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Modeling the spread of bird flu and predicting outbreak diversity

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Abstract

Avian influenza, commonly known as bird flu, is an epidemic caused by H5N1 virus that primarily affects birds like chickens, wild water birds, etc. On rare occasions, these can infect other species including pigs and humans. In the span of less than a year, the lethal strain of bird flu is spreading very fast across the globe mainly in South East Asia, parts of Central Asia, Africa and Europe. In order to study the patterns of spread of epidemic, we made an investigation of outbreaks of the epidemic in one week, that is from February 13–18, 2006, when the deadly virus surfaced in India. We have designed a statistical transmission model of bird flu taking into account the factors that affect the epidemic transmission such as source of infection, social and natural factors and various control measures are suggested. For modeling the general intensity coefficient $f(r)$, we have implemented the recent ideas given in the article *Fitting the Bill*, *Nature* [R. Howlett, Fitting the bill, Nature 439 (2006) 402], which describes the geographical spread of epidemics due to transportation of poultry products. Our aim is to study the spread of avian influenza, both in time and space, to gain a better understanding of transmission mechanism. Our model yields satisfactory results as evidenced by the simulations and may be used for the prediction of future situations of epidemic for longer periods. We utilize real data at these various scales and our model allows one to generalize our predictions and make better suggestions for the control of this epidemic.

MSC: 37N30; 37N25

Keywords: Bird flu; Mathematical model; Epidemiology; Predicting outbreak diversity

1. Introduction

Bird flu also known as avian influenza is an infection caused by a virus known as *orthomyxoviridae* in virus classification [55]. Influenza virus has only one species in it, which is called influenza A virus. These influenza viruses occur naturally among birds. Wild birds worldwide carry these viruses in their intestine but usually do not get sick from them. However, avian influenza is very contagious among birds and can make some domesticated birds including chickens, ducks and turkeys very sick and kill them [20,24,30,43]. Infected birds shed influenza viruses from their saliva, nasal secretions, etc. Susceptible birds become infected when they come in contact with the contaminated surfaces. Domesticated birds may become infected with avian influenza viruses through direct contact with infected waterfowl or other infected poultry [24,28,38] or through contact with surfaces (such as dirt or cages) or materials (such as water or food) that have been contaminated with the virus [1,15,39,45,49].

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Infection with bird flu viruses in domestic poultry causes two main forms of disease that are distinguished by low and high extremes of virulence. The "low pathogenic" form may go undetected and usually causes only mild symptoms (such as ruffled feathers). However, the highly pathogenic form spreads more rapidly through flocks of poultry. This form may cause diseases that affect multiple internal organs and has a mortality rate that reaches 90–100% often within 48 hours [8].

In 2006, the High Security Animal Disease Laboratory in Bhopal confirmed genetic signatures of the virus in eight samples of dead poultry tissues that it had received from Navapur in Nandurbar district near the Maharashtra–Gujarat border. For more than two years, the virus has ravaged poultry and caused human illness and death in many Southeast Asian countries and China. Between April and June 2005, a large number of wild water birds at Qinghai Lake in western China perished after being infected by the virus. During, July–August 2005, outbreaks involving the virus were reported from Mongolia, Siberia and Kazakhstan. The virus reached Turkey, Croatia, Romania and Greece by October 2005. Ukraine reported outbreaks in November 2005. The virus was infecting chicken and humans in northern Iraq by January 2006. In early February 2006, Nigeria became the first African nation to report the bird flu virus, with an outbreak at a large commercial poultry farm. In February 2006, many European countries, Egypt and Iran found wild birds infected with H5N1 virus [12,14,15,23,26,40,42].

Avian influenza or bird flu can result in immediate and severe disaster, for example, the outbreak in USA [48] in 1983–1984 led to destruction of more than 17 million birds at a cost of nearly US $56 million [21]. Similar case again happened in Hong Kong in 1997–1998 [12,15,38,39,42]. Therefore rapid and effective measures must be taken to stop the spread of epidemics. The most effective measures to prevent the transmission of bird flu are rapid destruction of all infected or exposed birds, proper disposal of carcasses and excrement, the quarantining and rigorous disinfectioning of farms and timely use of vaccine [4,25,35,36,50]. The information relating to the spread of this epidemic in Canada may be obtained from the website [3].

In general, the influenza virus or flu virus can be classified into three categories: types A, B and C, which are distinguished by differences in two major internal proteins. Influenza virus type A is the most significant epidemiologically and the most interesting from an ecological and evolutionary stand point, because it is found in a wide variety of bird and mammal species [9,41] and can undergo major shifts in immunological properties. Type B is largely confined to humans and very little is known about type C. Type A virus is responsible for causing bird flu, which was first found in Italy in 1878. Type A virus is further divided into subtypes based on differences in membrane proteins HA and NA, which are the most important targets for the immune system. The notation HhNn is used to refer to the subtype comprising the hth discovered HA proteins and the nth discovered NA protein. The subtype H5N1 virus of type A virus is the main cause of the bird flu [12,15,23,31,42]. Subtype is further divided into strains; each genetically distinct virus isolated is usually considered to be a separate strain [11,33].

According to the research of World Health Organization (WHO), the transmission mode of bird flu can be divided into following two types [21]:

- spread from one farm to another within a country and
- spread from country to country.

Generally, the virus resides in bird droppings, contaminated soil and airborne virus. Contaminated equipments, vehicles, food, cages and clothing like shoes can carry the viruses from farm to farm. Some evidence suggests that flies can also act as mechanical vectors [18]. Wet markets where live birds are sold under crowded and sometimes unsanitary conditions can be another source of spread. These constitute the main cause of the former transmission. Export and import of poultry products are the main cause of the latter transmission, since they can carry the viruses for long distances freely when artificial factors are prevented. Migratory birds can also be a cause of transmission between the countries [5,27]. Efforts have been made on the study of avian influenza and most of the recent papers focus on topics such as the route of transmission, physiological and biological properties, etc. The bird flu virus of low pathogenicity can mutate into highly pathogenic one after a short time; the virus is sensitive to temperature change (it was found that the virus survives for shorter time at a higher temperature). This kind of influenza is able to transmit to humans under some circumstances (http://www.who.int/mediacentre/factsheets/fs277/en/) [6,7,21,44,47,52]; however, no sufficient and clear evidences of human-to-human transmission have been found up to now [21].

Among these researches, an important approach to study bird flu is to establish a statistical transmission model, from which the general trends of epidemics can be predicted, and the effect of various control measures can be assessed