpasteurized and rural communities including pastoralists have the habit of drinking raw milk and eating raw meat. These factors constitute significantly high risk and burden of zoonotic diseases emanating from cattle production systems.

It is imperative that the importance of evaluating the impact of zoonoses to facilitate decision-making increases because of the imminent changes in the size and form of livestock production. However, currently there are difficulties to get data to measure impact of zoonoses. We experimented with a new methodology, including the implementation of an expert elicitation protocol and the assessment in monetary terms of zoonotic diseases on society. Results suggest impacts of zoonotic diseases are high, both from a livestock and human health perspective. This support the importance of a one-health approach. Ethiopia may consider refining the expert elicitation protocol and expand it to other diseases to provide information base for decision makers.

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APPENDIX

A1. DATA SOURCES

- **Protocol data**: After a thorough review of available literature and data, the ASL 2050 team designed an Expert Elicitation Protocol to gather information needed to calculate the economic and public health impact of the priority diseases in the countries. More than 250 experts were interviewed in 6 countries. The questions were asked in relative terms (i.e. per 1 000 cattle, per 100 000 consumers etc.) and were converted to national numbers using information from the production system briefs (animal population), number of livestock keepers (household surveys) and number of consumers (World Bank Consumption Database).
- **Household survey data:** The Ethiopia Socioeconomic Survey 2015/16 (Central Statistical Agency) was used to determine the number of households keeping livestock.
- **World Bank Consumption Database:** The World Bank Consumption Database provides information on the share of households consuming cattle and poultry products.
- **Global Livestock Environmental Assessment Model (GLEAM):** The GLEAM is a GIS framework that simulates the bio-physical processes and activities along livestock supply chains under a life cycle assessment approach. The aim of GLEAM is to quantify production and use of natural resources in the livestock sector and to identify environmental impacts of livestock in order to contribute to the assessment of adaptation and mitigation scenarios to move towards a more sustainable livestock sector. Dressing rates, estimates on share of adult cow population and calving rates were provided by the model.

A2. EQUATIONS

We determine the economic and public health impact in monetary terms, as a sum of the value of animals lost due to the diseases, the loss from salvage slaughtering and culling, the loss from production decrease and the social cost of human mortality and morbidity. The following sections describe the calculations and the sources of data for these components.

Economic and Public Health impact (USD)
=
Value of animals lost (I)
+
Loss from salvage slaughter and culling (II)
+
Loss from production decrease (III)
+
Social cost of human mortality (IV.1)
+
Social Cost of human morbidity (IV.2)

(I) <u>Value of animals lost</u>

The value of animals lost comprises three main components: the value of the animals that died due to the disease, the value of animals whose carcass had to be condemned and the value of calves who were not born due to fertility decrease caused by the disease:

Value of animals lost
=
Number of animals died due to disease (I.1)
*
Animal farmgate price (I.2)
+
Number of carcasses condemned (I.3)

*
Animal farmgate price (I.2)
+
Number of unborn calves (I.5)
*
Calf farmgate price (I.6)

I.1 **Number of animals died due to the disease**: The number of animals died due to the disease was asked in the protocol per 1,000 animals for Brucellosis, Bovine TB, Anthrax and Salmonellosis and per 1,000,000 birds for HPAI.
I.2 **Adult animal farmgate price:** To attach a monetary value to the number of animals lost, country data on the adult animal farmgate price was used.
I.3 **Number of carcasses condemned**: The number of carcasses condemned was asked in relative terms (see I.1) for cattle related diseases.
I.4 **Number of unborn calves:** The Protocol gathered information on the fertility loss in percentages due to cattle related diseases. To estimate the number of unborn calves, we determined the number of calves that were likely to be born among the infected animals in the given year by calculating the number of survivors as the difference between cases and deaths available from the Protocol and multiplying this with the share of adult cows and the calving rate that is available by production system in GLEAM. Then we applied the fertility loss in percentages to the number of calves that were to be born among survivors:

Number of unborn calves (I.4)
=
Number of survivors (Protocol: cases-deaths)
*
Share of adult cows (Country data and literature)
*
Calving rate (Country data and literature)
*
Fertility loss (Protocol)

(II) Salvage slaughter and culling

Carcasses (or parts thereof) may be condemned after culling (or salvage slaughter), therefore we must subtract the number of carcasses condemned to avoid double counting. The loss due to culling or salvage slaughtering one animal is determined as the difference in the sales value of a healthy adult and the salvage value. The salvage value of an animal has been calculated using a discount rate on the full price, given by experts consulted during the validation of the Protocol data.

Loss from salvage slaughter and culling (cattle)
=
(Number of salvage slaughter + Number of animals culled – Number of carcasses condemned) (II.1)
*
(Animal farmgate price (I.2) – Salvage value (II.2))

II.1 **Number of salvage slaughter, animals culled and carcasses condemned**: available from Protocol data, in relative terms (per 1,000 cattle) and converted to absolute numbers using cattle population data from the countries' Production Systems Spotlights.

II.2 **'Salvage value' of culls / salvage slaughter:** A discounted price of an animal culled (or salvage slaughtered), estimated using the discount rate given by experts consulted at the validation of Protocol results.

(III.) Loss from production decrease

The animals infected but not dead suffer a decrease in productivity, notably weight loss, milk production decrease and fertility loss. To evaluate the economic impact of a disease we estimate the value of total decrease in production:

Loss of production decrease (cattle)
=
Loss of meat production (III.1)
+
Loss of milk production (III.2)

(III.1) Loss of meat production

Loss of meat production
=
Number of survivors (cases-deaths, Protocol)
*
Weight loss in kilograms per head (Protocol)
*
Dressing percentage (Country data and literature)
*
Price of beef per kg (Country data, FAOSTAT)

(III.2) Loss of milk production

Loss of milk production
=
Loss from foregone lactation period (III.2.1)
+
Loss from milk productivity decrease (III.2.2)

III.2.1 **Loss from forgone lactation period**:

Loss from foregone lactation period
=
Number of unborn calves (see I.5 above)
*
Average litres per lactation (Country data by production system)

III.2.2 **Loss from milk productivity decrease**:

Loss from productivity decrease
=
Number of cows affected by productivity decrease (II.2.1)
*
Milk loss in litres per lactation period (Protocol)

II.2.1 Number of cows affected by productivity decrease: The number of cows affected by productivity loss are those survivors who were likely to have a calf and were not affected by the fertility loss (i.e. they had a calf):

Number of survivors (cases-deaths from Protocol)
*
Share of adult cows (Country data and literature)
*
Calving rate (Country data and literature)

*

(1-Fertlity loss) (Protocol)

Variables:

Number of livestock keepers by production system: We estimate the number of people who are posed to risk of disease through direct contact with animals. We use household survey data (LSMS and DHS) to estimate the number of people living in households keeping cattle and poultry. We assume that the distribution of livestock keepers among production systems are the same as the distribution of the number of farms among production systems. We use the animal population per production system and the average herd size to estimate the number of farms per production system.

Number of consumers who are not livestock keepers: In cases where people can be affected by the disease through consumption, we need to calculate the number of consumers but to avoid double-counting, we do not include livestock keepers. We determine the number of non-livestock keepers using household survey information described above. We use the share of households reporting consumption of cattle and poultry products using the Global Consumption Database of the World Bank.[8]

VI.1 DALY

A disability adjusted life years (DALYs) are calculated as the sum of the years of life lost due to premature mortality in the population and the equivalent "healthy" years lost due to disability during the sickness of survivors.

DALY
=
Number of deaths (Protocol)
*
(Average life expectancy (World Bank) – Average age of infection (Protocol))
+
Number of survivors (Protocol)
*
Duration of disease (Protocol)
*
DALY weight (WHO)

IV.2 Willingness to pay for a DALY

To attach a monetary value to a DALY, we need to determine the willingness to pay for a healthy year of life, i.e. the WTP to avoid a DALY. We use the value of statistical life calculated by the US Department of Transport, and translate it into a yearly value using the expected life span and a discount rate, following the methodology of the OECD. Then we translate this value into country context using a benefit transfer methodology. This methodology takes into account the differences in GDP per capita and the elasticity of the willingness to pay for a healthy life (i.e. how WTP changes as income grows).

Willingness to pay for a healthy life year
=
Willingness to pay for a healthy life year in the United States (PPP) (see below)
*
$(\text{GDP per capita in PPP of country} / \text{GDP per capita in PPP of US})^{\text{elasticity}}$

Willingness to pay for a healthy life in the United States (PPP)
=
Value of Statistical Life (US Department of Transport)
/
∑t=0..T(1+discount rate)t

[8] http://datatopics.worldbank.org/consumption/detail

I8675EN/1/02.18