



Spatio-temporal distribution & seasonality of highly pathogenic avian influenza H5N1 & H5N8 outbreaks in India, 2006-2021

Shailesh D. Pawar¹, Sadhana S. Kode¹, Sachin S. Keng¹, Deeksha S. Tare¹ & Satish A. Pande²

¹National Institute of Virology, Indian Council of Medical Research & ²Ela Foundation, Pune, Maharashtra, India

Received September 17, 2022

Background & objectives: The highly pathogenic avian influenza (HPAI) H5N1 and H5N8 viruses have been one of the leading causes of avian diseases worldwide, resulting in severe economic losses and posing potential zoonotic risk. There are no reports on the correlation of the seasonality of H5N1 and H5N8 viruses with the migratory bird season in India, along with the species affected. The present report describes the distribution and seasonality of HPAI outbreaks in India from 2006 to 2021.

Methods: The data on the occurrence and locations of outbreaks in India and affected bird species were collated from the Food and Agriculture Organization of the United Nations database and grouped by month and year. The distribution and seasonality of HPAI H5N1 and H5N8 viruses were analyzed.

Results: A total of 284 H5N1 outbreaks were reported since 2006, with a surge in 2021. The initial outbreaks of H5N1 were predominantly in poultry. Since 2016, 57 outbreaks of H5N8 were also reported, predominantly in wild birds. Most of the outbreaks of HPAI were reported from post monsoon onwards till pre-summer season (*i.e.* between October and March) with their peak in winter, in January. Apart from poultry, the bird species such as owl, Indian peafowl, lesser adjutant, crows and wild migratory birds such as demoiselle crane, northern pintail and bar-headed goose were positive for HPAI.

Interpretation & conclusions: Such studies on the seasonality of HPAI outbreaks would help in the development of prevention and control strategies. The recent human infections of H5N1 and H9N2 viruses highlight the need to strengthen surveillance in wild, resident, migratory birds and in poultry along with One Health studies in India.

Key words Avian diseases - HPAI - H5N1 - H5N8 - migratory birds - poultry - virus - zoonoses

The highly pathogenic avian influenza (HPAI) H5N1 and H5N8 viruses are zoonotic agents of increasing public health concern. Characterized by severe morbidity and mortality in birds, HPAI viruses also cause severe economic losses worldwide¹. The HPAI viruses have been known to cause infections in humans with a history of close contact with infected

poultry, resulting in mild-to-severe respiratory disease and fatality². The global spread of HPAI H5N1 affecting multiple species of birds is a global public health concern³.

The HPAI H5N1 virus was first detected in Asia in Guangdong Province, China, in 1996 which spread through live poultry markets in

Hong Kong to humans in 1997⁴. Such viruses were confined to southeast Asia until 2005. Afterwards, they continued to evolve into multiple clades from southeast Asia. A/Goose/Guangdong/1/96 (H5N1)-like viruses re-assorted further with other low pathogenic avian influenza viruses such as H9N2, which resulted in the generation of multiple genotypes of H5N1 viruses that spread to Europe, India and Africa affecting poultry⁵. The A/Goose/Guangdong/1/96-like viruses also circulated with different neuraminidase subtypes, including H5N2, H5N5, H5N6, and H5N8⁶. Apart from economic losses, the spread of H5N1 in poultry populations also increased the risk of human infections. The number of affected countries rose between 2003 and 2008, with expansion from east and southeast Asia to west Asia and Africa⁴. As of December 2021, H5N1 virus outbreaks have been documented on a large scale among poultry and wild birds in more than 77 countries^{7,8}. As of March 2022, 863 human cases of avian influenza (AI) H5N1 were reported worldwide with an average case fatality ratio of 53 per cent⁹. A significant rise in HPAI outbreaks in domestic and wild birds had been reported in October 2021, signalling expanded virus circulation¹⁰. The first human case of H5N1 virus infection in India was reported in June 2021, coinciding with the monsoon season in the country¹¹.

The HPAI H5N1 viruses are constantly evolving globally through complex genetic changes, which have infected poultry, wild birds as well as humans⁴. The first outbreak of the H5N1 virus in India was reported in January 2006, followed by outbreaks in poultry in different states¹². The HPAI viruses cause mortality in poultry, resident (domestic and wild birds) and migratory birds. In 2011, a massive outbreak of HPAI H5N1 was reported in crows in Jamshedpur, Jharkhand. These viruses were similar to the viruses circulating in Vietnam, Myanmar and Bangladesh¹³.

The HPAI H5N8 virus was first detected in the year 2010 among wild birds in Asia and later spread to domestic birds across China, South Korea and Japan. An outbreak of H5N8 virus was reported from ducks and chickens in South Korea, in the year 2014¹⁴. In 2016, an H5N8 outbreak was first reported in Asia, followed by Europe⁶. Outbreaks of HPAI H5N8 virus in India were reported in 2016 from various states¹⁵. In recent times, the first human case of HPAI H5N8 in the world was reported from Russia in 2021¹⁶.

There are close associations between migration of birds and spread of HPAI¹⁷. Notably, India falls in the Central Asian migratory bird flyway and is a major destination site for migratory birds¹⁸. Globally, there have been several studies reporting associations between climatic conditions and HPAI outbreaks^{4,5,7,19}. However, as yet there is only one report of seasonality of H5N1 virus outbreaks during 2006 to 2019 from India²⁰ and no reports exist on the seasonality of both HPAI H5N1 and H5N8 viruses; their correlation with the migratory bird season, nor on the species affected. Against this background, the present study describes the spatial and temporal distribution of HPAI outbreaks from January 2006 to December 2021 and the affected species of domestic and wild migratory birds. This would help in understanding the seasonality of HPAI outbreaks in India, which in turn could help outbreak prediction and preparedness for prevention and in developing control strategies.

Material & Methods

In the present study data for all reported H5N1 and H5N8 outbreaks in poultry and in wild resident and migratory birds from India, between January 2006 and December 2021, were collated from the Food and Agriculture Organization of the United Nations (FAO) website⁸. An outbreak of HPAI is characterized by a sudden rise in morbidity and mortality in avian species with reference to season and location. The FAO compiles information drawn from multiple national (Ministries of Agriculture or Livestock, Ministries of Health, Provincial Government websites and Centers for Disease Prevention and Control) and international sources (World Health Organization and World Organisation for Animal Health) as well as peer-reviewed scientific articles⁸. The extracted data were organized by year and month to estimate the average peak months for HPAI infections in India. The data were analyzed for year-wise and month-wise occurrences. The information on affected bird species, including domestic and wild migratory birds and the locations of outbreaks, were also collated.

Results

The first HPAI H5N1 outbreak was reported in 2006 from Navapur, Maharashtra, followed by a series of outbreaks annually. Later, from 2007 to 2010, most of the outbreaks were reported from the eastern and northeastern States but predominantly from West Bengal. Eventually, the virus spread to various

States across the country. Odisha reported sporadic yet consistent outbreaks from 2011 to 2020, with the maximum number of outbreaks in 2018. No subsequent outbreaks were reported till 2020 except one in 2012 from Maharashtra. However, a surge of outbreaks was reported in 2021.

The H5N8 virus was first reported in India in November 2016, with mortality in wild birds from five States, with maximum reports (25 events) from Kerala. There were no reports of H5N8 from India in the years 2018 and 2019. A sudden rise in the number of H5N8 outbreaks was reported from 2020 onwards, indicating a probable reintroduction of the virus.

A total of 341 outbreaks of HPAI viruses, including 284 H5N1 and 57 H5N8 outbreaks, were reported from 24 States of India during 2006 to 2021 (Supplementary Table and Fig. 1). Since 2006, maximum HPAI outbreaks have been reported from Maharashtra, West Bengal, Kerala and Odisha, with more than 26 outbreaks in each state.

The month-wise number of outbreaks from 2006 to 2021 was analyzed with reference to seasonality. The HPAI activity typically started in the post monsoon months of October to November, surged in the winter months with a peak in the month of January, usually the coldest month of the year. The activity continued till pre summer. The least number of outbreaks ($n=9$) were reported from the end of summer to monsoon (Fig. 2).

Initially, H5N1 outbreaks most often involved chickens. In the later years, the H5N1 cases were reported from crows, ducks and turkeys⁸. The H5N8 viruses were reported to infect birds such as crows, storks, chickens, ducks, wild ducks and a migratory greylag goose. Overall, apart from poultry, five different species of wild migratory birds were reported to be affected by H5N1 and H5N8 viruses (Table).

Discussion

The present report describes the seasonal patterns of both H5N1 and H5N8 virus outbreaks in India in the context of the migratory bird season and the species affected. It was observed that the maximum number of HPAI events were reported from India in the winter months. It has been shown that in cooler months, the virus is more transmissible among chickens and consequently to humans^{4,5,7,20}. This could be one of the probable reasons for increased

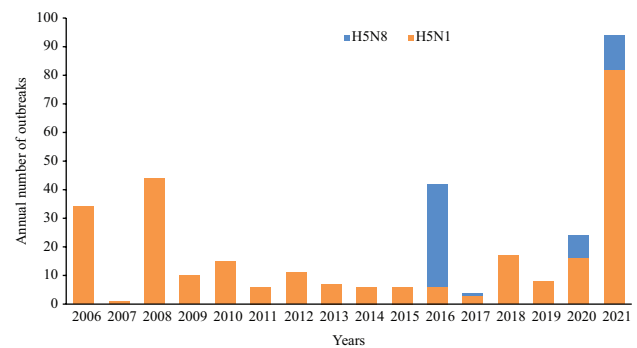


Fig. 1. Year-wise number of HPAI H5N1 and H5N8 virus outbreaks. HPAI, highly pathogenic avian influenza; FAO, Food and Agriculture Organization

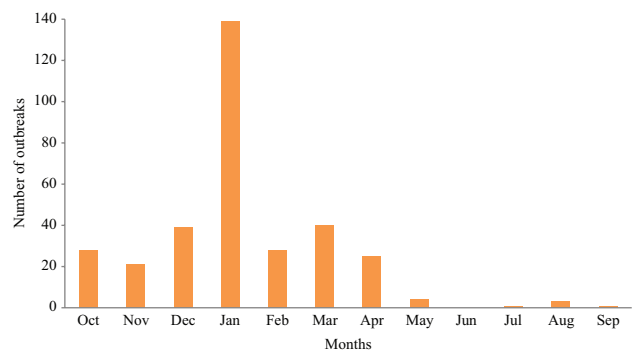


Fig. 2. Month-wise outbreaks of HPAI viruses in India, 2006 to 2021.

occurrence of outbreaks during the winter season. Increased HPAI events in the years 2006 and 2008 in India were concomitant with those observed in the rest of the continent⁸. The H5N8 outbreaks in India reported in 2016, 2020 and 2021 were concomitant with those reported in other parts of the world, indicating shared patterns in the global transmission of H5N8 viruses⁸. The seasonality of H5N1 virus infection amongst domestic and wild birds in India is similar to that in other east and west Asian countries⁴. Outbreaks usually begin to increase in October, peak in February and continue through April. The data from temperate regions show a strong seasonality characterized by a single peak in the winter months²¹. However, seasonal patterns of AI in east and southeast Asia show little variation, which contains both tropical and subtropical areas⁷. Despite diverse climatic conditions in Asia and North Africa, lower temperatures were associated with an increase in human H5N1 virus infections. Noticeably, environmental factors such as climate, topography, poultry density and human population, play vital roles in the spread of H5N1 virus²².

Table. Bird species affected by H5N1 and H5N8 viruses

Subtype	Species affected	Family	Scientific name	Type	Number of events
H5N1	Chicken	<i>Phasianidae</i>	<i>G. gallus</i>	Domestic resident	75
	Large-billed crow	<i>Corvidae</i>	<i>C. macrorhynchos</i>	Wild resident	23
	House crow	<i>Corvidae</i>	<i>C. splendens</i>	Wild resident	9
	Duck	<i>Anatidae</i>	Not known	Domestic	6
	Turkey	<i>Phasianidae</i>	<i>M. gallopavo</i>	Domestic	2
	Demoiselle crane	<i>Gruidae</i>	<i>A. virgo</i>	Wild migratory	1
	Bar-headed goose	<i>Anatidae</i>	<i>A. indicus</i>	Wild migratory	1
	Northern pintail	<i>Anatidae</i>	<i>A. acuta</i>	Wild migratory	1
	Eastern grass owl	<i>Tytonidae</i>	<i>T. longimembris</i>	Wild resident	1
	Indian peafowl	<i>Phasianidae</i>	<i>P. cristatus</i>	Wild resident	1
	Lesser adjutant	<i>Ciconiidae</i>	<i>L. javanicus</i>	Wild resident	1
	Bar-headed goose	<i>Anatidae</i>	<i>A. indicus</i>	Wild migratory	1
	Unspecified bird*	Not known	Not known	Domestic/wild	166
H5N8	House crow	<i>Corvidae</i>	<i>C. splendens</i>	Wild resident	5
	Large-billed crow	<i>Corvidae</i>	<i>C. macrorhynchos</i>	Wild/captive Resident	4
	Painted stork	<i>Ciconiidae</i>	<i>M. leucocephala</i>	Wild/captive Resident migratory	3
	Chicken	<i>Phasianidae</i>	<i>G. gallus</i>	Domestic resident	2
	Duck	<i>Anatidae</i>	Not known	Domestic	2
	Greylag goose	<i>Anatidae</i>	<i>A. anser</i>	Wild migratory	2
	Wild duck	<i>Anatidae</i>	Not known	Wild	1
	Unidentified	<i>Anatidae</i>	Not known	Captive	1
	Unspecified bird*	Not known	NA	Captive/domestic/wild	42

G. gallus, *Gallus gallus*; *C. macrorhynchos*, *Corvus macrorhynchos*; *C. splendens*, *Corvus splendens*; *M. gallopavo*, *Meleagris gallopavo*; *A. virgo*, *Anthropoides virgo*; *A. indicus*, *Anser indicus*; *A. acuta*, *Anas acuta*; *T. longimembris*, *Tyto longimembris*; *P. cristatus*, *Pavo cristatus*; *L. javanicus*, *Leptoptilos javanicus*; *M. leucocephala*, *Mycteria leucocephala*; *A. anser*, *Anser anser*; NA, not available

India falls in the southeast Asian region with a tropical climate. Broadly, the climate can be divided into four seasons, namely winter, summer, monsoon and post monsoon. Winters range from December to February, which falls within the avian migratory season in India²³; whereas summers last between March and May, with the hottest months being April and May. The third season, monsoon or rainy season, lasts from June to September and the postmonsoon season lasts from October to November²⁴.

The months showing maximum outbreaks (Fig. 2) coincided with the migratory bird season in India, which ranges from October to March²⁵. Furthermore, the maximum bird ring recoveries have been reported between January and March²⁶. Despite the vast differences in the climatic patterns across India, the seasonal trends were similar across the states

and throughout the 15 year period. The fact that the host range of HPAI viruses has broadened in India over the years highlights the need to closely monitor the ecological aspects of the disease as well. Massive outbreaks of H5N1 and H5N8 have been reported in India from all the biogeographic and bioclimatic zones with simultaneous circulations. In addition, low pathogenic AI (LPAI) H9N2 virus has also been reported in poultry along with other subtypes of LPAI such as H11N1 and H4N6 from wild and migratory birds in the country^{8,27,28}. Reassortment of AI viruses in nature has been associated with high densities of wild birds at breeding and wintering grounds²⁹. Cocirculation of different subtypes of AI viruses in common species is one of the risk factors for the generation of novel reassortant strains. The increased frequencies of outbreaks in poultry and involvement of

migratory, wild, resident birds may also lead to more chances of human exposure.

It has been demonstrated that the timing of H5N1 outbreaks is closely associated with wild fowl migratory flyway and bird migrations¹⁷. Three major migratory bird flyways that are connected to Asia are east Asia-east Africa, central Asia and east Asia-Australia flyways. The central Asian flyway is the shortest flyway which connects many central Asian countries to the Indian subcontinent. More than 300 species travel along the central Asian flyway¹⁸. Migratory bird flyways of east and central Asia include India in their path, indicating possible intermixing of viruses³⁰. Ringing data confirms that the migration of birds like bar-headed geese and other species from Mongolia to India takes place during winter³¹.

Until 2005, the H5N1 viruses were mostly confined to southeast Asia. However, they spread rapidly westward to India, Europe and Africa after infecting wild birds in Qinghai Lake, China⁵. The viruses circulating in India were closely similar to those prevalent in the regions of the east Africa/ west Asian and central Asian migratory bird flyways, supporting the hypothesis that the virus in India might have been introduced through migratory birds³². Besides, previous evidence showed that Siberia was a major hub for the dispersal of the virus through bird populations. Furthermore, it is established that southeast Asia and Africa are the major sources of genetically and antigenically novel strains⁴. The spread of H5N8 strains has been linked to the overlapping flyways of migratory wild birds coming from different continents, which pose a major concern worldwide³³.

In India, HPAI infections were reported from the migratory bird species, namely northern pintail, bar-headed goose, greylag goose and demoiselle crane; waterfowl act as a reservoir. These birds have an overall geographical distribution expanding from northern Asia to the Indian subcontinent *via* China, which coincides with the central Asian flyways. The first H5N8 outbreak in India was reported in painted stork, which has limited geographical distribution in the Indian subcontinent and some parts of southeast Asia such as Vietnam and Thailand. However, since the over-wintering habitats are shared with other birds such as greylag geese and bar-headed geese, which breed and migrate from northern countries such as Kazakhstan and Mongolia, crossing China, the possibility of transmission of the HPAI viruses among them in the wild cannot be ruled out.

The limitations of the present study were that mathematical models or correlations could not be carried out to show the effect of migration of wild birds on poultry outbreaks due to the unavailability of detailed datasets. In addition, cyclic/seasonal variations could not be studied in greater details.

The active AI surveillance in the country, poultry and wild birds, is conducted as per the guidelines of the Department of Animal Husbandry and Fisheries, Ministry of Agriculture and Farmers' Welfare, Government of India, comprising clinical, virological, and serological surveillance³⁴. These activities are carried out by the State Animal Husbandry Departments at the respective block levels.

In view of the frequent widespread outbreaks of HPAI viruses across the country, there is an increasing need to carry out systematic surveillance at the human animal interface, as a major step towards One Health studies in India.

Acknowledgment: Authors acknowledge Drs Priya Abraham, Director ICMR-NIV and Jayati Mullick for their support.

Financial support & sponsorship: None.

Conflicts of Interest: None.

References

1. Guan Y, Peiris JSM, Lipatov AS, Ellis TM, Dyrting KC, Krauss S, *et al*. Emergence of multiple genotypes of H5N1 avian influenza viruses in Hong Kong SAR. *Proc Natl Acad Sci U S A* 2002; 99 : 8950-5.
2. Li KS, Guan Y, Wang J, Smith GJD, Xu KM, Duan L, *et al*. Genesis of a highly pathogenic and potentially pandemic H5N1 influenza virus in Eastern Asia. *Nature* 2004; 430 : 209-13.
3. Beigel JH, Farrar J, Han AM, Hayden FG, Hyer R, de Jong MD, *et al*. Avian influenza A (H5N1) infection in humans. *N Engl J Med* 2005; 353 : 1374-85.
4. Lai S, Qin Y, Cowling BJ, Ren X, Wardrop NA, Gilbert M, *et al*. Global epidemiology of avian influenza A H5N1 virus infection in humans, 1997-2015: A systematic review of individual case data. *Lancet Infect Dis* 2016; 16 : e108-18.
5. Webster RG, Govorkova EA. H5N1 influenza – Continuing evolution and spread. *N Engl J Med* 2006; 355 : 2174-7.
6. Napp S, Majó N, Sánchez-González R, Vergara-Alert J. Emergence and spread of highly pathogenic avian influenza A(H5N8) in Europe in 2016-2017. *Transbound Emerg Dis* 2018; 65 : 1217-26.
7. Durand LO, Glew P, Gross D, Kasper M, Trock S, Kim IK, *et al*. Timing of influenza A(H5N1) in poultry and humans and seasonal influenza activity worldwide, 2004-2013. *Emerg Infect Dis* 2015; 21 : 202-8.
8. Food and Agriculture Organization of the United Nations. *FAO global AIV with zoonotic potential situation update – FAO*

- emergency prevention system for animal health (EMPRES-AH); 2022. Available from: https://www.fao.org/ag/againfo/programmes/en/empres/Global_AIV_Zoonotic_Update/situation_update.html, accessed on February 26, 2022.
9. World Health Organization. *Human infection with avian influenza A(H5) viruses*. Available from: <https://www.who.int/docs/default-source/wpro---documents/emergency/surveillance/avian-influenza/ai-20220401.pdf>, accessed on April 26, 2022.
 10. World Organisation for Animal Health. *The World Organisation for Animal Health (OIE) calls for increased surveillance of avian influenza as outbreaks in poultry and wild birds intensify*. Available from: <https://www.oie.int/en/the-world-organisation-for-animal-health-oie-calls-for-increased-surveillance-of-avian-influenza-as-outbreaks-in-poultry-and-wild-birds-intensify/>, accessed on February 26, 2022.
 11. Potdar V, Brijwal M, Lodha R, Yadav P, Jadhav S, Choudhary ML, et al. Identification of human case of avian influenza A(H5N1) infection, India. *Emerg Infect Dis* 2022; 28 : 1269-73.
 12. Chakrabarti AK, Pawar SD, Cherian SS, Koratkar SS, Jadhav SM, Pal B, et al. Characterization of the influenza A H5N1 viruses of the 2008-09 outbreaks in India reveals a third introduction and possible endemicity. *PLoS One* 2009; 4 : e7846.
 13. Bhat S, Nagarajan S, Kumar M, Murugkar HV, Kalaiyarasu S, Venkatesh G, et al. Antigenic characterization of H5N1 highly pathogenic avian influenza viruses isolated from poultry in India, 2006-2015. *Arch Virol* 2017; 162 : 487-94.
 14. Ku KB, Park EH, Yum J, Kim JA, Oh SK, Seo SH. Highly pathogenic avian influenza A(H5N8) virus from waterfowl, South Korea, 2014. *Emerg Infect Dis* 2014; 20 : 1587-8.
 15. Nagarajan S, Kumar M, Murugkar HV, Tripathi S, Shukla S, Agarwal S, et al. Novel reassortant highly pathogenic avian influenza (H5N8) virus in zoos, India. *Emerg Infect Dis* 2017; 23 : 717-9.
 16. World Health Organization. *Avian influenza a (H5N8) infects humans in Russian federation*. Available from: <https://www.euro.who.int/en/countries/poland/news/news/2021/3/avian-influenza-ah5n8-infects-humans-in-russian-federation>, accessed on February 26, 2022.
 17. Tian H, Zhou S, Dong L, Van Boeckel TP, Cui Y, Newman SH, et al. Avian influenza H5N1 viral and bird migration networks in Asia. *Proc Natl Acad Sci U S A* 2015; 112 : 172-7.
 18. Bird life international. Central Asia flyway factsheet. Available from: http://datazone.birdlife.org/userfiles/file/sowb/flyways/7_Central_Asia_Factsheet.pdf, accessed on February 27, 2022.
 19. Cheng C, Li J, Liu W, Xu L, Zhang Z. Modeling analysis revealed the distinct global transmission patterns of influenza A viruses and their influencing factors. *Integr Zool* 2021; 16 : 788-97.
 20. Chowdhury S, Hossain ME, Ghosh PK, Ghosh S, Hossain MB, Beard C, et al. The Pattern of highly pathogenic avian influenza H5N1 outbreaks in South Asia. *Trop Med Infect Dis* 2019; 4 : 138.
 21. Park AW, Glass K. Dynamic patterns of avian and human influenza in East and Southeast Asia. *Lancet Infect Dis* 2007; 7 : 543-8.
 22. Fang LQ, de Vlas SJ, Liang S, Looman CWN, Gong P, Xu B, et al. Environmental factors contributing to the spread of H5N1 avian influenza in mainland China. *PLoS One* 2008; 3 : e2268.
 23. Pande S, Deshpande P, Sant N. *Birds of Maharashtra*. Pune: Ela Foundation; 2011. p. 1-330.
 24. Indian meteorological department (IMD). IMD | Home. Available from: <https://mausam.imd.gov.in/>, accessed on February 26, 2022.
 25. Pawar SD, Pande SA, Tare DS, Keng SS, Kode SS, Singh DK, et al. Morphological and biochemical characteristics of avian faecal droppings and their impact on survival of avian influenza virus. *Food Environ Virol* 2018; 10 : 99-106.
 26. Balachandran S, Katti T, Manakadan R. *Indian migration bird atlas*. New Delhi: Oxford University Press; 2018. p. 1-216.
 27. Pawar S, Chakrabarti A, Cherian S, Pande S, Nanaware M, Raut S, et al. An avian influenza A (H11N1) virus from a wild aquatic bird revealing a unique Eurasian-American genetic reassortment. *Virus Genes* 2010; 41 : 14-22.
 28. Pawar SD, Kale SD, Rawankar AS, Koratkar SS, Raut CG, Pande SA, et al. Avian influenza surveillance reveals presence of low pathogenic avian influenza viruses in poultry during 2009-2011 in the West Bengal State, India. *Virol J* 2012; 9 : 151.
 29. Chen R, Holmes EC. Frequent inter-species transmission and geographic subdivision in avian influenza viruses from wild birds. *Virology* 2009; 383 : 156-61.
 30. Pawar S, Pande S, Jamgaonkar A, Koratkar S, Pal B, Raut S, et al. Avian influenza surveillance in wild migratory, resident, domestic birds and in poultry in Maharashtra and Manipur, India, during avian migratory season 2006-07. *Curr Sci* 2009; 97 : 550-4.
 31. Iverson SA, Gavrilov A, Katzner TE, Takekawa JY, Miller TA, Hagemeijer W, et al. Migratory movements of waterfowl in Central Asia and avian influenza emergence: Sporadic transmission of H5N1 from East to West. *Ibis* 2011; 153 : 279-92.
 32. Ray K, Potdar VA, Cherian SS, Pawar SD, Jadhav SM, Waregaonkar SR, et al. Characterization of the complete genome of influenza A (H5N1) virus isolated during the 2006 outbreak in poultry in India. *Virus Genes* 2008; 36 : 345-53.
 33. Selim AA, Erfan AM, Hagag N, Zanaty A, Samir AH, Samy M, et al. Highly pathogenic avian influenza virus (H5N8) clade 2.3.4.4 infection in migratory birds, Egypt. *Emerg Infect Dis* 2017; 23 : 1048-51.
 34. Department of Animal Husbandry & Dairying, Government of India. *Revised action plan 2021 for avian influenza*. Available from: <https://dahd.nic.in/circulars/revised-action-plan-2021-avian-influenza>, accessed on February 17, 2023.

Supplementary Table. H5N1 and H5N8 outbreaks from 2006 to 2021

State	Number of outbreaks														
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016			2017	
											H5N1	H5N1	H5N8	H5N1	H5N1
Maharashtra	32						1								
Gujarat	1										1	1	1		
Madhya Pradesh	1											2			
Manipur		1								1					
West Bengal			35	8	15	1		1							
Tripura			3			2	3				1				
Assam			16			1									
Meghalaya			1				1								
Sikkim				1											
Bihar				1			1	3							
Jharkhand						1									
Orissa						1	4	1	1		2		2		
Karnataka							1				1	2		1	
Chhattisgarh								2							
Punjab									1				1		
Kerala									4	1			25		
Andhra Pradesh										1					
Uttar Pradesh										3					
Daman and Diu											1				
Delhi												3			
Haryana													2		
Rajasthan															
Himachal Pradesh															
Uttarakhand															
Total	34	1	55	10	15	6	11	7	6	6	6	36	3	1	
Contd...															

State	Number of outbreaks										Total outbreaks			
	2018		2019		2020			2021						
	H5N1	H5N1	H5N1	H5N1	H5N8	H5N8	H5N8	H5N1	H5N8	HPAI				
Maharashtra							53			5	86	0	5	91
Gujarat										3	3	1	3	7
Madhya Pradesh					4	1	2	2			7	5		12
Manipur											2	0		2
West Bengal											60	0		60
Tripura											9	0		9
Assam											17	0		17
Meghalaya											2	0		2
Sikkim											1	0		1
Bihar	3	1			4						13	0		13
Jharkhand		5			1						7	0		7
Orissa	13	1			1						26	0		26
Karnataka					2						4	3		7
Chhattisgarh		1					2			1	5	0	1	6
Punjab							1			3	2	1	3	6
Kerala					3	6	1	1			9	32		41
Andhra Pradesh											1	0		1
Uttar Pradesh	1				1					1	5	0	1	6
Daman and Diu								1			1	1		2
Delhi										2	0	3	2	5
Haryana								6		1	0	8	1	9
Rajasthan						1	2	2		3	2	3	3	8
Himachal Pradesh										1	0	0	1	1
Uttarakhand										2	0	0	2	2
Total	17	8			16	8	61	12		22	262	57	22	341