Cost–benefit analysis of avian influenza control in Nepal

This paper (No. 26022015-00053-EN) has been peer-reviewed, accepted, edited, and corrected by authors. It has not yet been formatted for printing. It will be published in December 2015 in issue 34 (3) of the *Scientific and Technical Review*

S. Karki [1, 5]*, B. Lupiani [2], C.M. Budke [1], N.P.S. Karki [3], J. Rushton [4] & R. Ivanek [1]

(1) Department of Veterinary Integrative Biosciences, College of Veterinary Medicine and Biomedical Sciences, Texas A&M University, College Station, Texas, United States of America

(2) Department of Veterinary Pathobiology, College of Veterinary Medicine and Biomedical Sciences, Texas A&M University, College Station, Texas, United States of America

(3) Puja Pratisthan Marg, Baneshwor, Kathmandu, Nepal

(4) Department of Population and Production Health, Royal Veterinary College, Hatfield, London, United Kingdom

(5) Department of Livestock Services, Hariharbhawan, Lalitpur, Nepal

*Corresponding author: karki2@illinois.edu

Summary

Numerous outbreaks of highly pathogenic avian influenza A strain H5N1 have occurred in Nepal since 2009 despite implementation of a national programme to control the disease through surveillance and culling of infected poultry flocks. The objective of the study was to use cost–benefit analysis to compare the current control programme (CCP) with the possible alternatives of: *i)* no intervention (i.e. absence of control measures [ACM]) and *ii)* vaccinating 60% of the national poultry flock twice a year. In terms of the benefit–cost ratio, findings indicate a return of US$1.94 for every dollar spent in the CCP compared with ACM. The net present value of the CCP vs ACM, i.e.

the amount of money saved by implementing the CCP rather than ACM, is US$861,507 (the benefits of CCP [prevented losses which would have occurred under ACM] minus the cost of CCP). The vaccination programme yields a return of US$2.32 for every dollar spent when compared with the CCP. The net present value of vaccination vs the CCP is approximately US$12 million. Sensitivity analysis indicated that the findings were robust to different rates of discounting, whereas results were sensitive to the assumed market loss and the number of birds affected in the outbreaks under the ACM and vaccination options. Overall, the findings of the study indicate that the CCP is economically superior to ACM, but that vaccination could give greater economic returns and may be a better control strategy. Future research should be directed towards evaluating the financial feasibility and social acceptability of the CCP and of vaccination, with an emphasis on evaluating market reaction to the presence of H5N1 infection in the country.

Keywords

Avian influenza – Control programme – Cost–benefit analysis – Economic assessment – Nepal – Vaccination.

Introduction

Avian influenza (AI) is a highly contagious zoonotic disease caused by type A influenza viruses. These viruses infect several species of food-producing birds (chickens, turkeys, quails, guinea fowl, ducks, etc.), as well as pet and wild birds (1) and human populations (2). According to the pathogenicity of the particular strain of virus, the infection is classified as low-pathogenic AI or highly pathogenic AI (HPAI). All HPAI is caused by virus subtypes H5 and H7, but not all viruses of these subtypes are highly pathogenic (3). Following the first report, in 1996, of HPAI H5N1 on a goose farm in Guangdong Province, China (4), this strain has received much attention around the world because of its public health and economic importance. Among 650 laboratory-confirmed human cases of H5N1 that occurred globally between 2003 and January 2014, 386 persons died (5), and millions of birds either died or were culled in an effort to control the disease. In addition to the financial losses incurred through culling and mortality in birds, there are significant expenditures on H5N1 surveillance, prevention and control measures, and production losses such as a ban on business for a period of time. Indirect losses include ripple effects (such as price and demand shocks), trade impact, spill-over effects (such as effects on tourism and service sectors), and effects on the wider society, such as loss of workforce due to human sickness and mortality (6). Many of these impacts are related to human reaction to the presence and risk of H5N1.

Nepal faced its first outbreak of H5N1 in poultry in January 2009 in the eastern part of the country, 600 km from the capital of Kathmandu municipality, and outbreaks have continued to occur since then. However, no human cases of H5N1 have yet been recorded in Nepal. The Nepali government has been implementing a prevention and control programme for H5N1 since 2007. From 2007 to 2010 the programme was supported by the World Bank; since 2010 the Nepali government has supported the programme using its own resources. The programme involves surveillance, stamping-out operations, compensation, training and dissemination of information. These activities are directed under the bird flu control order (BFCO), Nepalese legislation that outlines the country's AI prevention and control practices. Nevertheless, despite ongoing control efforts, the number of H5N1 outbreaks has been increasing, and outbreaks have been reported in the Chitwan and Kathmandu districts, which are hubs for commercial poultry production. The increasing frequency of outbreaks in Nepal has led to questions on the effectiveness of the current control programme (CCP) and the societal resources spent on it, and to discussion about alternative control strategies such as vaccination of the national poultry flock.

A decision to change strategies can be facilitated by comparative economic analysis of a current control strategy and possible alternatives. A number of economic techniques, such as mathematical programming, network analysis, decision analysis, simulation and cost–benefit analysis (CBA), have been applied to decision-making on control of livestock diseases (7, 8, 9). The method of choice when assessing a change in strategy is frequently CBA (10), which estimates and compares the additional benefits of an intervention vs its additional costs over an extended period of time, using discounting to produce present values (11). The objective of the present study was to use a CBA framework to evaluate the economic worth of two alternatives to the H5N1 control programme currently implemented by the Nepali government: *i)* ceasing the CCP (i.e. absence of control measures [ACM]); *ii)* vaccinating 60% of the national domestic poultry flock twice a year. The baseline for the CCP was to have no intervention; for vaccination the baseline was the CCP. The economic profitability of moving from no intervention to the CCP (i.e. surveillance and culling policy) was tested against moving from the CCP to a vaccination policy.

Materials and methods

For each of the control options, the costs and benefits were estimated and evaluated as described in the followings sections. The estimated costs and benefits were discounted, i.e. the present value of costs (PVC) and the present value of benefits (PVB, i.e. the reduction in losses compared to another programme) were estimated by converting future values (FV) into present values (PV) to allow for their comparisons (9) using the formula of Marsh (1999) (12):

$$PV = FV / (1+r)^n \text{ (equation A)}$$

where n = number of years and r = discount rate per year. Lastly, the control programmes were evaluated using the ratio of the estimated PVB and PVC, i.e. the benefit–cost ratio (BCR), and the difference between the PVB and the PVC, i.e. the net present value (NPV). Unless otherwise stated, all monetary values in this study are expressed in United States dollars; as of 20 May 2013, the exchange rate was US$1 = 87.5 Nepali rupees (Central Bank of Nepal). A time frame of three years was used for evaluation of control measures to demonstrate the cumulative effect of the considered control options; this was based on the experience of the authors in Nigeria, where the costs and benefits of H5N1 control were analysed over a three-year period (13).

The Asian Development Bank has recommended use of a 10–12% discount rate for appraisal of projects in its member states, including Nepal (14). A 10% discount rate was therefore used on all costs and benefits to correct for the time value of money, and additional values of the discount rate were evaluated in a sensitivity analysis. The authors recognise that this rate is higher than for health projects. As part of the national prevention and control programme for H5N1, the Nepali government conducted a socio-economic analysis of a stamping-out operation through two non-governmental organisations: MountDigit Technology (P.) Ltd and Public Awareness Company (P.) Ltd in Kathmandu, Nepal. The report compiled as part of the analysis (15) provided important monetary information for the CBA.

In the process of CBA, several assumptions were made:

– Unless stated otherwise, control options were evaluated on the assumption of 19 H5N1 outbreaks per year under the CCP (this was the number of outbreaks that occurred in 2012).

– Ceasing to implement H5N1 control measures (i.e. ACM) would result in a 100% increase in the annual number of dead/culled birds (i.e. the number of H5N1-affected birds would double every year during the evaluation period). This assumption reflected the lack of data on infection trends under ACM in Nepal after implementation of the CCP in 2007; the implications of this assumption on CBA results were tested in a sensitivity analysis.

– The market loss resulting from H5N1 outbreaks under the CCP and ACM was assumed to be 10%, whereas it was assumed that there would be no market loss under the vaccination option. These assumptions (evaluated further in a sensitivity analysis), partly supported by a personal communication, reflected a complete lack of published data on the market loss from H5N1 infection in Nepal.

– The vaccination programme would prevent 80% of the losses (dead/ culled birds) that would otherwise occur under the CCP. In Egypt, a mass AI vaccination campaign that started in 2006 prevented about 80% of outbreaks in backyard poultry and more than 95% in commercial poultry (16). However, reporting is limited in Nepal, therefore data on commercial poultry were considered unreliable and for analysis it was assumed that 80% of outbreaks would be prevented by vaccination across all poultry production sectors in Nepal. The impact of this assumption on the CBA results was evaluated in sensitivity analysis.

– The poultry population would remain approximately constant during the evaluation period. This assumption reflected trends in the poultry population size in Nepal: the number of broilers and layers appears to have been slowly growing (15) and the number of backyard ducks (BD) has been decreasing; population sizes are fairly constant for other poultry groups (17). Thus, an overall constant population size during the evaluation period (Table I) was deemed appropriate.

The sections that follow explain the derivation process and sources of information for costs and benefits for each of the three control strategies: CCP, ACM and vaccination.

Current control programme

Costs under the current control programme

Costs incurred during the CCP originate from:

– cost of surveillance (including costs of farm visits, sampling and laboratory tests)

– cost of stamping-out operations and compensation

– cost of training, communication and information dissemination.

Each of these costs is elaborated below.

Cost of surveillance

Surveillance activities include farm visits to monitor for the presence of disease and for collection and testing of samples. As part of Nepal's national surveillance plan for HPAI, the 75 districts within the country have been divided into three categories: 20 high-risk districts (HRD), 21 medium-risk districts (MRD) and 34 low-risk districts (LRD)

(Fig. 1). For the purpose of active surveillance, eight sites were identified in the national surveillance plan for each HRD and four sites for each MRD. As described in the plan, only standard passive surveillance would be used in the LRDs, which does not incur additional costs. The risk sites are identified on the basis of their larger poultry population sizes and their trade activity. An animal health officer visits each HRD and MRD site once a week to look for unusual poultry mortalities and to collect samples; for this the officer receives $4.50 per week. Thus, the annual cost of farm visits = [(number of HRD*number of sites) + (number of MRD*number of sites)]*allowance per site per week*52 weeks per year = [(20*8) + (21*4)]*4.50*52 = $57,096.

As described in the national HPAI surveillance plan, a total of 12,780 samples (tracheal and cloacal swabs, serum samples, dead birds, fresh faeces) are collected across the country annually. Based on probable market costs in Nepal, $0.57 should be sufficient to purchase a sampling kit comprising one syringe and needle, one pair of gloves, cotton swabs, disinfectant (70% alcohol), a small plastic bag and serum vials. Thus, the total estimated annual cost for collection of samples = number of samples collected*cost of each sampling kit = 12,780*$0.57 = $7,285. In 2011, a total of 6,596 samples were tested with the AI type A antigen rapid test kit (Bionote, Republic of Korea), 524 serum samples were tested with the AI type A antibody enzyme-linked immunosorbent assay (ELISA) test kit (Idexx Laboratories, United States [USA]) and 191 samples were tested with a reverse-transcription polymerase chain reaction assay (Bio-Rad Laboratories, USA) at the Central Veterinary Laboratory, Nepal, and in regional veterinary laboratories (18). It was assumed that the same numbers were tested in 2012 (data for that year were not publicly available at the time of the study). The lower number of samples tested than collected might have been due to pooling of samples from an individual farm or household or to rejection of some samples by the laboratory because of quality issues. In Nepal, the per sample cost for the type A antigen rapid test was $6.70, the cost of the type A antibody ELISA test was $2.20 and the cost of the reverse-transcription polymerase chain reaction was $7.70. Thus, the estimated annual cost of laboratory testing = 6,596*$6.70 + 191*$7.70 + 524*$2.20 = $46,817.

The overall annual cost of surveillance is therefore given by the sum of the costs of farm visits, sampling and testing and is equal to $57,096 + $7,285 + $46,817 = $111,198.

Cost of stamping-out operations and compensation

According to the legal provision of the BFCO, when H5N1 is laboratory confirmed, the Government of Nepal declares an infected zone up to 3 km in radius, based on epidemiological assessment by experts of the Department of Livestock Services. The average cost of a stamping-out operation and compensation, based on the experience of earlier H5N1 control in Nepal (Implementation Completion and Results Report), is $10 per bird (19). During the 19 outbreaks of H5N1 in 2012, a total of 18,110 birds were destroyed in an effort to control the disease, therefore the total annual cost of stamping out and compensation was estimated as $181,100. No attempt was made to calculate the consequential losses incurred by the owners of the flocks affected.

Cost of training, communication and information dissemination

Public awareness campaigns are conducted through training sessions and mass media such as the national newspaper, national television channels, local radio stations, local newspapers, pamphlets and posters. The costs provided here are based on personal communication from an animal health officer who worked on the national HPAI control project (Dr Nabin Ghimire, Directorate of Livestock Production, personal communication, 2013). Costs per training session at district, regional and national levels were $250, $1,000 and $2,000, respectively. Each year there are typically four training sessions in each HRD, two sessions in each MRD and one session in each LRD, together with five regional training sessions and one national level training session. The cost of training at district level (HRD, MRD, LRD) = 4*20*$250 + 2*21*$250 + 1*34*$250 = $39,000; the cost at regional level = 5*$1,000 = $5,000; the cost at national level =

$2,000. The broadcasting costs were $250, $125 and $75 for each HRD, MRD and LRD, respectively; therefore the total broadcasting cost at district level = 20*$250 + 21*$125 + 34*$75 = $10,175. In addition, the total regional and national broadcasting costs were $5,000 and $6,000, respectively. The total cost of printing pamphlets, at national level, was $10,032. Thus, the overall annual cost associated with training, communication and information dissemination was estimated at $39,000 + $5,000 + $2,000 + $10,175 + $5,000 + $6,000 + $10,032 = $77,207.

In summary, the total annual cost for H5N1control under the CCP is given by the sum of the costs of:

– surveillance ($111,198)

– stamping-out operations and compensation ($181,100)

– training, communication and information dissemination ($77,207)

Thus, the overall annual total for H5N1 control = $369,505.

This total cost was discounted using equation A to obtain the present cost of the CCP for the first, second and third years of the programme in the amounts of $335,914, $305,376 and $277,615, respectively (Table II).

Losses under current control programme

Losses incurred under the CCP were grouped as:

– losses due to direct H5N1-associated mortality among poultry

– losses due to culling of poultry beyond the losses covered by government compensation

– losses due to a ban period on production, movement and trade imposed by the government

– losses due to market reaction.

Each of these losses is elaborated below.

Losses due to mortality caused by HPAI H5N1

In 2012, a total mortality of 41,100 poultry in Nepal was reported to the World Organisation for Animal Health (OIE). Among this total, 34,872 birds were commercial layers (CL), 2,850 were commercial broilers (CB), 1,410 were backyard chickens (BC) and 1,968 were broiler parents (BP). Farmers receive compensation only for poultry culled by the government, therefore losses were based on the prevailing farm-gate prices of the respective category of poultry: prices for CL, CB, BC and BP were $7.40, $3.00, $3.80 and $13.70, respectively (19). Thus, the annual loss resulting from HPAI-caused mortality under the CCP = 34,872 CL*$7.40 + 2,850 CB*$3.00 + 1,410 BC*$3.8 + 1,968 BP*$13.70 = $298,922.

Losses due to culling of poultry

Farmers' losses resulting from culling of birds were calculated by subtracting the compensation of $1.50 (provision of the BFCO) from the prevailing farm-gate price of the respective category of poultry and were estimated as $5.90 for CL, $1.50 for CB and $2.30 for BC. Thus, the total annual direct loss from culling = 16,748 CL*$5.90 + 150 CB*$1.50 + 1,212 BC*$2.30 = $101,826. There were no culling-related losses in BP in 2012.

Losses due to a production ban period imposed by the government

In accordance with the BFCO, the Nepali government imposes a ban on production for a period of 45 days in an outbreak zone (up to 3 km radius from the index case). However, it generally takes six months for backyard farmers to resume their poultry business (15). It is reported that during this six-month period each affected household loses 22 marketable chickens and, on average, 35 households are affected in each outbreak (15). At a gross value of $3.80 per kg and an average weight per chicken of 2 kg, the collective loss to the farmers is estimated to be $5,852 per outbreak. With 19 outbreaks per year, the total annual farmer loss is estimated at $111,188. In addition, traders lose $22,238 (estimated as 20% of farm-gate price) (15) through loss of business during the ban. Therefore the total annual loss in the backyard poultry system resulting from the production ban was estimated at $133,426.

It has been observed that broiler farmers lose two cycles of broiler production per H5N1 outbreak (15). The average margin per broiler is $0.40. In 2012, a total of 3,000 broilers were culled (150) or died (2,850) as a consequence of H5N1. If farmers do not raise broilers for two cycles, they will lose an estimated 2*3,000*$0.40 = $2,400. In addition, traders lose $480 (20% of farm-gate price) and meat processors lose $600 (25% of farm-gate price) (15) through loss of business during the ban period. Accordingly, the ban period resulted in an estimated total annual loss to the broiler industry of $3,480.

For layer farms, the average price per egg is $0.09 and, after deducting the cost of production, the average profit per egg is $0.009. Overall, 51,620 layers died or were destroyed in 2012 and an average daily egg loss of 37,166 (based on an average laying capacity of 72%) was assumed (15). Over the course of 45 days, it is estimated that layer farms lose 37,166*45 days*$0.009 = $15,052 from eggs. After a ban period is over, if farmers restock immediately, they need to wait another five months for replacement layers to produce eggs. Consequently farmers will lose income for an additional 150 days*$0.009*37,166 = $50,174. The cumulative loss will thus be $65,226. Again, traders lose $13,045 (20% of farm-gate price) and egg retailers lose $6,523 (10% of farm-gate price) (15) as a result of loss of business during the ban period. Thus, the total loss to the layer industry, due to the ban period, was estimated at $84,794 annually.

Thus, the overall annual total loss to the poultry industry resulting from the ban period imposed by the government was estimated at $133,426 + $3,480 + $84,794 = $221,700.

Losses due to market reaction

No published information was available on losses associated with the market reaction to H5N1 in Nepal. Data from other countries showed large variations in the drop in price and volume of sales resulting from

H5N1 outbreaks. For example, in Cambodia, Indonesia and Vietnam there were drops in broiler-meat prices of 75%, 50–85% and 50–60%, respectively, and 80–90%, 33% and 50% drops in sales of broiler meat (6). In Turkey, there was a 50% drop in both the price and the volume of broiler meat; in Egypt there was a 30% drop in price but there were no data on the drop in volume (6). In Bangladesh, there was an 8–13% drop in the price of broiler meat but the drop in volume of sales was not available (6).

For the purpose of the present study it was assumed that H5N1 outbreaks would affect 10% of the total annual volume of the national commercial poultry production. Specifically, with this volume of production affected (10%), the authors assumed that consumption would remain fairly stable, although there would be a 10% reduction in the price of poultry meat and eggs (Dr Rajesh Bhatta, Institute of Agriculture and Animal Sciences, Chitwan, Nepal, personal communication, 2013). Backyard poultry are mostly fed on leftover food scraps and therefore backyard producers are able to wait and sell their products when prices stabilise. It was assumed that there would be no indirect effects on backyard poultry farmers other than on farmers directly affected by the outbreaks.

According to data published on 7 October 2012 in MyRepublica, the national daily newspaper published in Kathmandu, quoting Dr T.C Bhattarai, a leading poultry entrepreneur in Nepal, the total broiler meat production in 2012 was estimated to be 132.17 million kg and total egg production 1.11 billion eggs (www.myrepublica.com).

The authors used these data to calculate the losses to the commercial poultry sector, as official government data were very limited. It was assumed that 10% of the total national poultry production would suffer reduction in price as a consequence of H5N1. The loss was considered to be $0.38 per kg of broiler meat and $0.009 per egg (15). Thus, the loss resulting from reduction in the price of poultry and poultry products was estimated at 13,217,000 kg broiler meat*$0.38 + 111,000,000 eggs*$0.009 = $6,021,460.

In Nepal, 78.87 million broiler day-old chicks (DOC) and ten million layer DOC were produced in 2012 (www.myrepublica.com). For the purpose of the present study, it was assumed that 10% of the total DOC produced would suffer a price reduction as a consequence of H5N1 (Dr Rajesh Bhatta, personal communication, 2013). The authors assumed $0.74 as the average price for a broiler DOC and $0.86 for a layer DOC (Dr Rajesh Bhatta, personal communication, 2013). During outbreaks, prices are generally reduced by about $0.23 per DOC (Dr Rajesh Bhatta, personal communication, 2013). This would cause a loss of 7,887,000*$0.23 = $1,814,010 to broiler DOC producers and a loss of 1,000,000*$0.23 = $230,000 to the layer DOC producers. The total loss to the DOC producers would be $2,044,010.

Thus, the overall total loss due to market reaction under the CCP would be $6,021,460 + $2,044,010 = $8,065,470.

In summary, the total annual loses estimated for H5N1 control under the CCP, assuming that the number of birds affected by HPAI per year would be the same as for 2012 (19 outbreaks), is given by the sum of the losses due to:

– H5N1-caused mortality among poultry ($298,922)

– culling of poultry beyond the losses covered by government compensation ($101,826)

– ban period on production, movement and trade imposed by the government ($221,700)

– market reaction ($8,065,470)

Overall annual total losses $8,687,918

This total loss under the CCP was compared with the total loss under each of the two alternative programmes (ACM and vaccination) to obtain estimates of the benefits of an evaluated programme, which were then discounted to obtain the PVB over time (as explained in the following sections and shown in Tables II and III).

Absence of control measures

Costs under absence of control measures

The ACM means that the government would take no action to control H5N1, farmers would not receive any compensation for losses and there would be no ban period for the poultry in the outbreak zone. The cost of ACM would therefore be zero.

Losses under absence of control measures

The following losses were identified for ACM:
- losses due to H5N1-caused mortality
- losses due to market reaction.

Losses due to highly pathogenic avian influenza-caused mortality

Implementation of the CCP had started in Nepal before the first H5N1 outbreak in 2009 and therefore no information is available on infection trends under ACM. As a starting point (evaluated further in a sensitivity analysis) it was assumed that the number of birds dying from H5N1 would double in each subsequent year. The loss to farmers was calculated on the basis of the prevailing farm-gate price of the respective category of poultry. Thus, the total estimated direct loss due to H5N1-related mortality was 69,744 CL*$7.40 + 5,700 CB*$3.00 + 2,820 BC*$3.80 + 3,936 BP*$13.70 = $597,845 in the first year, $1,195,690 in the second year and $2,391,379 in the third year.

Losses due to market reaction

The authors assumed that the losses due to market reaction would be identical to those under the CCP, i.e. the estimated total annual loss would be $8,065,470.

In summary, the total losses under ACM, obtained by adding annual losses due to H5N1-caused mortality and market reaction were estimated at $8,663,315, $9,261,160 and $10,456,849 for the first, second and third years of the programme (Table II).

The difference between the losses under the ACM and losses under the CCP represents the prevented losses or the benefits of the CCP for years 1, 2, and 3 of the programme, which were respectively estimated to be −$24,603, $573,242 and $1,768,931. These estimates were discounted to obtain the PVB of the CCP for the first, second and third years, i.e. −$22,366, $473,754 and $1,329,024, respectively (Table II).

Vaccination programme

Vaccination is one of the strategies for control of H5N1. Inactivated AI vaccines have helped to prevent morbidity, mortality and loss of egg production, and to control the spread of disease and reduce economic losses (20). At least 80% of the susceptible poultry population needs to be vaccinated to control the infection (21) and vaccination twice a year would be more effective when considering the rapid turn-around in poultry production (22). Vietnam, for example, has practised vaccination twice a year (23). However, it is very hard to achieve 80% vaccination coverage in a country such as Nepal, where there are large numbers of backyard birds. Thus, it would seem reasonable to target vaccination of 60% of the national flock twice a year. Before selecting a candidate vaccine for such a national vaccination strategy, the antigenic characteristics of the dominant circulating strains in Nepal and the adjoining regions should be determined. It is also important to continue monitoring the antigenic characteristics of circulating viruses following the introduction of vaccination control, as experience from other countries has shown that vaccines may need to be updated to maintain efficacy (24) and, specifically, to maintain the assumed levels of protection as used in the model for the CBA. Under a vaccination programme, it is reasonable to expect that a few outbreaks (possibly of smaller scale) would still occur. Following this rationale and the experience from Egypt (16), the authors assumed that the vaccination programme would prevent 80% of the losses (deaths/culled birds) that would otherwise occur under the CCP. In other words, it was assumed that approximately 20% of the birds lost under the CCP would also die under the vaccination programme.

Costs under vaccination

Costs incurred during the vaccination programme would be:

– cost of the vaccine

– cost of administering vaccine

– costs of surveillance (farm visits, sample collection and laboratory testing, including differentiation of infected and vaccinated animals)

– cost of the stamping-out operation and compensation

– cost of training, communication and information dissemination.

Cost of vaccine

The average cost per dose of AI vaccine is about $0.04, the prevailing market price. The current size of the poultry population is given in Table I. The cost of vaccine was calculated as 60% of the population*cost of one dose*number of vaccinations per year. The total annual cost for purchase of vaccine would therefore be 30,000,000 CB*$0.04*2 + 3,600,000 CL*$0.04*2 + 72,000 layer parents (LP)*$0.04*2 + 678,000 BP*$0.04*2 + 6,955,301 BC*$0.04*2 + 227,852 BD*$0.04*2 = $3,322,652.

Cost of administering vaccine

Avian influenza vaccines are administered subcutaneously (25), which makes vaccination tedious and costly. The average prevailing price for vaccinating an individual bird in Nepal is $0.002 (Dr Rajesh Bhatta, personal communication, 2013). The cost of vaccine administration was calculated as the cost of vaccine administration per bird*number of vaccinations per year*60% of the population. The total annual cost of vaccine administration was therefore 30,000,000 CB*$0.002*2 + 3,600,000 CL*$0.002*2 + 72,000 LP*$0.002*2 + 678,000 BP*$0.002*2 + 6,955,301 BC*$0.002*2 + 227,852 BD*$0.002*2 = $166,133.

Cost of surveillance

It was assumed that the annual cost of surveillance under the vaccination programme would be identical to that incurred under the CCP, i.e. $111,198.

Cost of stamping-out operations and compensation

It was assumed that under the vaccination programme a constant small number of HPAI outbreaks would continue to occur annually and would result in the culling of 20% of the birds that would have been culled under the CCP. Taking $10 as the cost of the stamping-out operation and compensation per bird (19) and the loss of 3,622 birds (20% of the loss under the CCP), the cost of stamping out and compensation would be 3,622*$10 = $36,220 annually.

Cost of training, communication and information dissemination

The cost of training, communication and information dissemination under the vaccination programme would be identical to the cost incurred under the CCP, which was estimated as $77,207 annually.

Overall, the total annual cost of the vaccination programme would therefore be the sum of the costs of vaccine purchase, vaccine administration, surveillance, the stamping-out operation and compensation, and training, communication and information dissemination i.e. $3,322,652 + $166,133 + $111,198 + $36,220 + $77,207 = $3,713,410. This total cost was discounted using equation A to obtain the present value of vaccination cost for the first, second and third years of the programme in the amounts of $3,375,827, $3,068,934 and $2,789,940, respectively (Table III).

Losses under vaccination

Losses under the vaccination programme would be:
- losses due to H5N1-related mortality
- losses due to culling of poultry.

Losses due to highly pathogenic avian influenza H5N1-related mortality

Under the assumption that vaccination would not prevent the deaths of 20% of the birds dying under the CCP, the total annual estimated direct loss from H5N1-related mortality based on the farm-gate price would be 6,974 CL*$7.40 + 570 CB*$3.00 + 282 BC*$3.80 + 394 BP*$13.70 = $59,787.

Losses due to culling of poultry

Under the assumption that 20% of the birds culled under the CCP would still be culled under the vaccination programme, the total direct loss due to H5N1-related culling based on per unit loss (farm-gate price after deducting compensation) would be 3,350 CL*$5.90 + 30 CB*$1.50 + 242 BC*$2.30 = $20,367 per year.

The overall loss under the vaccination programme would therefore be the sum of the losses resulting from H5N1-related mortality and culling of poultry, giving an annual total of $80,154.

It was assumed that the vaccination programme would help restore the domestic poultry market to a pre-outbreak level and prevent some of the costs associated with the stamping-out operation and compensation. The difference between the losses under the CCP and losses under the vaccination programme represents the prevented losses or benefits of the vaccination programme, and was estimated as $8,687,918 − $80,154 = $8,607,764 per year. This total estimate of benefits of the vaccination programme was discounted using equation A to obtain the PVB for the first, second and third years of the vaccination programme, i.e. $7,825,240, $7,113,855, and $6,467,140, respectively (Table III).

Sensitivity analysis

A sensitivity analysis was used to evaluate the robustness of the model under differing discount rates (5%, 10%, 15%), differing numbers of birds dying under ACM (200% increase, 100% increase, 50% increase and 50% decrease compared with mortality under the

CCP), differing market losses (5%, 10%, 15%) and differing numbers of birds dying or culled under the vaccination programme (10%, 20%, 50% compared with those under the CCP). The break-even point (a situation of no gain or loss where the NPV becomes zero) was calculated for the market loss and the number of birds dying under the ACM.

Results

Economic evaluation of the control options showed that the CCP is better than ACM and that vaccination would be better than the CCP. The BCR was 1.94 and the NPV $861,507 for CCP vs ACM (Table II), whereas the BCR was 2.32 and NPV $12,171,534 for vaccination vs CCP (Table III).

The results of the sensitivity analysis are shown in Table IV. When testing the effect of discount rates 5%, 10% and 15% on the comparison of CCP vs ACM, the NPVs were $1,018,331, $861,507 and $731,496 and BCRs were 2.01, 1.94 and 1.87, respectively (Table IV). When comparing vaccination vs CCP, the NPVs were $13,328,539, $12,171,534 and $11,174,912 and the BCRs 2.32, 2.32 and 2.32, respectively, at discount rates of 5%, 10% and 15% (Table IV). The changes in NPVs and BCRs for differing discount rates were small, indicating a negligible role of the considered discount rate of 10% on the CBA results; the positive NPVs and BCRs >1 show that it is better to implement either of the two control programmes (CCP or vaccination) than to have no intervention.

Sensitivity analysis was also used to evaluate the effect of the assumed market loss of 10% under the CCP and ACM by considering two additional values for market loss: 15% and 5%. Note that a zero market loss was assumed under the vaccination programme. The NPVs for comparison of CCP at 10% market loss vs ACM at 5%, 10% and 15% market loss were −$9,167,308, $861,507 and $10,890,322 and the BCRs were −8.98, 1.94 and 12.85, respectively (Table IV). The NPVs for comparison of vaccination (0% market loss) vs CCP at 5%, 10% and 15% market loss were $2,142,719, $12,171,534 and $22,200,349 and BCRs were 1.23, 2.32 and 3.40, respectively (Table IV). These results indicate that the perceived value of the CCP compared with the ACM depends on the assumed market loss. Break-even point analysis showed that the CCP would no longer be better than ACM if the market loss during ACM was <9.57% compared with the 10% market loss considered under the CCP. On the other hand, for the tested values of market loss, vaccination is consistently better than the CCP. In addition, a break-even point for market loss was calculated in comparison of the CCP and vaccination and showed that there would be no gain or loss from application of the vaccination programme if the market loss under the CCP was only 3.93% ($3,171,173) (a fixed 0% market loss was assumed for the vaccination programme).

In the main analysis, it was assumed that there would be a 100% increase in the number of birds dying each year under the ACM option. Sensitivity analysis was used to evaluate scenarios assuming a 200% or 50% increase or a 50% decrease in the numbers of birds affected by HPAI under the ACM option. The estimated NPVs were $6,635,583, $861,507, −$745,398 and −$2,241,133, respectively, and the BCRs were 8.22, 1.94, 0.19 and −1.44, respectively, for 200%, 100% and 50% increases and 50% decrease in the numbers of birds dying from HPAI under the ACM option (Table IV). These results highlight the importance of the assumed change in numbers of affected birds under ACM. The break-even point analysis showed that continuation of the CCP would be justified only if the numbers of birds dying from HPAI increased by more than 76% every year during the evaluation period. The CCP would not be justified if the number of birds dying from HPAI increased by less than 76% every year or, obviously, if the numbers decreased (which is unlikely).

In the main analysis it was assumed that a few smaller outbreaks would continue to occur under the vaccination programme. These would incur a loss of 20% of the birds affected under the CCP. To test this assumption, additional scenarios were evaluated where 0%, 10% and 50% of birds lost through mortality and culling under the CCP would die despite vaccination. Results showed that when the number of birds lost under the vaccination option was at 0%, 10%, 20% and

50% of the CCP level, the BCRs were 2.36, 2.34, 2.32 and 2.25, and the NPVs were \$12,460,939, \$12,316,244, \$12,171,534 and \$11,737,454, respectively (Table IV). That means that it would be worth investing in the vaccination programme even if outbreaks continue to occur. However, this conclusion would change if the market loss under the CCP differed from the assumed 10%. As indicated above, for the scenario with 20% bird loss, the break-even point would occur when the market loss was 3.93% in the CCP compared with no market loss under the vaccination programme.

Discussion

Using a CBA framework, the authors evaluated whether continuing investment in the HPAI control programme currently being implemented in Nepal is justified when compared with two alternatives: ACM and a vaccination programme. Their findings indicate that current control measures are economically profitable against a no-intervention approach, with a return of \$1.94 for every \$1.00 spent in the CCP compared with ACM; the NPV of the CCP vs ACM was \$861,507. However, the vaccination programme yields a return of \$2.32 for every \$1.00 spent in this programme when compared with the CCP; the NPV of vaccination vs CCP was \$12,171,534.

In Nigeria, a return of \$52 for every dollar invested in a vaccination programme was estimated in a comparison with no intervention (13). Such a high estimated BCR compared with the estimates in the present paper might be due to differences in the baseline outbreak losses between Nigeria and Nepal and also due to factors in the Nigerian regional poultry trade. It should also be noted that Nigeria reported control of HPAI without vaccination, indicating that the very high return is perhaps an overestimate; such a rate of return would suggest a very strong private incentive to offer vaccine. The estimate in the present paper indicates a more realistic return.

Results of the sensitivity analysis indicate that the findings are robust to differing rates of discounting, whereas results are sensitive to the assumed market loss and the number of birds affected in the outbreaks under the ACM and vaccination options. Assumption of the same market loss under ACM as under the CCP may be considered an underestimation of the loss, because a greater number of outbreaks might provoke a stronger market reaction. On the other hand, an overestimated market loss could lead to an overestimated benefit of the CCP. The BCR and NPV for the vaccination programme compared with the CCP might be overestimations, as it was assumed there would be no market loss under the vaccination programme. Although assumptions about probable market losses under the ACM and vaccination options have strong impact on the results and conclusion of the study, they reflect the absence of information on the expected market loss under these options in Nepal. Addressing this information gap is of critical importance for a reliable CBA of H5N1 control strategies in Nepal. As a point of comparison, in Nigeria the market loss was calculated by multiplying per unit absolute loss with the total national volume of poultry products and loss in exports (13); for example, a 46% fall in the market price of eggs (the price of a $2.19 tray of 30 eggs reduced by $1.01 during peak H5N1 infection) and loss in export of 12,000 tons of poultry meat per month at $2.73 per kilogram. The differences in the considered losses between Nepal and Nigeria are therefore not readily comparable, because of differences in the methods used.

What cannot be known from the results of the present study in Nepal is that if the monetary value of the market loss resulting from H5N1 is low (e.g. when market loss is lower under ACM [9.57%] than CCP [10%] and when market loss is <3.93% under the CCP compared with no loss under vaccination) the benefit of preventing this loss would be negligible. That means that investment in an H5N1 control programme (CCP or vaccination) would not be justified unless public health and other benefits of a control programme, which were not accounted for in the current study, are also considered.

The results show that if the numbers of birds dying from HPAI under ACM continued to increase by more than 76% every year during the evaluation period, the benefits of the CCP would outweigh its costs. However, that would not be the case if the increase in numbers of affected birds was more modest (<76% per year), in which case continued investment in the CCP would not be justified. The problem is that the course of H5N1 outbreaks in Nepal under ACM is impossible to predict. However, it is reasonable to expect that the numbers of affected birds would rise rapidly over a few years after the start of the ACM option, as assumed here.

Nepal's export market for poultry and poultry products is negligible. Outbreaks of H5N1 in Nepal have no effect on international poultry trade under the CCP or the alternative programmes. However, Nepal's poultry industry is almost able to meet the domestic demands for poultry meat and eggs, although the country has to import parent stocks and vaccines. Under these conditions, safeguarding the domestic poultry industry is a priority for Nepal. If the number of outbreaks continues to increase, Nepal may need to consider vaccination as an alternative to the CCP. A mass vaccination programme and bio-security measures helped overcome HPAI in Pakistan (26). In the present study it was assumed that vaccination would reduce bird loss from H5N1-associated mortality and culling by 80% when compared with the CCP. Sensitivity analysis indicated that it would be worth investing in a vaccination programme, even if this reduction in the loss of birds is an overestimation. However, although the vaccine protects from clinical disease (and mortality), there is a possibility that asymptomatic circulation of virus may continue and result in the spread of infection (27), in which case the benefits of vaccination may no longer outweigh the costs. Nevertheless, even in the case of infection spread, vaccination may still outweigh other strategies, as production losses would be significantly reduced.

The CBA used in the study has important limitations. The authors did not consider the public health implications of HPAI in Nepal, as there have been no recorded H5N1-related human illnesses in the country. It was implicitly assumed that there would be no human health losses in the future and under the evaluated alternative control scenarios. If human health losses were to occur, the estimate of the benefits would be an underestimate. The authors did not consider other indirect benefits of H5N1 control programmes in Nepal, such as increased availability of animal protein to the backyard poultry farmers. Backyard farmers mostly rely on the eggs and chicken meat produced in their own households as a protein source. If birds die from H5N1 and backyard farmers do not rear poultry during the production ban period, their protein intake decreases; however, quantifying this value is difficult. Nevertheless, not accounting for this indirect benefit may have underestimated the total benefit of the CCP and vaccination programmes.

In conclusion, from the findings of the CBA, implementation of one of the control programmes, either the CCP or the proposed vaccination programme, would be better than taking no action on H5N1 control in Nepal. Vaccination appears a better prospect than the CCP; however, the concerns related to the possibility of asymptomatic virus circulation under the vaccination programme and a complex epidemiological situation (field and vaccine strains) need to be further evaluated in the context of Nepal before any implementation. Furthermore, critical information gaps on the expected market loss under ACM and a vaccination programme were identified in this study.

There were massive outbreaks of H5N1 in Nepal in July and August 2013, which coincided with the final stages of the CBA reported here. Nearly 131,000 poultry died in those outbreaks (1), almost three times the number of the birds dying from H5N1 in 2012 (considered as the baseline year in the CBA). This recent rise in numbers of affected birds under the CCP raises questions on the validity of the assumption of a constant number of birds dying under the CCP during the evaluation period, thus suggesting that the benefit of the CCP might have been overestimated. However, this latest development is also an opportunity to realise that many more birds would have died if nothing had been done to control H5N1 and, further, supports the conclusion that control measures should be in place in Nepal and they should be better than the current programme.

Acknowledgements

The authors acknowledge the Fulbright Student Scholarship Programme for funding SK for his MS studies and extend their thanks to Dr Rajesh Bhatta, Institute of Agriculture and Animal Science, Chitwan, and Dr Ashesh Bhattarai, Bhattarai Poultry Farm, Kaski for providing important information. The authors also thank two anonymous reviewers for their excellent suggestions on how to improve the manuscript.

References

1. World Organisation for Animal Health (OIE) (2013). – Update on highly pathogenic avian influenza in animals (Type H5 and H7). Available at: www.oie.int/animal-health-in-the-world/update-on-avian-influenza/2013/ (accessed on 15 May 2013).

2. Yee K.S., Carpenter T.E. & Cardona C.J. (2009). – Epidemiology of H5N1 avian influenza. *Comp. Immunol. Microbiol. Infect. Dis*., **32**, 325–340.

3. Alexander D. & Brown I. (2009). – History of highly pathogenic avian influenza. *In* Avian influenza (T. Mettenleiter, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **28** (1), 19–38.

4. Xu X., Subbarao K., Cox N.J. & Guo Y. (1999). – Genetic characterization of the pathogenic influenza A/Goose/Guangdong/1/96 (H5N1) virus: similarity of its hemagglutinin gene to those of H5N1 viruses from the 1997 outbreaks in Hong Kong. *Virology*, **261**, 15–19.

5. World Health Organization (WHO) (2013). – Cumulative number of confirmed human cases of avian influenza A/(H5N1) reported to WHO (24 January 2014). Available at: www.who.int/influenza/human_animal_interface/EN_GIP_20130116 CumulativeNumberH5N1cases.pdf / (accessed on 6 June 2014).

6. Otte J., Hinrichs J., Rushton J., Roland-Holst D. & Zilberman D. (2008). – Impacts of avian influenza virus on animal production in developing countries. CAB Reviews: Perspectives on agriculture, veterinary science, nutrition and natural resources, **3** (080), 1–18.

7. Bennett R. (1992). – The use of 'economic' quantitative modelling techniques in livestock health and disease-control decision making: a review. *Prev. Vet. Med.,* **13**, 63–76.

8. Rushton J., Thornton P.K. & Otte M.J. (1999). – Methods of economic impact assessment. *In* The economics of animal disease control (G. Murray & P.M. Thornber, eds). *Rev. Sci. Tech. Off. Int. Epiz.*, **18** (2), 315–342.

9. Rushton J. (2009). **–** The economics of animal health and production. CAB International, Wallingford, Oxfordshire.

10. Dijkhuizen A., Huirne R. & Jalvingh A. (1995). – Economic analysis of animal diseases and their control. *Prev. Vet. Med.*, **25**, 135–149.

11. Tiongco M. (2008). – Costs and benefits of HPAI prevention and control measures: a methodological review. DFID pro-poor HPAI risk reduction strategies project Africa/Indonesia region report. Available at: http://r4d.dfid.gov.uk/PDF/Outputs/HPAI/wp13_IFPRI.pdf (accessed on 3 October 2013).

12. Marsh W. (1999). – The economics of animal health in farmed livestock at the herd level. *In* The economics of animal disease control (G. Murray & P.M. Thornber, eds). *Rev. Sci. Tech. Off. Int. Epiz.*, **18** (2), 357–366.

13. Fasina F., Meseko A., Joannis T.M., Shittu A., Ularamu H., Egbuji N., Sulaiman L. & Onyekonwu N. (2007). – Control versus no control: options for avian influenza H5N1 in Nigeria. *Zoonoses Public Hlth*, **54**, 173–176.

14. Willenbockel D. (2011). – A cost-benefit analysis of Practical Action's livelihood-centred disaster risk reduction project in Nepal. IDS, Brighton. Available at: community.eldis.org/ (accessed on 20 May 2013).

15. Anon. (2012). – Avian influenza control project: socio-economic analysis of stamping out operation. MountDigit Technology (P.) Ltd and Public Awareness Company Pvt. Ltd, Kathmandu, Nepal.

16. Peyre M., Samaha H., Makonnen Y.J., Saad A., Abd-Elnabi A., Galal S., Ettel T., Dauphin G., Lubroth J., Roger F. & Domenech J. **(**2009**)**. **–** Avian influenza vaccination in Egypt: limitations of the current strategy. *J. Mol. Gen. Med.*, **3** (2), 198–204.

17. Department of Livestock Services (DLS) (2011). – Livestock statistics of Nepal. DLS, Kathmandu, Nepal.

18. Central Veterinary Laboratory (CVL) (2011). – Annual Technical Bulletin 2010/11. CVL, Kathmandu, Nepal.

19. World Bank (2013). – Implementation completion and results report (IDA-H2680). Available at: wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2012/02/01/000356161_20120201234242/Rendered/PDF/ICR20290P100340isclosed0Feb01020120.pdf (accessed on 23 May 2013).

20. Halvorson D.A. (2002). – The control of H5 or H7 mildly pathogenic avian influenza: a role for inactivated vaccine. *Avian Pathol.*, **31**, 5–12.

21. Tiensin T., Nielen M., Vernooij H., Songserm T., Kalpravidh W., Chotiprasatintara S., Chaisingh A., Wongkasemjit S., Chanachai, K. & Thanapongtham W. (2007). – Transmission of the highly pathogenic avian influenza virus H5N1 within flocks during the 2004 epidemic in Thailand. *J. Infect. Dis.*, **196**, 1679–1684.

22. Chen H. (2009). – Avian influenza vaccination: the experience in China. *In* Avian influenza (T. Mettenleiter, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **28** (1), 267–274.

23. Domenech J., Dauphin G., Rushton J., McGrane J., Lubroth J., Tripodi A., Gilbert J. & Sims L.D. (2009). – Experiences with vaccination in countries endemically infected with highly pathogenic avian influenza: the Food and Agriculture Organization perspective. *In* Avian influenza (T. Mettenleiter, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **28** (1), 293–305.

24. Food and Agricultural Organization of the United Nations (FAO) (2011). – FAO-OIE-WHO Technical Update: Current evolution of avian influenza H5N1 viruses. Available at: www.fao.org/docrep/014/al874e/al874e00.pdf/ (accessed on 14 June 2014).

25. Steitz J., Wagner R.A., Bristol T., Gao W., Donis R.O. & Gambotto A. (2010). – Assessment of route of administration and dose escalation for an adenovirus-based influenza A virus (H5N1) vaccine in chickens. *Clin. Vaccine Immunol.*, **17**, 1467–1472.

26. Naeem K. (2003). – The avian influenza H7N3 outbreak in South Central Asia. *Avian Dis.*, **47**, 31–35.

27. Ellis T.M., Leung C.Y., Chow M.K., Bissett L.A., Wong W., Guan Y. & Malik Peiris J. (2004). – Vaccination of chickens against H5N1 avian influenza in the face of an outbreak interrupts virus transmission. *Avian Pathol*., **33**, 405–412.

Table I

Total size of poultry population and the population to be vaccinated (60%) against highly pathogenic avian influenza in Nepal

Source: www.myrepublica.com (commercial figures); Department of Livestock Services, Nepal (17) (backyard figures)

Type	Population	60% of population
Commercial broilers	50,000,000	30,000,000
Commercial layers	6,000,000	3,600,000
Layer parents	120,000	72,000
Broiler parents	1,130,000	678,000
Backyard chickens	11,592,168	6,955,301
Backyard ducks	379,753	227,852

Table II

Summary of costs and benefits of the current control programme vs absence of control measures

	Year 1	Year 2	Year 3	Total
Losses under ACM	$8,663,315	$9,261,160	$10,456,849	$28,381,324
Losses under CCP	$8,687,918	$8,687,918	$8,687,918	$26,063,754
Undiscounted benefits of CCP vs ACM	–$24,603	$573,242	$1,768,931	$2,317,570
PVB at 10% discount rate	–$22,366	$473,754	$1,329,024	$1,780,412
Undiscounted cost of CCP	$369,505	$369,505	$369,505	$1,108,515
PVC of CCP at 10% discount rate	$335,914	$305,376	$277,615	$918,905
NPV	–$358,280	$168,378	$1,051,409	$861,507
BCR				1.94

ACM: absence of control measures
BCR: benefit–cost ratio
CCP: current control programme
NPV: net present value
PVB: present value of benefits
PVC: present value of costs

Table III
Summary of costs and benefits of vaccination vs current control programme

Costs and benefits	Year 1	Year 2	Year 3	Total
Losses under CCP	$8,687,918	$8,687,918	$8,687,918	$26,063,754
Losses under vaccination	$80,154	$80,154	$80,154	$240,462
Undiscounted benefits of vaccination vs CCP	$8,607,764	$8,607,764	$8,607,764	$25,823,292
PVB at 10% discount rate	$7,825,240	$7,113,855	$6,467,140	$21,406,235
Undiscounted cost of vaccination	$3,713,410	$3,713,410	$3,713,410	$11,140,230
PVC at 10% discount rate	$3,375,827	$3,068,934	$2,789,940	$9,234,701
NPV	$4,449,413	$4,044,921	$3,677,200	$12,171,534
BCR				2.32

BCR: benefit–cost ratio
CCP: current control programme
NPV: net present value
PVB: present value of benefits
PVC: present value of costs

Table IV

Results of sensitivity analysis for different discount rates, market losses and poultry mortalities

Parameter	Tested value	NPV	BCR
CCP vs ACM			
Discount rate	5%	$1,018,331	2.01
	10% (baseline)	$861,507	1.94
	15%	$731,496	1.87
Market loss	5%	−$9,167,308	−8.98
	10% (baseline)	$861,507	1.94
	15%	$10,890,322	12.85
Poultry mortality under ACM	50% decrease	−$2,241,133	−1.44
	50% increase	−$745,398	0.19
	100% increase (baseline)	$861,507	1.94
	200% increase	$6,635,583	8.22
Vaccination vs CCP			
Discount rate	5%	$13,328,539	2.32
	10% (baseline)	$12,171,534	2.32
	15%	$11,174,912	2.32
Market loss	5%	$2,142,719	1.23
	10% (baseline)	$12,171,534	2.32
	15%	$22,200,349	3.40
Poultry mortality under vaccination	0%	$12,460,939	2.36
	10%	$12,316,244	2.34
	20% (baseline)	$12,171,534	2.32
	50%	$11,737,454	2.25

ACM: absence of control measures
BCR: benefit–cost ratio
CCP: current control programme
NPV: net present value

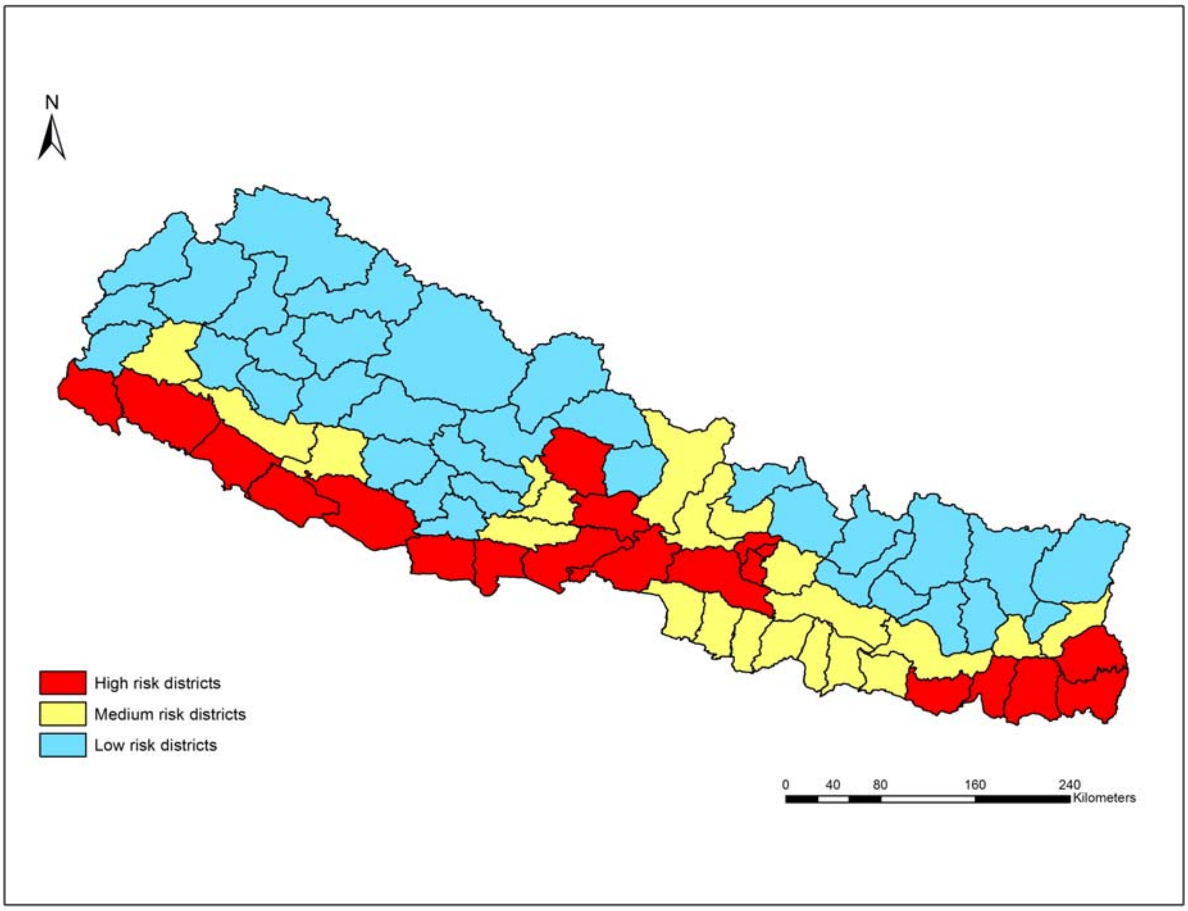

Fig. 1

Districts of Nepal and their risk categories for highly pathogenic avian influenza H5N1