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Part One

The Why and How of Risk Mapping

Introduction

Why risk maps?

Risk maps are tools that decision-makers can use to help focus their disease surveillance efforts on areas at greatest risk of disease outbreak.

The aim of this risk mapping project is to identify areas at higher risk for the introduction and spread of highly pathogenic avian influenza (HPAI) H5N1—commonly called "bird flu"—in Africa. "Introduction" refers to a first occurrence in a place; "spread" refers to disease movement once introduced.

We lack adequate knowledge so far about the epidemiology of bird flu in Africa, concerning both introduction and spread. Better information is essential since more than 85 percent of households in rural Africa raise poultry. An epidemic could therefore devastate both livelihoods and food sources, as well as raise the risk of disease transmission to humans.

The risk map project for bird flu in Africa

This project presents risk maps which have been generated for bird flu for the African continent and sub-regions. Project staff have used state-of-the-art techniques for creating the best maps possible based on the data currently available. These maps will be refined as our knowledge of the epidemiology of bird flu improves.

The maps in this report were created using multicriteria decision modelling (MCDM). MCDM combines observations and knowledge from numerous sources including published studies, known outbreaks, geographic representation of a wide range of risk factors, direct field observation and experts' experience to produce a risk map.

Bird flu status so far in Africa

The first outbreak of bird flu in Africa occurred in 2006. Since then the disease has affected 11 countries: Burkina Faso, Niger, Nigeria, Togo, Benin, Ghana, Ivory Coast, Sudan, Egypt, Cameroun and Djibouti. In March 2009, Egypt still reported ongoing outbreaks (see Figure 1, page 1-5).

This Initial Report presents

- The rationale and methodology for risk mapping of bird flu in Africa
- The risk-factor layers from which the risk maps are generated
- The first generation of risk maps, for the continent and several sub-continental regions.

The Final Report will feature risk maps improved through incorporation of improved data, field work, and expert validation.

Use of risk maps: some words of caution

Decision-makers and map users should always exercise caution when interpreting risk maps.

- Maps cannot predict an outbreak; they can only indicate where the risk of an outbreak is higher or lower than other areas.
- So far we have only a limited understanding of the epidemiology of the disease in Africa.
- Maps are imperfect since important data are sometimes unavailable, and other data may be inaccurate.
- Possibly important risk factors cannot be mapped. These include beliefs and cultural practices regarding poultry.

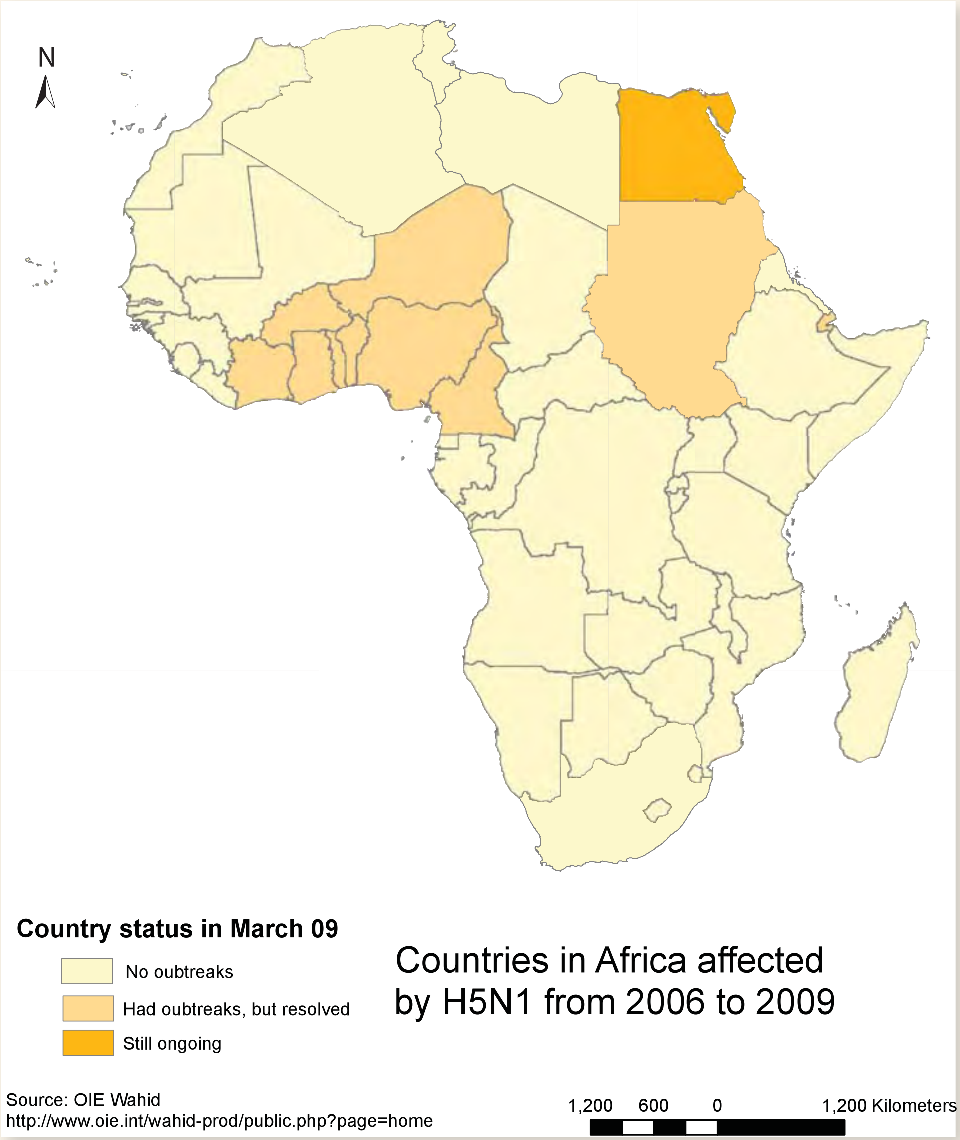

Figure 1:
Countries in Africa affected by bird flu between 2006 and March 2009, and their current status with regards to the disease.

Methodology

The methodology for generating the risk maps is based on multi-criteria decision modelling(MCDM) (Pfeiffer et al., 2008). It combines knowledge and observations from numerous sources including published studies, direct field observation, experts' experience and geographical representation of risk factors associated with the introduction and spread of the disease. It is driven by our best epidemiological understanding of the different factors associated with an increased risk of the disease.

MCDM involves the following steps:

1. Define the objective(s) of the mapping exercise. (In this case they are to map the risk of introduction and risk of spread of bird flu in Africa.)
2. Identify risk factors and how they are associated with the risk of disease. (e.g. a risk factor for the spread of bird flu may be poultry density; the association between the risk factor and the outcome is that the higher the poultry density in an area, the more likely the virus will spread.)
3. Find publicly available maps of risk factors and create a map "layer' for each. (Researchers identified 12 layers representing risk factors associated with poultry trade and transport, and migratory flyways.)
4. Digitally manipulate the maps so that they are in the correct format for inclusion in the MCDM.
5. Define the relative importance of each factor in relation to the objective. (e.g. in Africa it appears that the poultry trade may pose a greater risk to the introduction of bird flu than migratory birds.)
6. Combine risk-factor layers to produce a final, weighted estimate of relative risk for each location in the study area. This process results in a risk map.
7. Perform a sensitivity analysis. This analysis is a statistical check on the calculations underlying the risk maps.
8. Validate the maps. This process is ongoing. We will validate the risk maps with field observations of actual outbreaks in Africa, and also with expert opinion.

The process in more depth

Step 1
Defining the objective(s)

The objectives of the multicriteria decision model are to:

a) To identify areas in Africa with a high or low likelihood for the introduction of bird flu

b) To identify areas in Africa with a high or low potential for bird flu to spread, once introduced into the continent.

Step 2
Defining the risk factors

A systematic search of peer-reviewed, published studies on avian influenza helped researchers identify risk factors for the introduction and spread of bird flu in Africa. Of the risk factors that emerged, the team selected those that can be mapped. For instance, proximity to waterbodies and main roads can be mapped, while cultural beliefs regarding poultry cannot be mapped.

Searches were performed on two comprehensive databases of journals and other scientific literature:

1) PubMed/Medline, a widely used general medical database, and

2) ISI Web of knowledge (Athens), which includes a wealth of literature on veterinary medicine and public health.

Key words for the searches were standardised across the two databases to produce comparable searches (Table 1).

Table 1:
Standardised key words used in the literature search of two databases

Key words	**PubMed** (Field specified: MeSH terms)	**ISI Web of knowledge** (Field specified: Topic)
avian Influenza	influenza in birds	avian Influenza
HPAI	influenza in birds	HPAI
H5N1	Influenza A Virus, H5N1 Subtype	H5N1
Africa	Africa	Africa
risk assessment	risk assessment	risk assessment
wild bird*	wild animal	wild birds
legal import*	commerce	trade
illegal import*	commerce	trade
risk*	risk	NOT USED
risk factor*	risk factors	risk factor*
establish*	epidemiology	establish*
endemic*	epidemiology	endemic*
transmiss*	disease transmission	transmiss*

More specific terms (e.g."biosecurity," "markets,""fomites,""ducks," etc. were assumed to be covered by the above search strategy, since the key words refer to broader concepts.

The keyword search produced several hundreds of articles published as of 5th March 2009. Researchers screened all (some were listed on both databases), then read the 136 most relevant ones. Of these, 48 identified risk factors for introduction and spread of bird flu (Figure 2).

Using the list of risk factors (Table 2), those suitable for mapping were extracted, and classified according to their relevance for introduction or spread of disease (Tables 3 and 4).

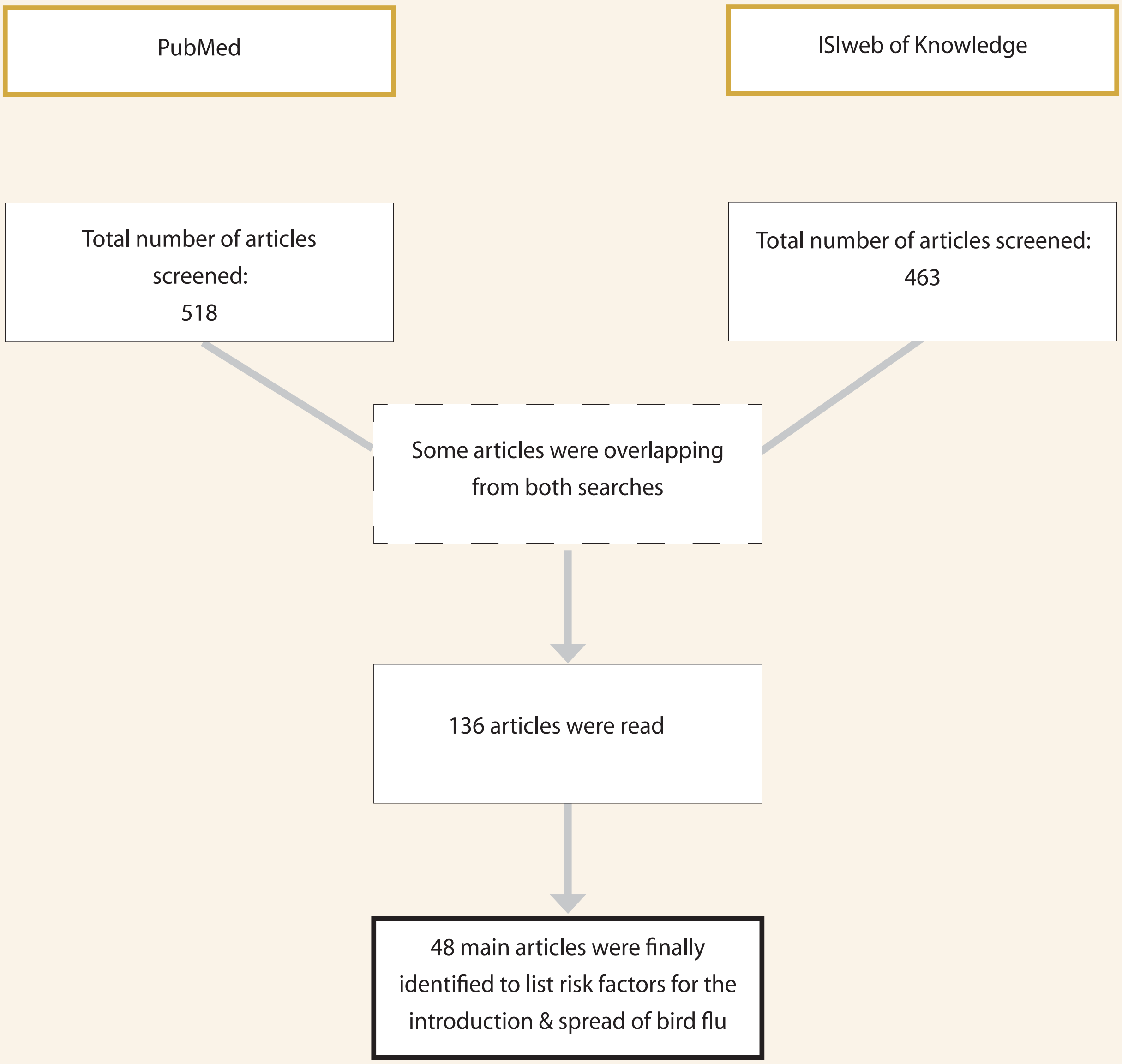

Figure 2:
Flow chart diagram indicating the screening and selection of relevant papers selected from the two databases.

Two selection criteria were used to identify risk factors useful for mapping activities:

a) Ability of the risk factor to be mapped.

Example 1: "Owner lives off farm" (Kung, Morris et al. 2007) is a risk factor for spread that cannot be represented on a map.

Example 2: "Water area" (Ducatez 2006) is a risk factor that can be represented on a map.

b) Importance of the risk factor according to the number of times reported in the literature review.

Table 2:
Risk factors for the occurrence of bird flu as identified in a review of 136 articles published on PubMed or ISI Web of Knowledge

Risk factors	Comments	References
Markets/ trade		
Days open (7 days) LPAI*	New Jersey	(Bulaga, 2003)
Live poultry market	China	(Cheung et al., 2007)
Sale of poultry at live bird markets	Vietnam, farm level	(Soares-Magalhaes, 2006)
Live bird markets	Vietnam	(Nguyen et al., 2005)
Live poultry market	Korea	(Choi et al., 2005)
Retail marketing of live poultry	HK, farm level	(Kung et al., 2007)
Unprotected trade	Nigeria	(Ducatez, 2006)
Importation of day old chicks	Ethiopia	(Soares-Magalhaes, 2007)
Legal and illegal trade of poultry	Global	(Gauthier-Clerc, 2007; Vannier, 2007)
Trade of poultry		(Kilpatrick et al., 2006)
Proximity to road / highway	Romania, China	(Fang et al., 2008; Ward et al., 2008)
Major cultural festivals with peak sale / consumption	Vietnam	(Pfeiffer et al., 2007)
Reducing distances to higher human population density aggregation	Vietnam, farm level	(Pfeiffer et al., 2007)
Migratory/ wild birds		
Migratory birds route	Europe	(Pfeiffer et al., 2006; Feare, 2007; Sabirovic et al., 2007)
	Ethiopia	(Goutard et al., 2007)
	Egypt	(Saad, 2007)
	America/ South Africa	(Abolnik, 2007)
	Global	(Kilpatrick et al., 2006; Stailknecht, 2007; Weber and Stilianakis, 2007; Gaidet et al., 2008b; Keawcharoen et al., 2008)
Farm practices		
Distance cases - susceptible		
Movements of poultry between holdings	Vietnam, farm level	(Soares-Magalhaes, 2006)
Direct distance to the nearest case farm	Japan, farm level	(Nishiguchi et al., 2007)
Proximity of infected premises < 1.5km	Italy, farm level	(Mannelli et al., 2006)
Biosecurity / Sanitary measures		
Type of housing (4 systems duck raising)	Thailand, farm level	(Songserm, 2006)
Backyard/small scale/free range systems	Nigeria, farm level	(Cecchi et al., 2008; Joannis et al., 2008)
Incomplete biosecurity measures of farm visitors	Japan, farm level	(Nishiguchi et al., 2007)
Owner lives off farm	HK, farm level	(Kung et al., 2007)
Use of non-family caretakers	US, farm level	(McQuiston, 2005)
Relative working in poultry industry	HK, farm level	(Kung et al., 2007)
Farm managed by employees (not owner)	Korea, farm level	(Yoon et al., 2005)
Sharing of farms equipment among farms	Japan, farm level	(Nishiguchi et al., 2007)
Carboards eggs trays (fomites?)	The Netherlands	(Thomas et al., 2005)
Movements of fomites into the poultry holdings	Vietnam, farm level	(Soares-Magalhaes, 2006)

Risk factors	Comments	References
Wild birds in feed trough	HK, farm level	(Kung et al., 2007)
Disposal of dying and dead birds	Vietnam, farm level	(Soares-Magalhaes, 2006)
Disposal of dead birds	US, farm level	(McQuiston, 2005)
Presence of mammalian wildlife on the farms	US, farm level	(McQuiston, 2005)
Use of untreated water for animal consumption	Vietnam, farm level	(Soares-Magalhaes, 2006)
Husbandry practices		
Age group of highest death rate at > 30 days old	HK, farm level	(Kung et al., 2007)
Birds of > 10 weeks old	US, farm level	(McQuiston, 2005)
Introduction of end-of-lay chickens	Japan, farm level	(Nishiguchi et al., 2007)
Increasing chicken density	Vietnam, farm level	(Pfeiffer et al., 2007)
Increased poultry flock density	Vietnam	(Henning et al., 2009)
Increased number of chicken house in use on farm	Korea, farm level	(Yoon et al., 2005)
Number of chickens on farms and stock density	HK, farm level	(Kung et al., 2007)
Keeping poultry over or near ponds and rice fields	Vietnam, farm level	(Soares-Magalhaes, 2006)
Increasing domestic water birds density	Vietnam, farm level	(Pfeiffer et al., 2007)
Agriculture / crop / ducks		
Greater % of rice paddy fields	Vietnam, farm level	(Pfeiffer et al., 2007)
Increasing % of aquaculture	Vietnam, farm level	(Pfeiffer et al., 2007)
Increased NDVI rainy season	Vietnam	(Henning et al., 2009)
Rice crop production (agriculture) and calendar	Thailand ducks	(Gilbert et al., 2006; Gilbert, 2007)
Abundance of free-grazing ducks	Thailand ducks	(Gilbert et al., 2006; Gilbert, 2007)
Domestic ducks	Asia	(Hulse-Post et al., 2005)
Domestic and wild ducks	Asia	(Sturm-Ramirez et al., 2005)
Aggregation site		
Wetlands / seasonality, hydrology: during dry season.	Thailand ducks	(Gilbert et al., 2006; Gilbert, 2007)
Resting sites for wild birds	Germany	(Hlinak et al., 2006)
Wetlands (Camargue): places of aggregation	France	(Jourdain et al., 2007)
Water inland area	Nigeria	(Ducatez, 2006)
Wetlands / water birds/ waterfowl Gaidet et al., 2008a; Martinez et al., 2009)	Africa, Nigeria, Spain	(Gaidet et al., 2007; Cecchi et al., 2008;
Proximity to wetlands	Romania, China	(Fang et al., 2008; Ward et al., 2009)
Proximity to river	Romania	(Ward et al., 2008)
Scavenging animals		
Vultures eating dead birds	Burkina Faso	(Ducatez et al., 2007)
Dogs carriers	Thailand	(Cleaveland et al., 2006)
Cats	Burkina Faso, Germany, Thailand, Cambodia	(Tiensin et al., 2005; Editorial-team, 2006; Ducatez et al., 2007; Desvaux et al., 2009)

**LPAI: Low Pathogenic Avian Influenza*

Table 3:
*Factors associated with the **introduction** of bird flu into Africa, and the hypothesized relationship between each factor and the introduction of disease*

Potential risk factors for the introduction of HPAI H5N1	Hypothesized relationship between potential risk factor and the introduction of HPAI H5N1 in Africa
Flyways	For the MCDM risk mapping, it was assumed that migratory birds constitute a risk for the introduction of HPAI H5N1 into Africa. The migratory flyways covering areas in Africa represent areas expected to be at higher risk of introduction of bird flu. The role of migratory birds in long distance transmission of HPAI H5N1 has been considered in several studies, but still remains controversial due to many knowledge gaps. Wild birds (esp. wild ducks) were identified as potential long distance vectors for the virus in various studies (Kilpatrick et al., 2006; Stailknecht, 2007; Gaidet et al., 2008b; Keawcharoen et al., 2008), while other authors considered it unlikely (Feare, 2007; Saad, 2007; Weber and Stilianakis, 2007). Different risk assessments of the introduction of HPAI H5N1 into different regions have concluded that the role of migratory birds was low but not negligible, with high uncertainty (Pfeiffer et al., 2006; Goutard et al., 2007; Sabirovic et al., 2007).
Surface water: wetlands and waterbodies	Increasing distance from surface water is expected to be associated with decreasing risk of introduction of the disease in Africa. Wetlands are considered as aggregation sites for migratory and resident wild birds and therefore constitute potentially higher risk areas for introduction and transmission of HPAI virus (Hlinak et al., 2006; Jourdain et al., 2007), as was suggested for Nigeria (Ducatez, 2006). Surveillance studies conducted in several major wetlands of Africa isolated AI viruses in Eurasian and Afro-tropical species of wild birds (Gaidet et al., 2007; Gaidet et al., 2008a). Distance to wetland areas containing migratory waterfowl species has also been hypothesised as a risk factor for the introduction of disease in Spain (Martinez et al., 2009).
International poultry trade: cross-border roads, ports and airports	For the MCDM risk mapping, it was hypothesized that international poultry trade occurs via roads, ports and airports, and that increasing density of ports, airports and roads is associated with a higher risk of introduction of HPAI H5N1. Poultry trade has been identified as a risk factor for introduction of HPAI (Ducatez, 2006; Kilpatrick et al., 2006). A study published in 2007 stressed the importance of formal and informal trade for the introduction of the disease in previously unaffected areas, as it seems was the case in Nigeria (Vannier, 2007). In addition, proximity to highways was found associated with risk of HPAI outbreak in China (Fang et al., 2008), and this is likely to be due increased movements of poultry and poultry products for trade.

Table 4:
Factors associated with the **spread** *of bird flu in Africa, and the hypothesized relationship between each factor and the spread of disease*

Potential risk factors for the spread of HPAI H5N1	Hypothesized relationship between potential risk factor and the spread of HPAI H5N1 in Africa
Roads	Increasing density of roads is expected to be associated with increasing movements of poultry and poultry products for trade, and thus higher risk of spread of disease. Outbreak risk was associated with proximity to major roads in Romania (Ward et al., 2008) and China (Fang et al., 2008). This is likely to be due to transport of poultry for trade via road.
Navigable rivers	Increasing distance from navigable rivers is expected to be associated with decreasing risk of spread of the disease. There is no published evidence for the direct role of navigable rivers in the spread of HPAIV, however given the identification of roads as a risk factor (Fang et al., 2008; Ward et al., 2008), such a role can be hypothesized for important rivers in Africa known to be used for transport of consumption goods and livestock.
Poultry density	Increasing density of poultry is expected to be associated with a higher contact rate between susceptible and infected birds and therefore greater risk of spread. It was found that H5N1 persistence in Nigeria was correlated with backyard chicken and duck numbers (Cecchi et al., 2008). Proximity to an infected farm has been shown to be an important factor in the spread of low pathogenicity influenza viruses (Mannelli et al., 2006) as well as distance to the nearest case farm (Nishiguchi et al., 2007). Conversely, (Fang et al., 2008) found no association between poultry density and the risk of HPAIV infection in China, arguing that this unexpected finding was due to a greater proportion of industrialised chicken production at higher poultry densities, with associated higher biosecurity standards and vaccination protocols. Henning et al. (2009) found that poultry density was a risk factor for HPAIV outbreaks in Vietnam, but only at medium population densities. High poultry density was postulated as a risk factor for HPAIV occurrence in Thailand (Tiensin et al., 2005) and in Hong Kong (Kung et al., 2007), although this has been shown to be associated more with duck density alone than total poultry density (Gilbert et al., 2006).
Presence of poultry markets/cities	Increasing density of cities is expected to be associated with increasing risk of spread of HPAI H5N1. Cities are associated with higher demand for poultry products and therefore the presence of trading areas providing live or freshly slaughtered birds. Low pathogenicity viruses have been isolated from poultry in live bird markets in the USA (Bulaga, 2003), China (Cheung et al., 2007) and Korea (Choi et al., 2005), and HPAI has been isolated from a live bird market in Vietnam (Nguyen et al., 2005). Sale of chicken at retail markets was also identified as a risk factor for HPAI infection of farms in Hong Kong (Kung et al., 2007). The risk of HPAI outbreak was found to be negatively associated with increasing distance from higher density human population areas (Pfeiffer et al., 2007), and this is likely to be due to increased intensity of production and trade of poultry in highly populated areas.
Natural wetlands and water bodies	Increasing distance from wetlands and waterbodies is expected to be associated with decreasing risk of spread of the disease. Proximity to wetlands has been shown to be a risk factor for the occurrence of HPAI in poultry in South-East Asia (Gilbert et al., 2006; Fang et al., 2008), as has proximity to rivers and wetlands in Romania (Ward et al., 2008; Ward et al., 2009). Distance to wetland areas containing migratory waterfowl species has been hypothesised as a risk factor for disease in Nigeria (Cecchi et al., 2008).
Irrigated areas	Proximity to irrigated areas is expected to be associated with increased risk of spread of HPAI H5N1. Rice crop production has been found to be associated with HPAI in Vietnam and Thailand (Gilbert, 2007; Pfeiffer et al., 2007), as has aquaculture (Pfeiffer et al., 2007).