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Economic losses occurring due to brucellosis in Indian livestock populations

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Abstract

Brucellosis is a serious public health issue in India. Estimation of economic losses occurring due to brucellosis is required to help formulate prevention and control strategies, but has not been done in India. We estimated economic losses due to brucellosis by sourcing prevalence data from epidemiological surveys conducted in India. Data for livestock populations were obtained from official records. Probability distributions were used for many of the input parameters to account for uncertainty and variability. The analysis revealed that brucellosis in livestock is responsible for a median loss of US $ 3.4 billion (5^{th}–95^{th} percentile 2.8–4.2 billion). The disease in cattle and buffalo accounted for 95.6% of the total losses occurring due to brucellosis in livestock populations. The disease is responsible for a loss of US$ 6.8 per cattle, US$18.2 per buffalo, US$ 0.7 per sheep, US$ 0.5 per goat and US$ 0.6 per pig. These losses are additional to the economic and social consequences of the disease in humans. The results suggest that the disease causes significant economic losses in the country and should be controlled on a priority basis.

Keywords: bovine brucellosis; ovine brucellosis; porcine brucellosis; economic loss; India; developing countries; zoonoses; partial budgeting

Highlights

- This is the first systematic analysis of the economic losses occurring due to brucellosis in livestock populations in India.
- The analysis revealed that brucellosis in livestock is responsible for a median loss of US $ 3.4 billion (5th–95th percentile 2.8–4.2 billion).
- There is urgent need to formulate intervention policies for prevention and control of this disease in India.

1. Introduction

First recorded in India in 1887 (IVRI, 1977), brucellosis has now become endemic throughout the country with prevalence of the disease ranging from 6.5% to 16.4% in different species of livestock (Aulakh et al., 2008; Kollannur et al., 2007; Lone et al., 2013; Shome et al., 2006; and Thoppil, 2000). Many factors such as absence of a control policy, failure to vaccinate young female calves, non implementation of test and slaughter, ban on cow slaughter in many Indian states, absence of treatment regimen and usual practice of selling positive reactor animals to other farmers are responsible for the spread of this disease among livestock in India.

The disease is a serious occupational hazard for humans, and has been found to be associated with farm workers, veterinarians, veterinary pharmacists, animal attendants, abattoir workers and laboratory attendants (Young, 1983). The seroprevalence of the disease in India has been found to be as high as 6.3% in veterinarians, 7.9% in veterinary pharmacists, 8.8% in animal attendants, 20.0% in laboratory workers, 10.5% in dairy farmers and 6.4% in abattoir workers (Bedi et al., 2007; Deepthy et al., 2013).

Brucellosis is being considered as an important economic concern (ILRI, 2012) with losses occurring in the human, livestock and wildlife populations. However, most data and evidence on the economic burden of brucellosis and benefits of its control are from the developed world even though the losses are believed to be higher in the developing countries (McDermott et al., 2013). The present paper presents economic losses occurring due to brucellosis in India.

2. Methods

Losses occurring due to brucellosis as per Bennett (2003) and McInerney, (1996) were estimated for sheep, goat, cattle, buffalo and pigs. The disease prevalence data were obtained from serological surveys (Aulakh et al., 2008; Kollannur et al., 2007; Lone et al., 2013; Shome et al., 2006; Thoppil, 2000) and livestock population data from official records (Table 1–supplementary material) (DAHD & F, 2010). Many input parameters such as decrease in carcass weight, milk production and draught power, life expectancy and reproductive rates were obtained from the published scientific literature (Table 1–supplementary material). The prices of animal carcasses and milk were obtained through market surveillance or from published scientific literature (Table 2–supplementary material). All the analyses were conducted using R-statistical program (R statistical package version 3.0.1. R Development Core Team, http://www.r-project.org). The detailed assumptions and the equations used in the analysis are presented as supplementary material in Tables 1 and 3, respectively.

Table 1. Total losses associated with brucellosis in livestock in India estimated in the study

Species	Type of losses	Million US Dollars (1 US $ = Rs. 60/-)	
		Median	5th – 95th percentile
Sheep	Production losses	44.9	41.3 – 48.8
	Product losses	2.2	0.6 – 3.6
	Foregone losses due to fecundity reduction	0.8	0.2 – 1.7
	Death losses	1.0	0.5 – 1.7
	Total losses	48.9	44.7– 53.6
Goat	Production losses	57.0	44.4– 72.4
	Product losses	9.2	6.0– 13.2
	Foregone losses due to fecundity reduction	3.4	1.00 – 7.0
	Death losses	1.8	0.9– 3.3
	Total losses	71.6	55.6– 91.4
Cattle	Production losses	736.2	687.0– 788.6
	Product losses	291.3	152. 7 – 469.8
	Foregone losses due to fecundity reduction	129.7	39.3– 280.4
	Death losses	185.5	86.9– 367.8
	Total losses	1357.1	1077.7– 1742.4
Buffalo	Production losses	986.6	739.7 – 1265.8
	Product losses	561.7	337.6– 878.7
	Foregone losses due to fecundity reduction	145.7	42.6– 319.5
	Death losses	209.9	97.5– 421.2
	Total losses	1918.3	1374.2– 2651.8
Pig	Production losses	3.8	3.1 – 4.5
	Product losses	1.8	0.5 – 3.1

	Foregone losses due to fecundity reduction	1. 5	0. 5 – 2.8
	Death losses	0.1	0.1 – 0.2
	Total losses	7.1	5.2 – 9.5
Total Losses		**3425.3**	**2788.7 – 4239.0**

Production losses for each species were calculated as losses occurring due to abortion in pregnant animals (equations 1 to 5), sterility (equation 6) and temporary infertility in animals that aborted (equations 7–8). Losses for each species were added to estimate total animal production losses.

Product losses were estimated by estimating and adding the losses due to decrease in milk production and carcass weight. Losses in milk production were estimated for the cattle, buffalo and goat industries as shown in equations 9-13 and then added. The losses in carcass weight were estimated for all the selected species considering the number of infected animals being slaughtered and the reduction in carcass weight (equations 14 - 17).

Forgone production due to fecundity reduction was estimated by accounting for foregone meat, milk and draught power in cattle; foregone milk and meat in buffalo; foregone milk and meat in goat; foregone meat and wool in sheep and foregone meat in pigs (see equations 18 – 41). To avoid double counting of losses, we only estimated foregone losses in the 85% of the breedable infected females that did not abort or become sterile but were infected with *Brucella* species. Foregone draught power for bull cattle was estimated by calculating the time required for an animal to cultivate a hectare of land and using market values for rent charged by tractor owner to work one hectare of land. This enabled us to estimate the cost of average draught power equivalence bull cattle per hour which was extrapolated to estimate draught energy produced per animal over lifetime.

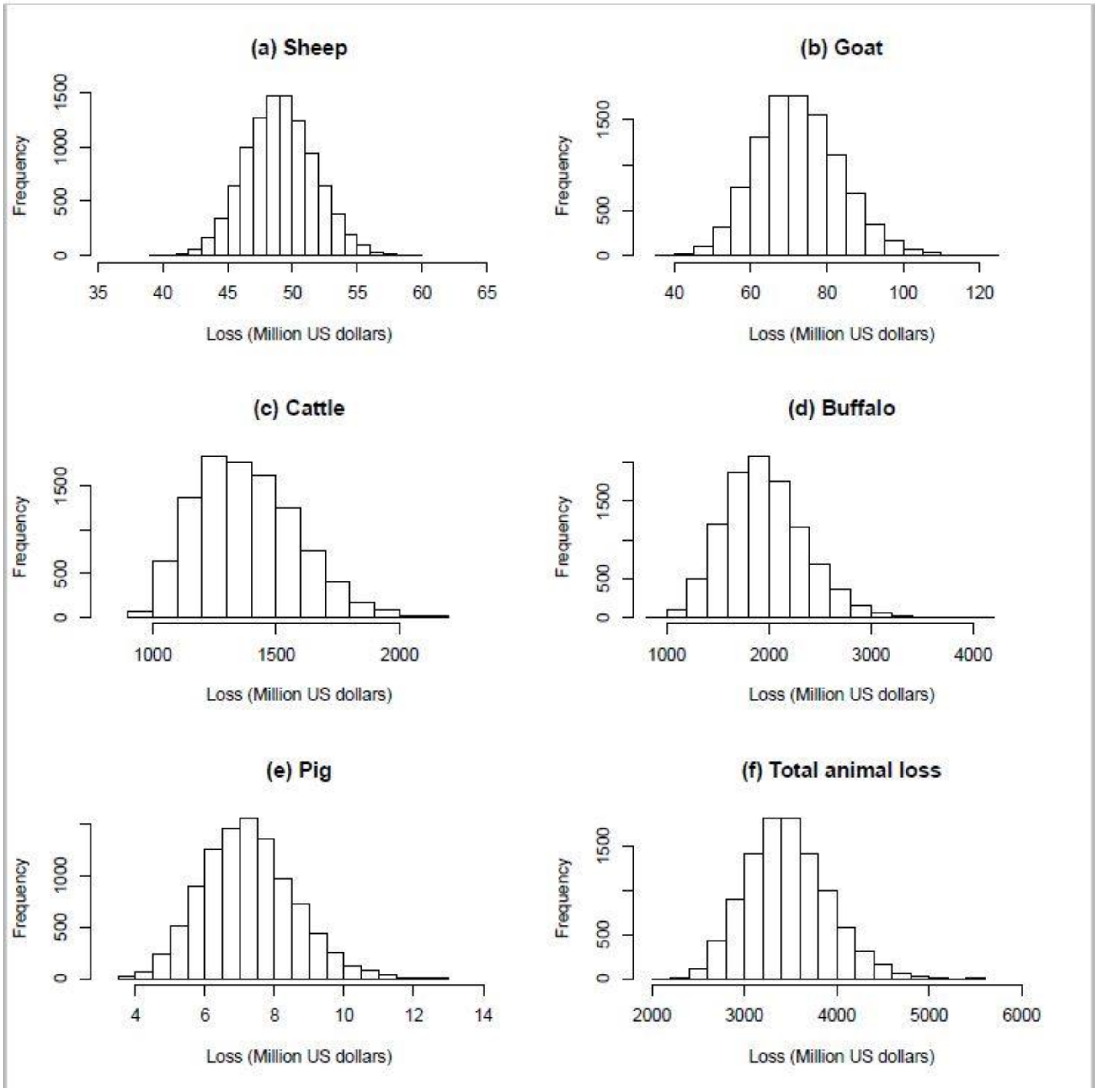
Death losses included losses due to peri natal mortality in young animals and mortality in adult animals that aborted. The numbers of young ones with peri natal mortality were estimated as per equation 42 for each species. For estimating losses occurring due to death of adult females, the losses for the remaining productive life of the animal were estimated similar to the estimation of foregone losses due to unborn animals. Total producer losses due to death in animals for each species were estimated and summed up to estimate total producer losses due to death in all the livestock populations.

Beta probability distributions were applied to account for uncertainties in the prevalence of livestock brucellosis. Uniform distributions were used for estimating number of aborted animals, aborted animals that become sterile, perinatal mortality and mortality rate in aborted animals which are infected with brucellosis (Bernues et al., 1997). We also applied triangular distributions for estimating decrease in fecundity, carcass weight, milk production, draught power and wool output. To estimate actual farmer profits due to decrease in fecundity, uniform distributions were applied in the range of 10-20% as benefits could vary under different rearing conditions. The 5^{th} and 95^{th} percentiles for the estimates were calculated by running Monte Carlo simulations for 10,000 iterations.

3. Results

Results presented in Table 1 suggest that brucellosis caused a loss of US $ 3.4 billion in total (Fig. 1). The losses in cattle and buffalo industries accounted for 95.6% of the total losses. The median production losses due to abortions, temporary infertility and sterility in adult animals were found to be US $ 735.7 million and US $ 985.4 million in cattle and buffalo, respectively. These losses significantly contributed towards losses occurring in cattle and buffalo industries. The loss in meat and milk resulted in a loss of US $ 292.9 million and US $ 557.1 in cattle and buffalo industries. The loss in meat resulted in a median loss of US $ 1.8 million in pig industry. Foregone milk, meat and draught power due to reduction in fecundity resulted in a median loss of US $ 131.7 million in the cattle industry. Foregone milk and meat due to reduction in fecundity in buffalo resulted in a median loss of US $ 145.8 million in buffalo industry. A median loss of 185.4 million and 210.8 million occurred due to death of adult animals and peri natal mortality in cattle and buffalo, respectively. The disease was found to be responsible for a loss of US$ 6.8 per cattle, US$18.2 per buffalo, US$0.7 per sheep, US$ 0.5 per goat and US$ 0.6 per pig in India.

Figure 1. Distributions of the losses due to brucellosis in India estimated in the study (in US dollars) (supplementary material).



4. Discussion

This is the first systematic analysis of economic losses occurring due to brucellosis in livestock populations in India. The losses were found to be as much as 18.7 times higher than that reported for cystic echinococcosis in livestock species in previous studies (Singh et al., 2014). Brucellosis is also a serious economic concern in several other countries (Samartino, 2002, Roth et al. 2003, Santos et al., 2013) suggesting that brucellosis causes huge economic losses in the developing countries.

The decrease in milk production most significantly contributed towards foregone production due to fecundity reduction associated with brucellosis. This is a serious issue as a large Indian human population is dependent on the dairy industry for their livelihood. On the other hand, losses in the cattle meat industry were fairly low. As discussed in the previous studies, this disparity is due to ban on cow slaughter in most of the Indian states (Singh et al., 2014).

We selected prevalence estimates from the peer reviewed literature. The disease is endemic in India and the animal husbandry, production and management practices are almost similar throughout the country. As per a report of International Livestock Research Institute, 2011 (cited in Mcdermott et al., 2013), a brucellosis prevalence of 16.0 % has been reported for ruminants in South Asia which is comparable to the data used for bovine brucellosis in the present study. Many other studies have also reported comparable prevalence of the disease throughout the country. For example, a prevalence of 11.9% of bovine brucellosis has been reported from Gujarat, western India (Patel et al., 2014). Similarly, prevalence of *Brucella* antibodies by an avidin biotin enzyme-linked immune sorbent assay was found to be 12.1% (true prevalence, 11.2%) in cattle and buffalo populations in Punjab state of north India (Dhand et al., 2005). A south Indian study reported a bovine brucellosis prevalence of 18.4% using milk ring test (Mohamand et al., 2014). Thus, although not perfect, we believe that our data are the best available estimates of disease prevalence in the country.

Sensitivity and specificity information about the diagnostic tests used was not generally available from the papers from which we sourced prevalence information. Therefore we used apparent, rather than true prevalence, for estimation of losses. Using sensitivity and specificity information of ‘similar’ tests from some secondary sources indicated that the true prevalence would have been higher in buffaloes and lower in all other species compared to the apparent prevalence. Therefore, the losses estimated would be different using true prevalence estimates but could not be estimated in this study.

Most of the data were sourced from studies conducted in India or from official records in India and only data that was unavailable in India was sourced from overseas. However, we believe these values to be quite reasonable and applicable under present Indian conditions. For example Hugh Jones et al. (1975) carried out an assessment of eradication of bovine brucellosis in England and Wales in 1975. The assumptions in that study were used in the current analysis. The prevalence of positive reactors in England and Wales in 1973 was believed to be 11.5% (Hugh Jones et al., 1975) which is quite similar to present prevalence of bovine brucellosis in India. Similarly, we also sourced some of the data for assumptions from the studies carried out in California 25-40 years ago (Carpenter, 1976). These assumptions have also been used in estimating losses occurring due to brucellosis in New Zealand (Shepherd et al., 1982). The abortions attributable to *Brucella* infections were common in New Zealand in 1960s (Moller, 1967) and serological surveys at that time indicated that infection was widespread in cattle populations (Adlam, 1978). The current situation of bovine brucellosis in India is not very different to these countries some 40-50 years ago. The Indian dairy industry and production system is still believed to be 40-50 years behind the developed countries and dairying being carried out under the primitive conditions. We believe that further studies should be carried out for refinement of these losses once more data about brucellosis epidemiology is available from India. For example, we would like to obtain more accurate estimates of number of females that abort, females that show temporary infertility and fecundity reduction so as to refine and more accurately predict losses occurring due to brucellosis in livestock populations in India.

To account for variability and uncertainty, we applied uniform distribution for estimating number of aborted animals, aborted animals that become sterile, perinatal mortality and mortality rate in aborted animals as we believe that losses will be uniformly distributed over the entire distribution. The uniform distributions have also been previously applied in studies done to estimate production losses for other diseases (Benner et al., 2010; Budke et al., 2005). We applied triangular distributions for estimating decrease in fecundity, carcass weight, milk production, draught power and wool output as extreme values were considered less likely. In addition, we used beta probability distributions in prevalence estimates. The beta probability distributions are routinely used to account for variability and uncertainty in prevalence estimates.

In India, brucellosis has also been reported from pet animals (Renukardhaya et al., 2002). High sero-prevalence of brucellosis has been reported in wild animals such as yaks (*Poephagus grunniens*) (Bandyopadhyay et al., 2009). The losses occurring due to brucellosis in these animals could not be estimated. Therefore, we believe our estimates are an underestimate of actual losses occurring among animals in India. Additionally, huge health, psychological and socioeconomic losses also occur among humans which could not be accounted in the present study but are planned to be evaluated in a future study.

4. Conclusion

For the first time, a systematic analysis of economic losses occurring due to brucellosis has been undertaken in India. Although losses from most other livestock diseases have not been estimated and a risk ranking or for all livestock diseases has not been performed, the economic losses estimated in the present study clearly provide the evidence that brucellosis is a serious concern in India and that there is urgent need to formulate policies for prevention and control of this disease in the country.

Conflict of interest statement

No financial or personal relationships between the authors and other people or organizations have inappropriately influenced (bias) this work.

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Table 1. Supplementary material

Epidemiological parameters used to estimate the economic losses associated with brucellosis in livestock, India

Parameter	Value	Range	Unit	Distribution	Reference
Sheep					
Population					
Total population	71558000	NA	Individual	Fixed	DAHD & F (2010)
Total breedable female population	53684000	NA	Individual	Fixed	DAHD & F (2010)
Annual pregnant sheep popn. of India	42947200	NA	Individual	Fixed	Calculation
No. of sheep slaughtered per year	23269000	NA	Individual	Fixed	DAHD & F (2010)
Prevalence of infection					
Prevalence of infection	6.50	NA	%	Beta (430, 6615)	Lone et al. (2013)
Production					
Sheep carcass	13		kg	Fixed	DAHD & F (2010)
Wool per Sheep	1.0	NA	Kg/year	Fixed	Banerjee (1991)
Mean lambing per year per ewe	1.25	0.9-1.6	Individual	Uniform	Banerjee (1991)
No. unborn lambs	82304	NA	Individual	Fixed	Calculation
Lamb mortality rate	10	NA	%	Fixed	NABARD (2010)
Goats					
Population					
Total population[a]	140537000	NA	Individual	Fixed	DAHD & F (2010)
Total breedable female	62489000	NA	Individual	Fixed	DAHD & F (2010)
Annual pregnant goat popn. of India	49991200	NA	Individual	Fixed	Calculation
In milk	28868000	NA	Individual	Fixed	DAHD & F (2010)
No. of goats slaughtered per year	50707000	NA	Individual	Fixed	DAHD & F (2010)

Parameter	Value	Range	Unit	Distribution	Reference
Prevalence of infection					
At inspection	6.49	NA	%	Beta (44, 677)	Shome et al. (2006)
Production					
Average carcass weight	10	NA	kg	Fixed	DAHD & F (2010)
Mean kidding per year per doe	2.67	2.01-3.33	Individual	Uniform	Banerjee (1991)
Average milk yield of goat	0.37	NA	kg/day	Fixed	DAHD & F (2010)
Lactation length	160	NA	day	Fixed	Banerjee (1991)
No. unborn kids	37624	NA	Individual	Fixed	Calculation
Kid mortality	15	NA	%	Fixed	NABARD (2010)
Cattle					
Population					
Total population[a]	199075000	NA	Individual	Fixed	DAHD & F (2010)
Total breedable female population	72915000	NA	Individual	Fixed	DAHD & F (2010)
Annual pregnant cattle popn. of India	58332000	NA	Individual	Fixed	Calculation
In milk	38928000	NA	Individual	Fixed	DAHD & F (2010)
No. of slaughtered cattle per year	2476000	NA	Individual	Fixed	DAHD & F (2010)
Prevalence of infection					
At inspection	9.30	NA	%	Beta (1246, 13396)	Kollannur et al. (2007)
Production					
Average carcass weight	90	NA	kg	Fixed	DAHD & F (2010)
Mean calving per year per cow	1	NA	Individual	Fixed	Banerjee (1991)
Average milk yield of cattle	4.505	2.14-6.87	Kg/day	Uniform	DAHD & F (2010)
Time required for one bullock pair to cultivate 0.33 hectare of land	6	NA	Hours	Fixed	Phaniraja and Panchasara (2009)

Parameter	Value	Range	Unit	Distribution	Reference
Percentage of females reared for milk	100	NA	%	Fixed	Singh et al. (2014)
Percentage of male population slaughtered	5	NA	%	Fixed	Singh et al. (2014)
Percentage of male population used for draught power	30	NA	%	Fixed	Singh et al. (2014)
Calf mortality	5	NA	%	Fixed	NABARD (2010)
No. of unborn calves	216157	NA	Individual	Fixed	Calculation
Average working hrs per year per draught cattle	360	NA	hr	Fixed	Calculation
Buffalo					
Population					
Total population[a]	105343000	NA	Individual	Fixed	DAHD & F (2010)
In milk	35479000	NA	Individual	Fixed	DAHD & F (2010)
Breedable Female population	54475000	NA	Individual	Fixed	DAHD & F (2010)
Annual pregnant buffalo popn. of India	43580000	NA	Individual	Fixed	Calculation
No. of slaughtered Buffalo per year	5884000	NA	Individual	Fixed	DAHD & F (2010)
Prevalence of infection					
At inspection	16.41	NA	%	Beta (32, 195)	Aulakh et al. (2008)
Production					
Average carcass weight	106	NA	kg	Fixed	DAHD & F (2010)
Mean calving per year	1	NA	Individual	Fixed	Banerjee (1991)
Average milk yield of dairy buffalo	4.57	NA	Kg/day	Fixed	DAHD & F (2010)
No. of unborn calves	130631	NA	Individual	Fixed	Calculation
Calf mortality	5	NA	%	Fixed	NABARD (2010)
Pigs					
Population					
Total population[a]	11134000	NA	Individual	Fixed	DAHD & F (2010)
No. of pigs slaughtered	6746000	NA	Individual	Fixed	DAHD & F (2010)
Total no. of breedable female	3055000	NA	Individual	Fixed	DAHD & F (2010)

Parameter	Value	Range	Unit	Distribution	Reference
Annual pregnant sow popn. of India	2444000	NA	Individual	Fixed	Calculation
Prevalence of infection					
At inspection	9.50	NA	%	Beta (72, 756)	Thoppil (2000)
Production					
Average weight of pig carcass	35	NA	kg	Fixed	DAHD & F (2010)
Mean no. of piglets per year	16	NA	Individual	Fixed	Banerjee (1991)
No. of unborn pigs	83072	NA	Individual	Fixed	Calculation
Piglet mortality	20	NA	%	Fixed	NABARD (2010)
Productivity losses – all livestock (assumptions)					
Percentage of abortion in infected animals	0.15	0.10- 0.20	%	uniform	Bernues et al. (1997);
Percentage of aborted animals which become sterile	0.2	0.10-0.30	%	uniform	Hugh Jones et al. (1975); Carpenter (1976);
Mortality risk in aborted animals	0.01	0.005-0.015	%	uniform	Shepherd et al. (1982); Gomez (1986);
Percentage of peri natal mortality in young ones from infected animals	0.10	0.05-0.15	%	Triangular	Murillo (1989)
Decrease in milk production	0.15	0.10-0.20	%	Triangular	
Decrease in carcass weight	0.05	0.0-0.10	%		
Temporary infertility in infected animals	2	NA	Months	Fixed	Hugh Jones et al. (1975)
Decrease in fecundity	5.5	0.0–11.0	% decrease per year	Triangular	Singh et al. (2014)
Decrease in draught power output	2	0.0–4.0	% decrease per year	Triangular	Singh et al. (2014)
Decrease in wool output	2.5	0.0–5.0	% decrease per year	Triangular	See text
Productive lifespan	35	NA	% of average lifespan	Fixed	See text
Farmer's benefit from unborn animal produce	15	10 – 20	%	Uniform	See text

Table 2. Supplementary Material

Cost parameters used to estimate the economic losses associated with brucellosis in livestock, India

Parameter	Average cost (in Rs.)	Reference
Sheep		
Sheep carcass	131.26 (Rs./Kg)	Ranjan and Rawat (2011)
Cost of abortion	500	Market value
Cost of temporary infertility in each animal	700	Market value
Cost of a sterile female animal	700	Market value
Sheep wool	38	NABARD (2010)
Goats		
Goat carcass	131.26 (Rs./Kg)	Ranjan and Rawat (2011)
Cost of abortion	1000	Market value
Cost of temporary infertility in each animal	700	Market value
Cost of a sterile female animal	500	Market value
Goat's milk at farm gate	20	Market value
Cattle		
Beef carcass	112.18 (Rs./Kg)	Ranjan and Rawat (2011)
Cost of abortion	6500	Market value
Cost of temporary infertility in each animal	5500	Market value
Cost of a sterile female animal	10000	Market value
Cow's milk	26	Market value
Buffalo		
Buffalo carcass	112.18 (Rs./Kg)	Ranjan and Rawat (2011)
Cost of abortion	6500	Market value
Cost of temporary infertility in each animal	5500	Market value
Cost of a sterile female animal	8000	Market value
Buffalo's milk	30	Market value

Pigs		
Pig carcass	95 (Rs./Kg)	Wright et al. 2010
Cost of abortion	500	Market value
Cost of temporary infertility in each animal	700	Market value
Cost of a sterile female animal	500	Market value
Rent charged by tractor owner to work one hectare of land	1125 (Rs.)	Market value

Table 3. Supplementary Material

Equations used for estimating losses occurring due to brucellosis in livestock populations in India.

Losses due to brucellosis in livestock populations			
Animal Production Losses			
Losses due to abortions			
Pregnant population of India	=	Total breedable female livestock population of India × 0.8	...(1)
Total pregnant population infected with brucellosis	=	Pregnant population of India × prevalence of infection	...(2)
Number of deaths among infected animals that aborted	=	Total pregnant population infected with brucellosis × proportion of animals aborted × mortality risk in aborted animals	...(3)
Number of survivors among infected animals that aborted	=	Total pregnant population infected with brucellosis – Number of deaths among infected animals that aborted	...(4)
Losses due to abortions occurring due to brucellosis	=	Number of survivors among infected animals that aborted × cost of each abortion	...(5)
Losses due to sterility in animals that aborted			

Losses due to sterility in aborted animals	=	Total pregnant population aborted due to brucellosis x proportion of aborted animal which become sterile x replacement cost of a sterile animal	... (6)
Losses due to temporary infertility in animals			
Total breedable female population infected with brucellosis	=	Total breedable female population of India per year × prevalence of infection	... (7)
Losses due to temporary infertility in animals	=	Total breedable female population infected with brucellosis x cost of temporary infertility in each animal	... (8)
Animal Product Losses			
Losses in milk production			
Number of infected 'in milk' animals	=	Total number of female animals in milk × Prevalence of infection	. (9)
Milk production per animal per lactation	=	Average milk production per animal per day × lactation length (days)	. (10)
Milk loss per animal per annum due to brucellosis	=	Milk production per animal per lactation × Proportional reduction in milk production due to brucellosis per year	. (11)
Milk loss due to brucellosis	=	Milk loss per animal due to brucellosis × Number of infected 'in milk' animals	. (12)
Cost of lost milk in animals	=	Total milk loss due to brucellosis × Price of milk	. (13)
Losses in carcass weight			
Number of infected animal slaughtered per year	=	Number of animal slaughtered per year × Prevalence of infection at inspection	... (14)

Loss of carcass weight per animal due to brucellosis	=	Average weight of carcass × Proportional reduction in carcass weight	... (15)
Total loss of carcass weight	=	Number of infected animal slaughtered per year × Loss of carcass weight per animal due to brucellosis	... (16)
Cost of carcass weight loss in animals	=	Total loss of carcass weight × Price of meat	... (17)
Forgone production due to fecundity reduction			
Number of infected breedable females	=	Total breedable female population × Prevalence of infection at inspection	... (18)
Number of infected breedable females having fecundity reduction		Number of infected breedable females – Total pregnant livestock population aborted due to brucellosis	... (19)
Number of unborn offspring	=	Number of infected breedable females having fecundity reduction × Mean numbers of offspring per year per animal × Decrease in fecundity	... (20)
Number of unborn offspring that would have survived	=	Unborn offspring × (1 – Newborn offspring mortality rate)	... (21)
Number of unborn offspring infected with brucellosis	=	Unborn offspring that would have survived × Prevalence of infection at inspection	... (22)
Number of healthy unborn offspring without brucellosis	=	Unborn offspring that would have survived – Unborn offspring infected with brucellosis	... (23)
Number of unborn male or female offspring without brucellosis	=	Healthy unborn offspring without brucellosis × Percentage of male or female offspring born	... (24)
Foregone meat			
Number of unborn male offspring without brucellosis that would have been slaughtered	=	Unborn male offspring without brucellosis × Proportion of male animals that undergo slaughter	... (25)
Productive lifespan	=	Average lifespan × proportion of lifespan in production	...

			(26)
Meat loss due to brucellosis	=	Healthy unborn male offspring without brucellosis that would have been slaughtered × Average weight of carcass	... (27)
Cost of lost meat	=	Meat loss due to brucellosis × Price of meat	... (28)
Foregone draught power			
Unborn male offspring without brucellosis that would have been used for draught	=	Unborn male offspring without brucellosis × Proportion of male animals used for draught purpose	... (29)
Average draught power equivalence bull cattle per hour	=	Rent charged by tractor owner to work one hectare of land/ Time required by one bull cattle to cultivate same piece of land	... (30)
Draught energy produced per animal over lifetime	=	Average draught power equivalence bull cattle per hour × Working hours per year per animal x Productive lifespan	... (31)
Total cost of lost draught power	=	Draught energy produced per animal over lifetime × Healthy unborn male offspring without brucellosis that would have been used for draught purposes	... (32)
Foregone milk			
Milk produced per animal over lifetime	=	Milk produced per animal per lactation × Productive lifespan	... (33)
Total milk loss from unborn healthy female offspring	=	Milk produced per animal over lifetime × Healthy unborn female offspring without brucellosis	... (34)
Cost of lost milk	=	Total milk loss from unborn healthy female offspring × Price of milk	... (35)

Foregone wool			
Wool produced per animal over lifetime	=	Productive lifespan × Average wool produced per animal/year	... (36)
Wool loss due to brucellosis	=	Healthy unborn offspring without brucellosis × wool produced per animal over lifetime	... (37)
Cost of lost wool	=	Wool loss due to brucellosis × Price of wool	... (38)
Total foregone production due to fecundity reduction			
Losses from healthy unborn offspring without brucellosis	=	cost of lost meat + cost of lost draught power + cost of lost milk + cost of lost wool	... (39)
Losses due to fecundity reduction	=	Losses from healthy unborn offspring without brucellosis + Losses from healthy unborn offspring with brucellosis	... (40)
Actual loss in farmers' profit due to fecundity reduction	=	Total loss due to fecundity reduction × farmer's profit percentage	... (41)
Death losses			
Peri natal mortality in young animals			
Number of young ones with peri natal mortality	=	Total brucellosis infected pregnant female population not aborted x peri natal mortality risk in young ones born from infected animals	... (42)