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Chinh C. Tran is a PhD candidate at the Department of Natural Resources and Environmental Management, University of Hawai'i at Mānoa. He is also a recipient of the East West Center-National Science Foundation doctoral fellowship. He was involved in the project "Coupled Natural-Human Systems and Emerging Infectious Diseases: Anthropogenic environmental change and avian influenza in Vietnam."

John F. Yanagida is a Professor in the Department of Natural Resources and Environmental Management, University of Hawai'i at Mānoa. He received his PhD degree in Agricultural Economics from the University of Illinois, Champaign-Urbana. He has also served as a Visiting Scholar at Jilin University PRC, Visiting Lecturer at the Agricultural University of Tirana, Albania, and Visiting Researcher at the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), Bangkok, Thailand.

Jefferson Fox is a Senior Fellow at the East-West Center in Honolulu. He studies land-use and land-cover change in Asia and the possible cumulative impact of these changes on the region and the global environment.

Sumeet Saksena is a Fellow in the Research Program at the East-West Center. He is also Affiliate Faculty at the Department of Urban And Regional Planning, University of Hawaii at Manoa. He has a PhD in Environmental Science and Engineering from the Indian Institute of Technology Bombay, India.

This paper has been prepared as part of the 'Coupled Natural-Human Systems and Emerging Infectious Diseases: Anthropogenic environmental change and avian influenza in Vietnam' project funded by the US National Science Foundation.

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Publications Office| East-West Center
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Policy Implications for Prevention of Highly Pathogenic Avian Influenza Subtype H5N1 in Conjunction with Risk Factors in the Red River Delta, Vietnam

Chinh C. Tran[1,2*], John F.Yanagida[1], Sumeet Saksena[2], Jefferson Fox[2]

[1] Department of Natural Resources and Environmental Management, University of Hawai'i at Manoa,
1901 East-West Road, Honolulu, HI 96822, USA; E-Mail: jyanagid@hawaii.edu
[2] East-West Center, 1601 East-West Road, Honolulu, HI 96848, USA;
E-Mails: saksenas@eastwestcenter.org (S.S.); foxj@eastwestcenter.org (J.F.)

***** Author to whom correspondence should be addressed; E-Mail: cctr222@hawaii.edu

Abstract

The challenge is to develop the vaccination program that is more successful in containing and preventing the Highly Pathogenic Avian Influenza subtype H5N1 from recurrence in the Red River Delta, Vietnam and reducing vaccination costs. This study addresses the tradeoff between the current policy which implements an annual two-round vaccination for the entire geographical area of the Delta and an alternative policy which involves more frequent vaccination in higher probability areas for the disease occurrence within the Delta. The ex-ante analysis framework is used to identify the location of higher probability areas for the alternative policy and evaluate the accuracy of the analysis. The efficacy and cost analysis of vaccination programs are then implemented for the tradeoff between the current and the alternative policies. The ex-ante analysis suggests that the focus areas for the alternative vaccination program include 1137 communes, corresponding to 50.6% of total communes in the Delta and mostly located in the coastal areas to the east and south of Hanoi. The efficacy and cost analyses suggests that the alternative policy would be more successful in reducing the rate of disease occurrence and the costs of vaccination as compared to the current policy.

Keywords: HPAI H5N1, Red River Delta, alternative vaccination program, ex-ante analysis, weighted overlay, BRT models, cost analysis

1. Introduction

The Highly Pathogenic Avian Influenza (HPAI) subtype H5N1 has had serious, detrimental effects on the economy and human health in Vietnam since the first reported outbreak on 27 December 2003 (OIE 2004). Millions of poultry were culled due to the disease occurrences, causing an estimated economic loss of 3000 billion VND (approximately US$ 187.15 million)[1] (Phan et al. 2010; Peyre et al. 2008). The average growth rate of poultry population was reduced from 7.6% for the period 2000 – 2003 (before HPAI H5N1 occurrence) to -3.8% for the period 2003 – 2006 (during HPAI H5N1 disease occurrence) (Desvaux et al. 2008). Market demand and price decreases further caused economic losses to poultry producers (Tran et al. 2013; World Bank 2007). The disease also seriously affected human health. By 19 November 2010, a total of

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[1] Exchange rate at 1USD = 16,030 VND as of 12/31/2007 by the State Bank of Vietnam.

119 human cases of HPAI H5N1 were reported, with 59 deaths (Center for Agricultural Policy 2011).

Financial support from many international organizations, such as the Food and Agriculture Organization (FAO) of the United Nations, World Bank and others, helped to contain the disease through a mass vaccination campaign implemented nationally from late September to the beginning of November 2005. The goal of the vaccination program was to reduce the spread of the HPAI H5N1 virus as stated in the Directive No. 25/2005/CT-TTg dated 12 July 2005[2]. Since then, the vaccination campaign had been applied in two rounds every year until 2010 (with the first round from April – May and the second round from October – November). The vaccination campaign covered most provinces in the country. The vaccination program continued in later years but on a smaller scale and primarily implemented in order to prevent the spread of the virus.

The Red River Delta has been identified as a high-risk area for the disease (Minh et al. 2009; Pfeiffer et al. 2007a). The Delta has been severely affected by the three large epidemic waves of HPAI H5N1 outbreaks and other sporadic outbreaks. The first wave occurred from January – February 2004, the third wave and the fifth wave took place from October – December 2005 and May – September 2007, respectively (FAO 2008a; Pfeiffer et al. 2007a; Pfeiffer et al. 2007b). As a result, compulsory vaccination was implemented across all geographical areas for all provinces in the Delta. Although the launch of the vaccination campaign was thought to contribute to the reduction of the disease occurrence (Henning et al. 2009), it did not fully contain the disease. Sporadic outbreaks have been reported over the years and presently with the reported outbreaks in Bac Ninh and Nam Dinh provinces in January and February 2014 (OIE 2014).

Although the vaccination program has shown to be a viable means of protection against the HPAI H5N1 virus (Henning et al. 2009) and it covered all geographical areas of the Red River Delta, the campaign was carried out only twice a year in April – May and October – November. However, poultry production occurs all year round. A later study (see Tran et al. 2013) confirmed that November to January and April to June were the periods most vulnerable for disease occurrence. A sizeable portion of poultry production remained unvaccinated at different times of the year. The circulation of HPAI H5N1 virus was found in unvaccinated waterfowl (Minh et al. 2009; Taylor and Do 2007). Therefore, it is assumed that unvaccinated poultry between two rounds will be at risk of infection. Although mandatory vaccination occurs twice a year, farmers are encouraged to vaccinate whenever a new production period begins but are reluctant to vaccinate more frequently because of added costs. The cost of vaccination was estimated to be approximately US$10 million per round (Sims and Do 2009). Therefore, it is critical for the animal health authorities to design a vaccination plan that effectively contains the disease in the Delta on a year round basis.

A number of studies have identified factors affecting the occurrence and spread of the HPAI H5N1 virus in Vietnam in general and in the Red River Delta in particular. It was suggested that higher average monthly temperatures and poultry density in combination with lower average

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[2] **Directive No. 25/2005/CT-TTg** dated 12 July 2005 from the Prime Minister regarding vaccination against the avian influenza

monthly precipitation and humidity and elevation significantly affected the occurrence of HPAI H5N1 in the Delta (Tran et al. 2013). Other factors linked with the disease at the national level were: (i) a higher proportion of land used for rice paddy fields and aquaculture, (ii) increases in production, trade and movement of live poultry and (iii) the expansion of free-grazing ducks (Desvaux et al. 2011; Gilbert et al. 2008; Pfeiffer et al. 2007a; Gilbert, Chaitaweesub, et al. 2006). Given these findings, it is not likely that all areas within the Red River Delta are equally susceptible to the disease. Previous studies provided little information on spatial locations where efforts should be concentrated in order to prevent and control the spread of the disease in the Delta (Tran et al. 2013; Desvaux et al. 2011; Gilbert et al. 2008; Pfeiffer et al. 2007b).

This study explores implications of an alternative policy, which is likely to be more successful in containing and preventing the disease from recurrence in the Red River Delta, Vietnam and reducing vaccination costs. Specifically, the alternative policy involves shifting vaccination for HPAI H5N1 from the entire Delta to specific areas identified as high probability areas for the disease occurrence within the Delta. This modification would involve more frequent vaccination campaigns throughout the year. Two key questions emerge with this proposal: (i) Where are the high probability areas (focus areas) for the alternative policy?; (ii) Is it beneficial for the Government to switch to the alternative policy in terms of the efficacy and the costs of vaccination program? To answer the questions and fulfill the objective, this study (i) identifies the focus areas for the alternative policy to be implemented in the Red River Delta and (ii) processes the tradeoff between the current policy and the alternative policy based on the efficacy and cost analyses of vaccination programs.

2. Study area, data sources and data pre-processing.

This study focuses on the Red River Delta of Vietnam (Figure 1) which represents one of the two largest flood plains in Vietnam. The Delta includes two large river systems – the Red river and Thai Binh river systems that support agricultural and livestock activities. The Red River Delta includes 8 provinces and 2 municipalities, the capital city of Hanoi and the main port of Hai Phong. The Delta plays an important role and interacts with a wide range of environmental and socioeconomic sectors including industry, commerce, services, agriculture, tourism, etc. Livestock production is among the main activities in the Delta, including poultry, pig and cow husbandry. Poultry production has faced serious problems caused by the HPAI H5N1 disease.

The HPAI H5N1 outbreaks data were provided through an East West Center (EWC) – National Science Foundation (NSF) project (EWC 2013). The Red River Delta in Vietnam has been identified as a high-risk area for the disease (Minh et al. 2009; Pfeiffer et al. 2007a). The Delta has been severely affected by the three large epidemic waves of HPAI H5N1 outbreaks. The first wave occurred from January – February 2004, the third wave and the fifth wave took place from October – December 2005 and May – September 2007, respectively (FAO 2008a; Pfeiffer et al. 2007a; Pfeiffer et al. 2007b). A number of outbreaks in the second epidemic wave which was from November 2004 to March 2005 were also reported in the Red River Delta despite the main effects in the Mekong Delta. Other sporadic outbreaks over the period from December 2003 until the present with the recently reported outbreaks in Bac Ninh and Nam Dinh provinces in January and February 2014 (OIE 2014). Although the disease occurred in the Delta from the end of 2003, the dates and locations of occurrences were not formally reported until the end of March 2004 (Pfeiffer et al. 2007a). This EWC study analyzed reported disease data for the period starting from the end of March, 2004 to the end of December, 2007 which included 267 confirmed HPAI

H5N1 outbreaks in the Red River Delta. The data were reported at the commune level and coded as 1 if the disease was found or 0 if there was no disease reported.

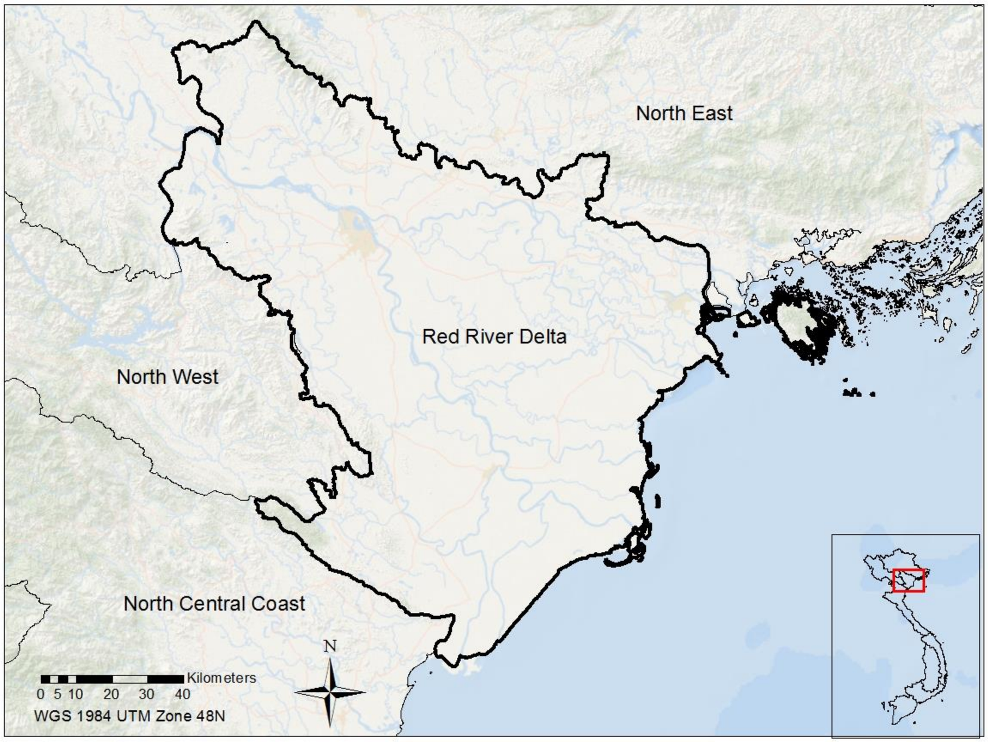

Figure 1: The study area – The Red River Delta, Vietnam

Other data used for the analysis are identified based on earlier studies of HPAI H5N1 in Vietnam. They include factors which previously were found to have effects on the occurrence of the disease such as the percentage of land used for rice paddy fields and aquaculture (Pfeiffer et al. 2007a), chicken and water bird density (Pfeiffer et al. 2007a; Gilbert et al. 2008; Desvaux et al. 2011) and elevation (Gilbert et al. 2008; Tran et al. 2013). Two other land use factors, characterizing built-up and forest/perennial trees features, are also included.

These variables, percentage of land used for rice paddy fields, aquaculture, built-up and forest/perennial trees, and chicken and water bird density, are measured at the commune level and obtained from the 2006 Vietnam Agricultural Census provided by the East West Center—National Science Foundation project. For this study, the weighted overlay technique is used whereby each factor is categorized into 4 groups by using the Jenks natural breaks classification method (Jenks 1967). This is a commonly used statistical method in ArcGIS to group data in categories. This procedure arranges variable values into different classes which reduces the variance within each class while increasing the variance between classes through an iterative process (Baz, Geymen, and Er 2009). This method was found to be a suitable classification method for mapping epidemiological data (Brewer and Pickle 2002; North 2009). Details are presented in Table 1.

Table 1: Data sources and classification descriptions of variables

Name	Unit	Label	Source
HPAI H5N1 occurrences	Unit		East West Center – National Science Foundation project
Water bird density Group 1: 0 - 892 Group 2: > 892 - 2097 Group 3: > 2097 - 4299 Group 4: > 4299	Number of heads/km^2	1 = Low 2 = Medium low 3 = Medium high 4 = High	The 2006 Vietnam agricultural census
Chicken density Group 1: 0 - 1738 Group 2: >1738 - 3992 Group 3: >3992 - 9472 Group 4: >9472	Number of heads/km^2	1 = Low 2 = Medium low 3 = Medium high 4 = High	The 2006 Vietnam agricultural census
Elevation Group 1: ≤ 5 Group 2: > 5 - 15 Group 3: > 15 - 200 Group 4: > 200	M	1 = Coastal areas 2 = Lowland 3 = Midland 4 = Upland	SRTM 90-m resolution DEM: http://srtm.csi.cgiar.org/
Land used for rice paddy field Group 1: ≤ 13.3 Group 2: > 13.3 - 32.6 Group 3: > 32.6 - 48.5 Group 4: > 48.5	%	1 = Low 2 = Medium low 3 = Medium high 4 = High	The 2006 Vietnam agricultural census
Land used for aquaculture Group 1: ≤ 4 Group 2: > 4 - 11 Group 3: > 11 - 29 Group 4: > 29	%	1 = Low 2 = Medium low 3 = Medium high 4 = High	The 2006 Vietnam agricultural census
Land used for built-up Group 1: ≤ 41 Group 2: > 41 - 56 Group 3: > 56 - 80 Group 4: > 80	%	1 = Low 2 = Medium low 3 = Medium high 4 = High	The 2006 Vietnam agricultural census
Land used for forest/perennial trees Group 1: ≤ 3 Group 2: > 3 - 11 Group 3: > 11 - 25 Group 4: >25	%	1 = Low 2 = Medium low 3 = Medium high 4 = High	The 2006 Vietnam agricultural census
Landsat TM/ETM+ Bands 1-5, 7			The USGS EROS Data Center (http://glovis.usgs.gov/)

Elevation data are obtained from the Shuttle Radar Topography Mission (SRTM) 90-m resolution Digital Elevation Model (DEM) (CGIAr-CSI 2010). The Red River Delta topography is reclassified into 4 groups of elevation (above 200m, from 15 m to 200 m, from 5 m to 15 m and less than 5 m) and coded from 1 to 4 respectively to represent upland, midland, lowland and coastal areas (see Tran et al. (2013)). Of which, coastal areas were found to be most vulnerable to disease occurrence. These data are then retrieved for each commune at its centroid and merged with other data using commune codes for the statistical analysis.

Remotely sensed Landsat TM/ETM+ Bands 1-5, 7 data that cover the study area were downloaded from the USGS EROS Data Center (USGS 2013). The data provide critical information for identifying areas vulnerable to HPAI H5N1. The Red River Delta is covered by 4 Landsat tiles: P126R045, P126R046, P127R045 and P127R046 (Figure 2). This study uses the application of support vector machine (SVM) for land use/land cover classification. It is used to classify land use/land cover in the Red River Delta into four categories that represent built-up, agriculture, forest/perennial trees and water areas. This is a supervised learning algorithm based on statistical learning theory that determines a hyper plane for optimally separating two classes. The SVM method has been successfully applied in several studies on biophysical tasks, land cover land use including vegetation, agriculture, impervious surfaces such as urban areas, etc. (Schneider 2012; Castrence et al. 2014; Mountrakis, Im, and Ogole 2011).

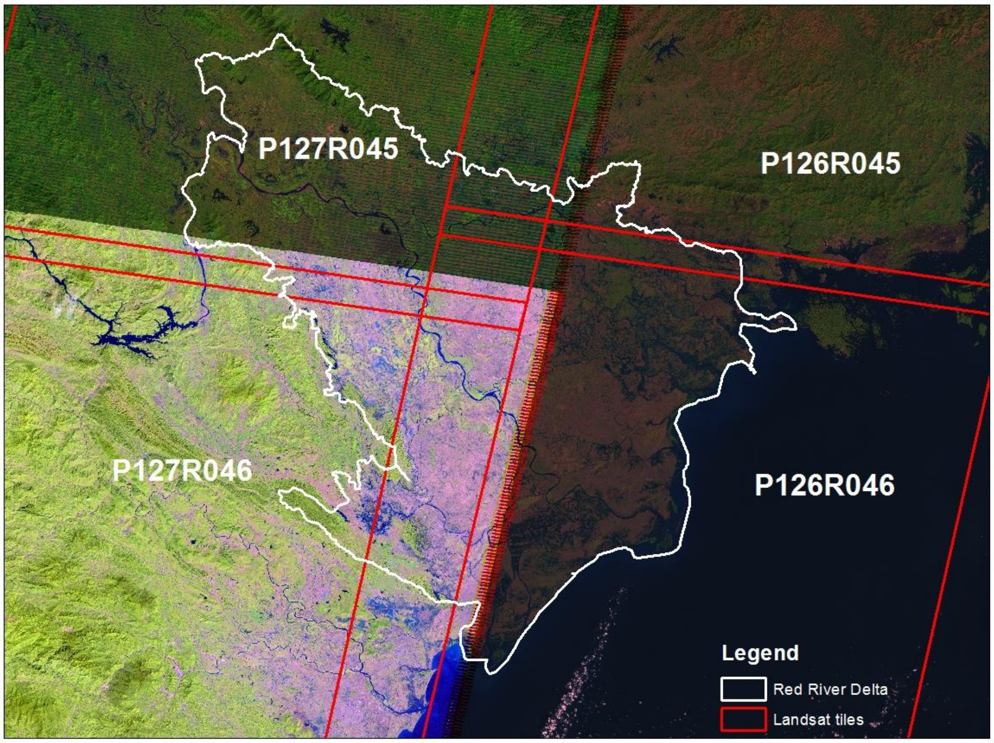

Figure 2: Landsat tiles covering the Red River Delta of Vietnam

Prior to classification, the Red River Delta boundary polygon was divided into 4 polygon subsets respectively located within 4 tiles. Landsat scenes were then stacked into a single image per tile and cropped to the corresponding polygon subsets of the Red River Delta. The groundtruth point locations with defined built-up, agriculture, forest/fruit trees and water labels for each subset were identified and double checked by visualizing point locations in different map sources such as the Landsat scenes themselves, Google Earth images and Bing maps. These groundtruth point locations were used as training data for supervised classification.

The classification process was performed using ENVI version 4.8 (Exelis Visual Information Solutions, CO, USA) and ArcGIS version 10.1 (ESRI, Redlands, CA, USA). Outputs were the classification maps of land use/land cover for each subset and were mosaiced together to produce the final land use/land cover classification map for the Red River Delta. The map represented built-up, forest/fruit trees, water and agriculture areas as shown in red, yellow, blue and green, respectively. They are coded from 1 to 4 respectively indicating the increasing contribution to the higher risk of the disease occurrence (Figure 3).

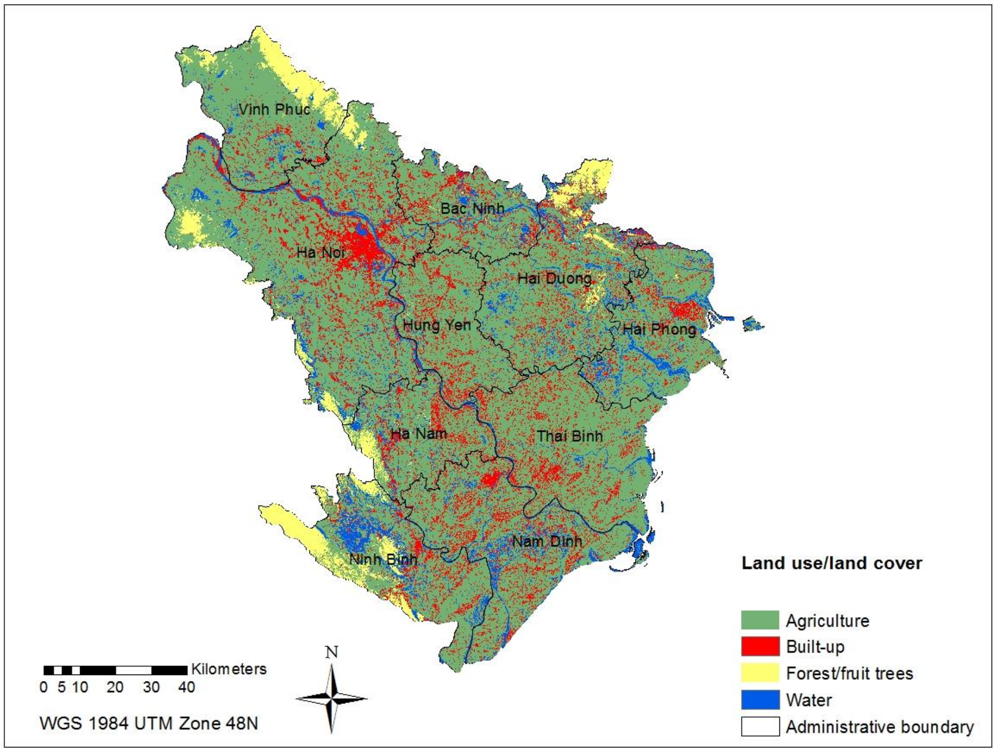

Figure 3: Land use/land cover of the Red River Delta.

The classification results suggested that agricultural activities are dominant in the Red River Delta as shown in green. Water for agricultural production is provided by large river systems with the main Red and Thai Binh rivers flowing through the Delta. Water is transported to the entire area through a complicated channel system and stored in ponds or lakes to form a large alluvial plain area. Other important information that the land use/land cover map conveys is the location of urban core areas of cities in different provinces. These are areas where the intense red pixels are concentrated. It is noticeable that the urban core area of Hanoi accounts for a large proportion of red areas in the Delta. Forest areas are mainly located in the outskirt of the Delta and a portion of the yellow pixels represents fruit tree areas in Hai Duong province.

3. Analytical methods

For the first objective to identify the focus areas for the alternative policy in the Red River Delta, this study adopts the framework of ex-ante analysis. The term "ex-ante" means "from before" in Latin (Wagner, Dunbar, and Weil 2007). The ex-ante analysis uses the outbreak data available at the time of the launch of the current vaccination program in 2005. For the second objective to process the tradeoff between the current and the alternative policy, the outbreak data after the launch of the vaccination program is used in addition to the outbreak data before the program. Outbreak data are divided into two datasets. The first dataset contains the data before the launch of the current vaccination program in 2005 which includes the second and the third epidemic waves with a total of 193 outbreaks. The second dataset consists of outbreak data that occurred after 2005 which comprises of the fifth epidemic wave with 74 outbreaks. The use of the first dataset is to identify the focus location for the alternative policy. The second dataset is to evaluate the efficacy and costs of the vaccination program for the tradeoff between the current and the alternative policies.

For ex-ante analysis, weighted overlay analysis is applied to identify the focus locations for the alternative vaccination program. This method has been considered as one of the most suitable techniques and frequently used for site selection and suitability models in spatial analysis (ESRI 2014). It has been widely applied in several fields e.g., disease management, climate change, habitat conservation, sustainable ecosystems or land-use planning, etc. (Gilbert, Xiao, et al. 2006; Shahid 2011; Jayakumar, Arockiasamy, and Britto 2002; Münch and Conrad 2007; Diamond and Wright 1988). The technique requires that all input factors are classified into different groups and weighted to determine their relative influence accordingly. The analytical procedure for weighted overlay analysis in this study involves a two-stage process: (1) boosted regression trees (BRT) followed by (2) weighted overlay operations.

In the first stage, boosted regression trees is performed to determine the relative influence of each group for a given physical, environmental factor (e.g., chicken density, water bird density, elevation, and percentage of land used for rice paddy fields, aquaculture, built-up, and forest/perennial trees) in relation to HPAI H5N1 occurrence. BRT utilizes a combination of decision trees and boosting algorithms to improve prediction accuracy through an iterative process (Elith, Leathwick, and Hastie 2008; Elith et al. 2006). A stochastic process which includes a probabilistic component used in the decision trees to select relevant predictor variables allows improvement in prediction performance. The use of boosting improves accuracy in a single tree through a sequential process that allows trees to be fitted iteratively through a forward stage-wise procedure. Boosting with stochasticity is managed through a bag fraction which identifies the selected portion of data to be drawn from original data at each step. The model is best performed with a bag fraction ranging from 0.5 to 0.75 (Elith, Leathwick, and Hastie 2008). The number of trees for optimal prediction is determined based on values assigned for learning rate which shrinks the contribution of each tree in the model and tree complexity which specifies the number of nodes in a tree. The rule of thumb recommended for BRT is to fit models with at least 1000 trees. A smaller learning rate and larger tree complexity are preferred since it increases the number of trees (Elith et al. 2006; Elith, Leathwick, and Hastie 2008). Several combinations of learning rate and tree complexity are tested to choose the best setting for model performance which is determined through cross-validation (CV) technique. The final model setting is the combination of a tree complexity of 4 and a learning rate of 0.005 with a bag fraction of 0.75 which were previously used in Martin et al. (2011).

Several BRT models are run through two phases. The first phase determines the relative influence of each group within a physical environmental factor to the occurrence of the HPAI H5N1 disease. Dummy variables representing each group within a factor are created and fitted into the BRT model with response variable of HPAI H5N1 outbreaks. There are 4 BRT models being run separately for 4 physical, environmental factors (chicken density, water bird density, elevation and land use/land cover category which include the percentage of land used for rice paddy fields, aquaculture, perennial trees and forest, and built-up areas). The second phase ascertains the relative influence of each physical environment factor (chicken density, water bird density, elevation, and percentage of land used for rice paddy fields, aquaculture, built-up and forest/perennial trees) associated with disease occurrence. This information is essential for the weighted overlay technique employed in the next stage which determines the focus areas for the vaccination campaign. The estimation procedure for BRT is conducted through R package version 3.0.2, founded by the members of the R Development Core Team as a part of the Free Software Foundation's GNU project.

The second stage determines the potential focus area for the vaccination program by performing a series of overlay operations in ArcGIS 10.1. The overlay operation is manipulated through raster analysis in ArcGIS 10.1 platform. Therefore, it is required that all input factors are stored in raster format. Therefore, all vector layers detailing categorical data for chicken density and water bird density are converted to raster format together with elevation and land use/land cover classification. All raster data layers were converted to the same spatial resolution at 30x30 and clipped to the Red River Delta administrative maps. Steps for weighted overlay analysis are orderly followed (ESRI 2014):

(1) Assign the weighted relative influence obtained from the first phase of the BRT for each corresponding group within an input factor layer through raster reclassification processes.

(2) Multiply reclassified input raster layers by weighted relative influence obtained from the second phase of the BRT. The output values are rounded to the closest integer number.

(3) Add the resulting input raster layers to produce the output raster layer.

The analysis provides suitability maps with suitability scores in integer numbers scaled from 0 to 100. The higher suitability scores represent the higher probability of contracting the HPAI H5N1 disease. Areas with higher suitability scores are suggested as good candidates where the alternative vaccination program should be focused.

For the tradeoff between the current and the alternative policies, the efficacy and the costs of vaccination program are estimated for each policy. The second dataset which includes data of the fifth epidemic wave with 74 affected communes is used in addition to the first dataset. The efficacy of the vaccination program is the measure of proportionate reduction in the rate of disease occurrence as the result of the vaccination program. This can be achieved through the calculation based on the relative risk of disease (Weinberg and Szilagyi 2010).

$$\text{Efficacy} = \frac{\text{ARU - ARV}}{\text{ARU}} * 100 \qquad (1)$$

where ARU and ARV are respectively the infection rates before and after the launch of the vaccination program. The infection rate is the number of affected communes divided by the total communes in the Red River Delta.

To implement the vaccination program, the government is responsible for all the costs including the costs of vaccine, labor and other costs associated with vaccination. The costs for the vaccination program is the product of the number of birds vaccinated, the cost of vaccination per bird and the number of vaccination rounds per year. However, the program did not fully contain the disease. The fifth epidemic wave was reported in 2007. To contain and prevent the disease, Vietnamese government implemented the stamping out method which culled all birds in affected communes and emergency vaccination to vaccinate all birds in surrounding communes. These are extra costs of the vaccination program. The total costs of vaccination program, therefore, are comprised of the cost for the government vaccination program, the cost of emergency vaccination, government compensation for birds culled and farmer's loss because of value difference between market price and government's compensation when the disease occurs.

$$\text{Cost} = A * \text{C} * N + B * C + I * G + (P - G) * I \qquad (2)$$

where A is the number of birds vaccinated; C is the costs of vaccination per bird; N is the number of vaccination rounds per year; B is the number of birds vaccinated because of emergency vaccination; I is the number of birds culled due to the disease occurrence; G is the government compensation per bird culled and P is the market price per bird.

4. Results and discussions

4.1. Boosted regression trees analysis.

In the first phase, four BRT models are run separately for four physical, environmental factors, including chicken density, water bird density, elevation and land use/land cover to identify the relative influence of each group within a factor to the HPAI H5N1 occurrence. The weighted relative influence results are shown in Table 2.

The results revealed that lower groups of water bird density and chicken density are found to have higher relative influence as compared to other groups within each factor. Specifically, water bird density group 2 and group 1 have higher relative influence at 76% and 11% respectively as compared to 7% and 6% for group 3 and 4. Chicken density group 1 is found to have highest weight at 37% and followed by group 2 at 27% influence, group 3 at 25% and group 4 at 11%. It was noted that the traditional production methods with free range water bird farming and backyard chicken farming have been considered to be typical Asian production methods which have the potential of contracting and spreading the HPAI H5N1 virus to other neighboring farms (Alhaji and Odetokun 2011; FAO 2008b). Poultry sectors 3 and 4 (as classified by (FAO 2004)) include open sheds, backyard chicken or free range water bird farming and characterized by small scale production with less than 2000 birds (Desvaux et al. 2008). On the other end, poultry sectors 1 and 2 are characterized by industrial and commercial poultry production which operate with standard procedures and keep poultry indoors continuously during production and maintain high biosecurity standards (FAO 2004; FAO 2007). These large producers have more than 2000 birds per production cycle. Therefore, it is expected that poultry sectors 3 and 4 would fall more in the medium low density group. This resulted in higher density of free range water bird on paddy fields which was found likely to increase the probability of the disease occurrence in Vietnam (Pfeiffer et al. 2007a; Gilbert et al. 2008). Communes with medium water bird density are thought to have increased risk of contracting the disease (Henning et al. 2009).

Table 2: Relative influence of each group within a factor

Name	Group	Relative influence	Ranking
Water bird density	1	11	3
	2	76	4
	3	7	2
	4	6	1
Chicken density	1	37	4
	2	27	3
	3	25	2
	4	11	1
Elevation	1	73	4
	2	16	3
	3	11	2
	4	0	1
Land use/land cover	Agriculture	46	4
	Built-up	35	3
	Aquaculture	17	2
	Forest/perennial trees	2	1

Lower elevation was previously identified to be correlated with the HPAI H5N1 disease in Vietnam in general and in the Red River Delta, Vietnam in particular (Tran et al. 2013; Gilbert et al. 2008). This finding is further confirmed by BRT estimation. It is suggested that topographic elevation features noticeably contributes differently to the disease occurrence. Coastal areas with elevation less than 5m (Group 1 for Elevation in Table 1) play the most important role for disease occurrence. It is estimated to have 73% relative influence (Table 2). These are flat plain areas where rice production is the predominant agricultural activity in the Red River Delta. Lowland and midland areas are ranked the second and third at 26% and 11% influence. These areas are located to the west of the Delta, including the capital city of Hanoi. Land used for rice production also has the highest contribution to disease occurrence with a 46% influence and followed by land used for built-up purposes at 35% (Table 2). This result is in agreement with studies by Pfeiffer et al. (2007a) and Gilbert et al. (2008) which suggested the link between HPAI H5N1 occurrence and the higher proportion of land use for rice paddy fields and closer distance to higher densely populated areas. Water bird movement through rice paddy fields has been defined as a potential source for the widespread HPAI H5N1 virus (Minh et al. 2009;

Pfeiffer et al. 2007a; Gilbert et al. 2008; Gilbert et al. 2007; Gilbert, Chaitaweesub, et al. 2006). In contrast to lower elevation areas, upland areas with elevation greater than 200m were found not likely to affect the disease. Evergreen forests or forestry production dominates in these areas (EAP-AP 1994). This result is also consistent with BRT estimation for land use/land cover which showed that the relative influence of land used for forest/perennial trees is small and measured at 2%.

In the second phase of the BRT, all categorical variables including chicken density, water bird density, elevation, percentage of land used for rice paddy fields, aquaculture, perennial trees and forest, and for built-up areas are fitted into the BRT model to determine the relative influence of each factor to the HPAI H5N1 occurrence. The results (see Table 3) suggest that water bird density has the largest effect on disease occurrence with relative influence estimated at 19%. Ducks, as a reservoir host for the HPAI H5N1 virus, have been discussed in earlier studies (Gilbert et al. 2008; Gilbert, Chaitaweesub, et al. 2006; Pfeiffer 2007; Minh et al. 2009; Webster et al. 2007; Songserm et al. 2006; Smith et al. 2006). The number of recorded duck related disease occurrences steadily increased from 11% in 2003/2004 to its peak of 78% in 2006/2007 (Minh et al. 2009).

Table 3: Relative influence of each factor to the HPAI H5N1 occurrences

Variable	Relative influence (%)
Water bird density	19
Land used for rice paddy field	18
Elevation	18
Land used for aquaculture	17
Land used for built-up	14
Chicken density	12
Land used for forest/perennial trees	2

The next highest relative influence factors are land used for rice paddy field, elevation, land used for aquaculture, land used for built-up, chicken density and land used for forest/ perennial trees. Land used for forest/ perennial trees has the smallest effect with 2% relative influence. This result further confirms the findings from BRT estimations for elevation and land use/land cover in the first phase whereby upland areas with forest/perennial trees land cover type are not likely to favor HPAI H5N1 occurrence.

4.2. Weighted overlay results.

The BRT estimation results provide essential information for weighted overlay analysis. Weighted relative influence values are assigned to corresponding raster layers through raster reclassification processes. Each value class in each input raster detailing water bird density, chicken density, elevation and land use/land cover is assigned a new, reclassified values on weighted relative influence scaled from 0 to 100, where 0 represents the lowest suitability and 100 the highest. For instance, in the land-use raster, agricultural land is highly suitable, while forest/perennial trees land is not. In the elevation raster, suitability values are high for coastal areas and low for highland areas. In the water bird density raster, suitability is higher in the area where lower water bird density is found and lower in high water bird density area. The same trend is found for chicken density where communes categorized in group 1 and 2 has higher suitability scores as compared to group 3 and 4.

Each of the input rasters is then weighted using weighted relative influence from Table 3. In this weighted overlay, water bird density has a 19% influence, land used for rice paddy field an 18% influence, elevation a 18% influence, land used for aquaculture a 17% influence, land used for built-up a 14% influence, chicken density a 12% influence and land used for forest/perennial trees a 2% influence. The output suitability map is shown in Figure 4.

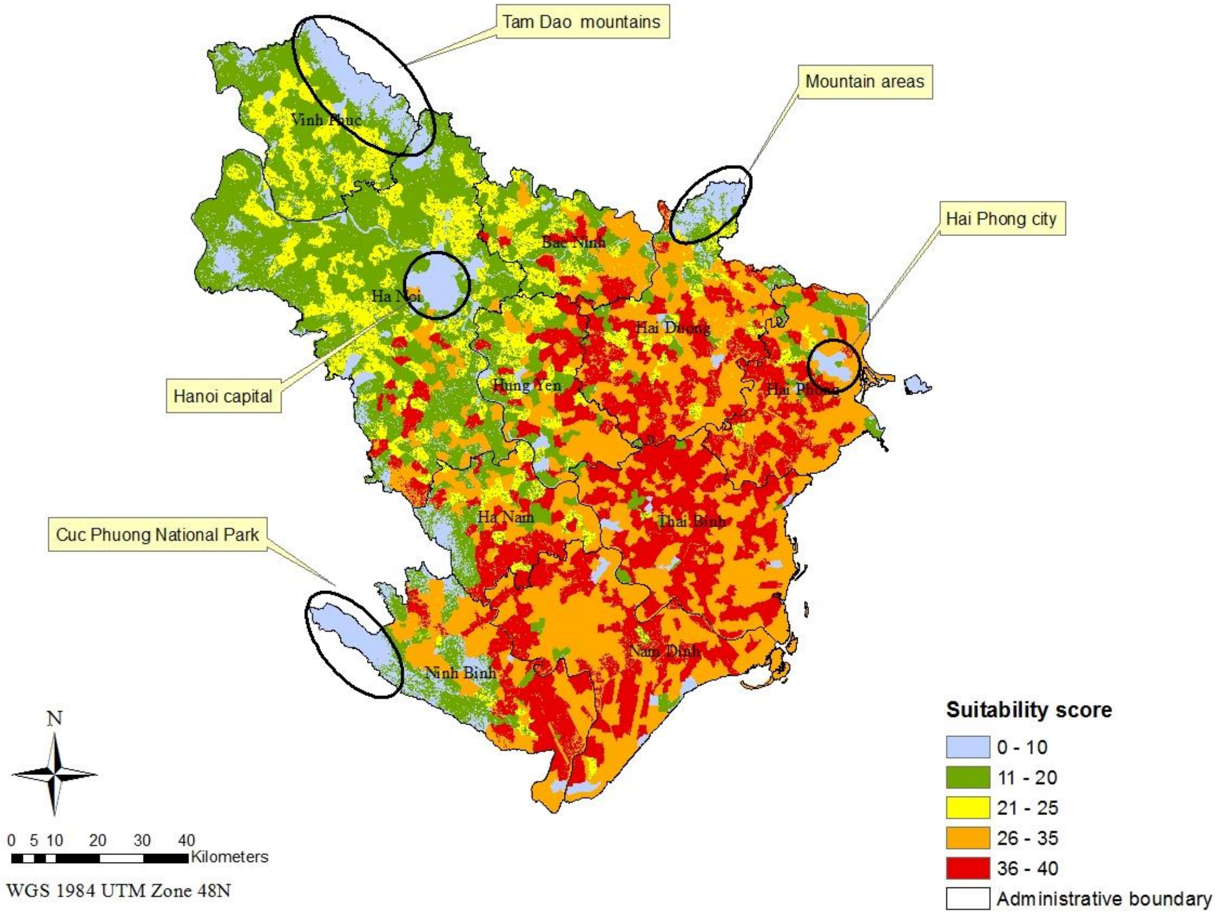

Figure 4: Suitability scores for the HPAI H5N1 occurrence in the Red River Delta

The highest suitability score areas are shown in red, followed by orange. Yellow, green and blue areas have lower suitability scores. It is noticeable that these areas (suitability scores ranging from 0 – 10, 11 – 20 and 21 - 25) are mostly located to the west and northwest of the Red River Delta. The lowest suitability score areas are either in urban cores or mountainous areas. They include urban core areas of Hanoi, Hai Phong, Hai Duong, Bac Ninh, Hung Yen, Nam Dinh and Thai Binh provinces and mountain areas of Ba Vi of Hanoi, Tam Dao of Vinh Phuc, Cuc Phuong national park of Ninh Binh and mountain areas located to the north of Chi Linh district of Hai Duong province. These areas are characterized by various economic activities in urban cores, forestry production or tourism services in mountain areas other than agriculture and poultry production. One of the most popular tourist attractions in the Red River Delta that attract millions of visitors every year are Cuc Phuong National Park and Bai Dinh Temple located in the mountains in the West of Ninh Binh. Tourism is the main economic activity in this area.

The areas with high suitability scores (ranging from 26 – 40) as shown in red and orange are chosen as the focus areas for the alternative vaccination program against HPAI H5N1. These areas are mostly located in the coastal areas to the east and south of Hanoi. A total of 1137 communes, corresponding to 50.6% of total communes in the Delta, are selected for the alternative policy. The areas were also previously identified to have highest probability of disease occurrence in the Delta (Tran et al. 2013). They include provinces near the Gulf of Tonkin, including Hai Phong, Thai Binh, Nam Dinh, Hai Duong and eastern part of Hung Yen and Ha Nam provinces. Almost the entire areas of Hai Duong, Hai Phong, Thai Binh and Nam Dinh provinces are identified as the focus areas for vaccination program except urban cores and mountains in the north of Hai Duong. Agricultural intensification is fully supported by water sources from the Red and Thai Binh river systems. Water bird production with free range farming is the most intensive in the Red River Delta together with the Mekong Delta (Edan and Bourgeois 2006). Thanh Oai, Thuong Tin, Ung Hoa and Phu Xuyen districts of Hanoi are also identified as the focus areas. They are located to the south of Hanoi capital. These areas are famous for high quality free range duck meat product providing popularly for consumers in Hanoi market, especially the brand "Vit co Van Dinh".

4.3 Efficacy and Cost analyses of vaccination programs and policy implications

The ex-ante analysis identifies the focus areas for the alternative vaccination program against the HPAI H5N1 disease which involves shifting vaccination for HPAI H5N1 from the entire Delta to the identified focus areas within the Delta. These areas are extracted and overlaid with the spatial distribution of the fifth HPAI H5N1 (Figure 5a). Although the current policy vaccinated all the poultry population in the Red River Delta, it was conducted only twice a year (April-May and October-November). This means unvaccinated poultry at different time of the year (Jan-Mar, Jun-Sep and Dec) is still at risk of the disease infection. The fifth wave of outbreak with 74 communes affected was the result of this missed vaccination in time. They were mostly located in the coastal areas to the east and south of Hanoi. The disease was mostly reported in unvaccinated poultry (OIE 2007).

It was noted that the optimal length of a both chicken and duck production cycles was estimated at 10 weeks, including a two-week cleaning period (Tran 2010; Tran and Yanagida 2014). Assuming that producers continuously conduct production, there would be 5 duck production cycles per year. Therefore, the alternative policy would involve 5 vaccination campaigns throughout the year. Henning et al. (2009) noted that the vaccination showed a viable means of protection against the HPAI H5N1 virus. As a result, it is expected that these high probability areas are protected from the HPAI H5N1 disease under the alternative policy. Figure 5(b) shows that a total of 61 out of 74 infected communes in the fifth epidemic is correctly predicted in the focus areas for the alternative vaccination program. As a result, the alternative policy would protect these 61 communes from the disease but the other 13 communes which are not covered by this policy are affected by the disease.

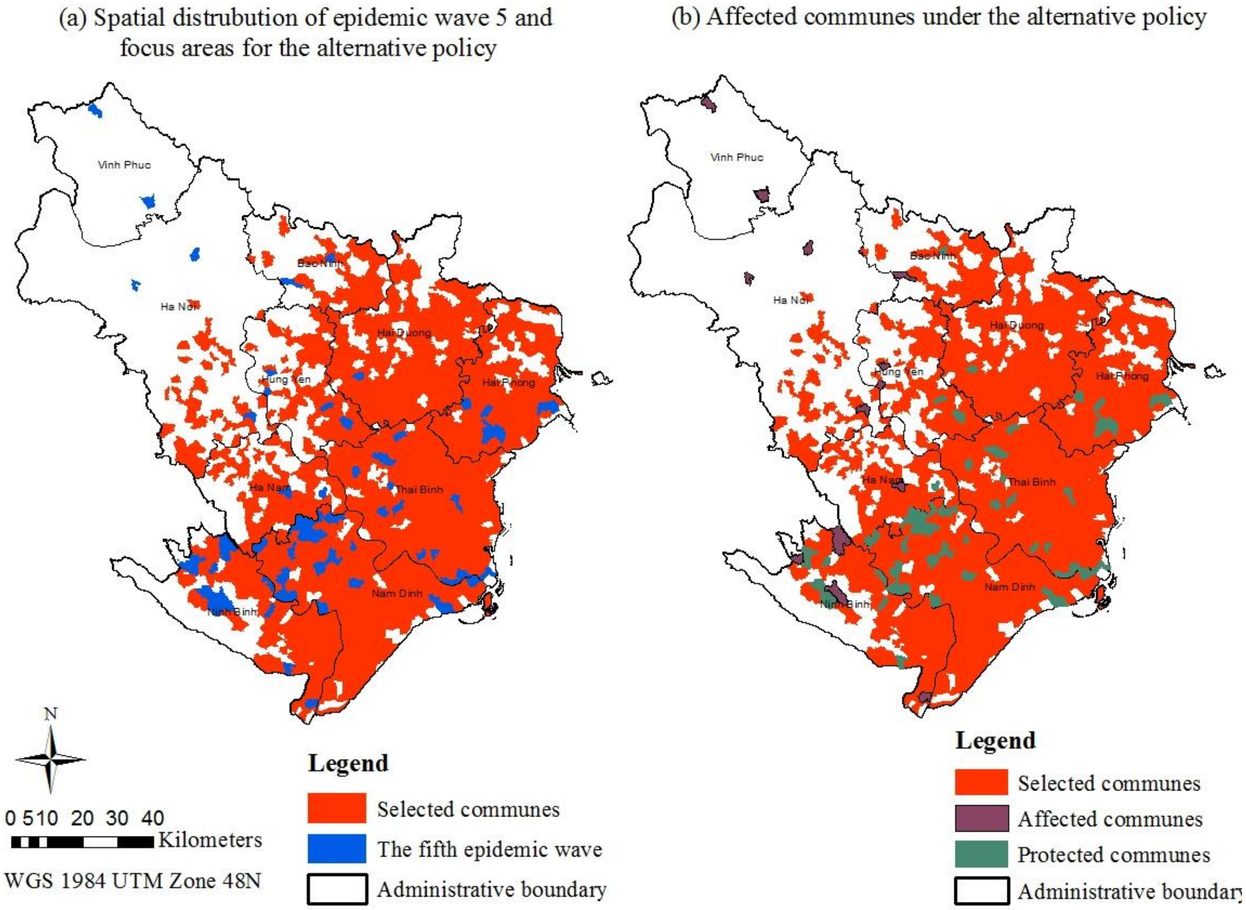

Figure 5: The focus areas for vaccination program and accuracy evaluation.

Table 4: The efficacy analysis of the two policies

	Unit	Before vaccination	Current policy	Alternative policy
total number of communes	Communes	2248	2248	2248
Number of affected communes	Communes	193	74	13
Infection rate		0.0859	0.0329	0.0058
Efficacy[3]	%		61.66	93.26

The efficacy analysis of the vaccination programs is conducted by using Equation 1 to investigate which policy would be more successful in preventing the disease occurrence. The analysis results are shown the Table 4. It is noted that the total number of communes in the Red River Delta are 2248 communes. There are 193 communes affected by the disease before the implementation of the current policy. It results in the infection rate $\text{ARV} = 0.0859$. The current vaccination policy contributed to the reduction of the affected communes to 74 as reported in the fifth epidemic waves, resulting in the infection rate $\text{ARU} = 0.0329$. The alternative is expected

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[3] The calculation of efficacy follows the Equation 1

to further reduce the number of communes affected to 13 communes which yields the infection rate $\mathrm{ARU} = 0.0058$.

Using Equation 1 for the calculation of the efficacy of each policy, Table 4 shows that efficacy results for the alternative policy and for the current policy are respectively estimated at 93.26% and 61.66%. It is suggested that the alternative policy would be more successfully in reducing the rate of disease occurrence measured at 93.26% as compared to the current policy at 61.66%. It is expected that the alternative policy which involves more frequent vaccination in the identified high risk areas within the Red River Delta would better prevent the occurrence of the disease than the current policy.

For the cost analysis of the current and the alternative policies, the results are shown in Table 5.

Table 5: The cost analysis of the two policies.

	Unit	Before vaccination	Current policy	Alternative policy
Number of birds vaccinated	Thousand heads	0	59,241	31,171
Times of vaccination per year	Unit	0	2	5
Vaccination cost	Million US$	0	4.50	5.92
Number of affected communes	Communes	193	74	13
Number of birds culled	Thousand heads	6,375	2,165	395
Government compensation	Million US$	7.95	2.68	0.49
Number of communes included in emergency vaccination	Communes	543	304	92
Number of birds vaccinated in emergency vaccination	Thousand heads	0	8,625	2,898
Cost of emergency vaccination	Million US$	0	0.33	0.11
Farmers loss	Million US$	4.95	1.65	0.30
Total loss	Million US$	12.90	9.16	6.82

It is noted that the current vaccination campaign covered the entire poultry population in the Red River Delta and was conducted twice a year. The cost for a HPAI H5N1 vaccination in Viet Nam are estimated at US$ 0.038/head, including vaccine cost of US$ 0.016 per dose, a labor cost of US$ 0.013 and other costs associated with vaccination of US$ 0.009 (Hinrichs, Sims, and McLeod 2006). As a result, the costs of the current policy is estimated at US$ 4.50 million per year. The alternative policy consists of about half of total communes in the Delta, covering 1137 communes with poultry population of 31,171 thousand birds. Having vaccinated poultry five times per year would cost US$ 5.92 million year. By examining at the costs of vaccination only, this shows that the costs of the alternative policy is higher than the current policy (US$ 5.92 million vs US$ 4.50 million).

When the disease occurs, the all birds in affected communes are culled due to the stamping out program and all birds in surrounding communes. However, before the official vaccination campaign was launched in the end of 2005, the only emergency response to the disease occurrence was stamping out program. This results in 6,375 thousand birds in 193 affected commune culled in the second and the third epidemic waves. After the implementation of the current policy, a total of 2,165 thousand birds are affected and culled and 8,625 thousand birds are vaccinated as the result of the emergency response to the disease occurrence. Under the alternative policy, it is estimated that 395 thousand birds in 13 communes are affected and culled by the disease. Other 2,898 thousand birds in 92 surrounding communes are vaccinated due to the emergency vaccination.

The government incurs more losses from the stamping out and emergency vaccination. The average amount of compensation per bird culled due to the disease occurrence was regulated at US$ 1.24/head (23,000VND/head)[4], in Decision No 719/QD-TTg dated 5 June 2008. In addition, the average market value of a bird was estimated at US$ 2 (Sims and Do 2009). The farmers also suffer losses of US$ 0.76/head from production because of value difference between market price and government's compensation. This results in the Government's additional loss from compensation and farmers' loss of US$ 7.95 million and US$ 4.95 million, respectively, in the second and the third epidemic waves. Under the current policy, the emergency vaccination was implemented which caused the government estimated US$ 0.33 million in addition to the government compensation and farmers loss measured at respectively US$ 2.68 million and US$ 1.65 million. These losses are also estimated at US$ 0.49 million, US$ 0.11 million and US$ 0.30 million for the government and farmers respectively under the alternative policy.

Table 5 suggests that without vaccination, total losses imposed to the government and farmers are higher than the vaccination program and estimated at US$ 12.90 million. Except for the costs of vaccination (US$ 4.50 million vs US$ 5.92 million), and other costs, the alternative policy are lower than the current policy. The total losses comprising vaccination costs, government loss for compensation of birds culled and for emergency vaccination and farmers loss are calculated at US$ 9.16 million for the current policy as compared to US$ 6.82 million for the alternatively policy. The cost analysis indicates that the alternative policy would save government and farmer resources due to lower costs associated with disease eradication and prevention. The results of the analysis suggest that Vietnam may face lower costs with the alternative policy.

5. Conclusions

The challenge is to develop the most effective vaccination program against the HPAI H5N1 disease from a public policy perspective. The current vaccination policy which implemented an annual two round vaccination plan for the entire geographical area of the Red River Delta has not successfully controlled the disease. This study explores implications of an alternative policy, which is likely to be more successful in containing and preventing the disease from recurrence in the Red River Delta, Vietnam and reducing vaccination costs. It involves shifting from a two-round vaccination plan for the entire Delta to a more frequent vaccination plan for specific areas identified as higher risk areas for the disease occurrence within the Delta.

To address the tradeoff between the two policies, this study first identifies the location and spatial distribution of higher probability areas of disease occurrence in the Red River Delta for the alternative policy using an ex-ante analysis framework and then process the tradeoff between the current and the alternative policy through the analysis of the efficacy and the costs of vaccination programs. Weighted overlay analysis is applied for the ex-ante analysis. The analytical procedure involves a two-stage process: (1) boosted regression trees (BRT) to

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[4] Exchange rate at 1USD = 18,500 VND

determine the relative influence of each factor followed by (2) weighted overlay operations to identify the areas at higher risk of the disease based on their suitability scores. The efficacy and cost analyses are then implemented to assess the proportionate reduction in the rate of disease occurrence and the costs imposed by each policy on the government and farmers. The study takes into account factors which were previously found to have effects on the occurrence of the disease such as the percentage of land used for rice paddy fields and aquaculture, elevation and domestic water bird and chicken density.

The ex-ante analysis suggests that the alternative policy which involves more frequent vaccinations in the identified high risk areas within the Red River Delta would better prevent the disease from occurrence than the current policy which implements an annual two-round vaccination plan for the entire Delta. The focus areas for the alternative vaccination program against HPAI H5N1 are mostly located in the coastal areas to the east and south of Hanoi with elevation less than 5m. A total of 1137 communes, corresponding to 50.6% of total communes in the Delta, are selected for the alternative policy. The efficacy analysis suggests that the alternative policy would be more successfully in reducing the rate of disease occurrence measured at 93.26% as compared to the current policy at 61.66%. The cost analysis indicates that the alternative policy would save government and farmer resources because of lower costs associated with disease eradication and prevention. Total losses imposed on both the government and farmers are higher for the current policy (US$ 9.16 million) than for the alternative policy (US$ 6.82 million).

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