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LETTER

Re-emergence of Highly Pathogenic Avian Influenza H5N1 in Nigeria, 2014–2016: Role of Social Network and Value Chain Forces in Interstate Transmission

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Dear Editor,

Since 2004, high pathogenic avian influenza (HPAI) due to H5N1 virus among others has caused a major veterinary health crisis, resulting in the loss of millions of poultry through death or culling in several countries in Asia, the Middle East, Europe, Africa and North America (Alexander 2007; Lee *et al.* 2016). The first African outbreak was reported from Nigeria in 2006 in domestic poultry (Joannis *et al.* 2006) and persisted till 2008 (Fusaro *et al.* 2010). These outbreaks negatively affected animal and public health as well as the economy, and were caused by viruses belonging to genetic clades 2.2, 2.2.1, 2.2.2 and 2.3.2.1c (Aiki-Raji *et al.* 2008; Fusaro *et al.* 2010; Monne *et al.* 2015).

In Nigeria, avian influenza virus (AIV) and or AIV-specific antibodies have been detected in chickens (Joannis *et al.* 2006, 2008), waterfowls (Meseko *et al.* 2007), spur-winged geese and whistling ducks (Snoeck *et al.* 2011), and turkeys (Oluwayelu *et al.* 2015). In 2012, Couacy-Hymann *et al.* (2012) reported that Nigeria did not have any HPAI-H5N1 outbreak since July 2008 and seemed free of the pathogen. However, this "AI-free" status was interrupted by a major HPAI-H5N1 epizootic in 2015, about nine years after the first outbreak. This epizootic was first reported on 24th December, 2014 at a live bird market (LBM) in Sabon Gari, Kano State, where high mortality of chickens, geese and turkeys occurred. Almost simultaneously, and obviously due to bird movement from Kano State to the South during the Christmas season, anecdotal reports of increased bird deaths at LBMs in Onipanu and Mushin, Lagos State were made. Fifty thousand birds were susceptible with 3,300 deaths. Subsequently, 29 other outbreaks were recorded in 24 States and the Federal Capital Territory. The second wave of the epizootic started between 1st and 3rd January 2015, also in Kano State and parts of the Southwest, with 16 follow-up cases reported (OIE 2016a, b). Thereafter, cases of the disease continued to occur until November 2016 (Monne *et al.* 2015; OIE 2016a, b). Considering the recurrent outbreaks of HPAI-H5N1 in Nigeria and the challenge of mounting effective surveillance especially in the absence of vaccination policy, there is a need to design targeted risk-based interventions that are realistic and sustainable for prevention and control of the disease in the country.

We utilized social network and value chain analyses to investigate the HPAI-H5N1 outbreak which occurred in Nigeria between 24 December, 2014 and 15 November, 2016 with a view to providing better understanding of the disease dynamics and interplay of factors that contributed to its spread, severity and persistence within an epidemiological context. A total of 2,727,561 birds were exposed to the virus during the epizootic with an approximate mortality rate of 9.1% (248,482 birds; range: 1–25,000). Majority (67.4%) of the 482 field samples collected for laboratory confirmation by reverse transcriptase-polymerase chain reaction (RT-PCR) were "locally sourced" *i.e.,* collected from birds at LBMs and "unspecified" suppliers of day-old chicks, point-of-lay pullets, spent layers

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and local poultry, while 32.6% were from commercial/backyard poultry farms. Out of these 482 samples, 346 (71.8%) were positive for HPAIV H5N1, of which approximately 60% (n = 208) were obtained from LBMs and "unspecified" poultry suppliers. Although southern Nigeria had overall lower proportion of H5N1-positive cases by RT-PCR (36.4%) compared to the northern region (63.6%), there was significantly higher detection of positive cases from outbreaks in the south (126/134, 94.0%) than in the north (220/348, 63.2%) (Table 1).

Social network analysis showed that there were 43 vertices, 27 unique edges and 380 edges. There was only one connected component while the maximum shortest path between any two distances was 8. However, 27% of the graph was full of ties (Graph density = 0.0271) with an average geodesic distance of 3.186 and a clustering coefficient of 0.000 (Fig. 1).

Analysis of outbreak data showed that Kano, Plateau, Rivers and Lagos States were the most affected point locations of the epizootic during the study period (Fig. 2). Plateau (99% CI, $P < 0.0005$) and Kano States (95% CI, $P < 0.0005$) were hotspots for outbreaks while the southern states of Rivers and Bayelsa were cold spots (Fig. 2). Although several outbreaks were recorded in Lagos, Ogun, Oyo, Edo, Enugu, Ebonyi and Rivers States, they were not significant following hotspot analysis.

The findings of this study (Table 1, Fig. 1) show that the re-emergence of HPAI-H5N1 in Nigeria between December 2014 and November 2016 was first detected in LBMs, corroborating previous report (Monne *et al.* 2015). Live bird market networks are known to epidemiologically connect regions that otherwise may have remained isolated; as such they support large-scale and transboundary disease spread (Fournié *et al.* 2013). In Nigeria, LBMs are common and usually located in peri-urban areas where various bird species produced by multiple suppliers are mixed together, thus providing opportunity for maximum interaction and efficient contracting of infectious agents among the birds, and between humans and birds (Aiki-Raji *et al.* 2015). This is buttressed by the prospect of silent circulation and likely persistence of influenza viruses, including HPAI-H5N1, in LBMs as well as by reports of virological and serological evidence of AIVs in some LBMs in Nigeria (Coker *et al.* 2014; Aiki-Raji *et al.* 2015). Based on our findings in this study, there appears to be an upsurge of AIV outbreaks in Nigeria during the cold harmattan period that is coincident with increased bird movement (especially interstate transportation) and sales in the December festive season (Monne *et al.* 2015). Movement of live birds is a familiar risk factor for AIV dissemination to poultry flocks (Soares Magalhaes *et al.* 2010).

Analysis of point locations of HPAI-H5N1 outbreaks (Fig. 2) revealed that Kano, Plateau, Lagos and Rivers were the most severely affected states. However, only Kano and Plateau States were identified as hotspots of HPAI-H5N1 during the outbreak period even though several cases were recorded in the southern states of Lagos, Ogun, Oyo, Edo, Enugu, Ebonyi and Rivers (Fig. 2). It is possible that the regulatory authorities in these southern

Table 1 Summary of HPAI-H5N1 outbreak markers (December 2014 to November 2016).

	Number of cases	%
Sources of birds during outbreaks		
Commercial/backyard farms	157	32.6
LBMs/"unspecified" poultry suppliers	325	67.4
RT-PCR		
Positive	346	71.8
Negative	136	28.2
Source of positive cases		
Commercial/backyard farms	139	40.2
LBMs/"unspecified" poultry suppliers	207	59.8
Geographic origin of positive cases		
Northern region	220	63.6
Southern region	126	36.4
Within-region distribution of positive cases		
Northern region	220 (out of 348 cases)	63.2
Southern region	126 (out of 134 cases)	94.0

Statistical analysis was performed using SPSS version 21 (SPSS Inc., Chicago, IL). Range and proportions were calculated for relevant variables. The relationships between HPAI (H5N1)-positive cases by reverse transcriptase-polymerase chain reaction (RT-PCR) and corresponding variables were determined by Fisher's exact test at $P < 0.05$.

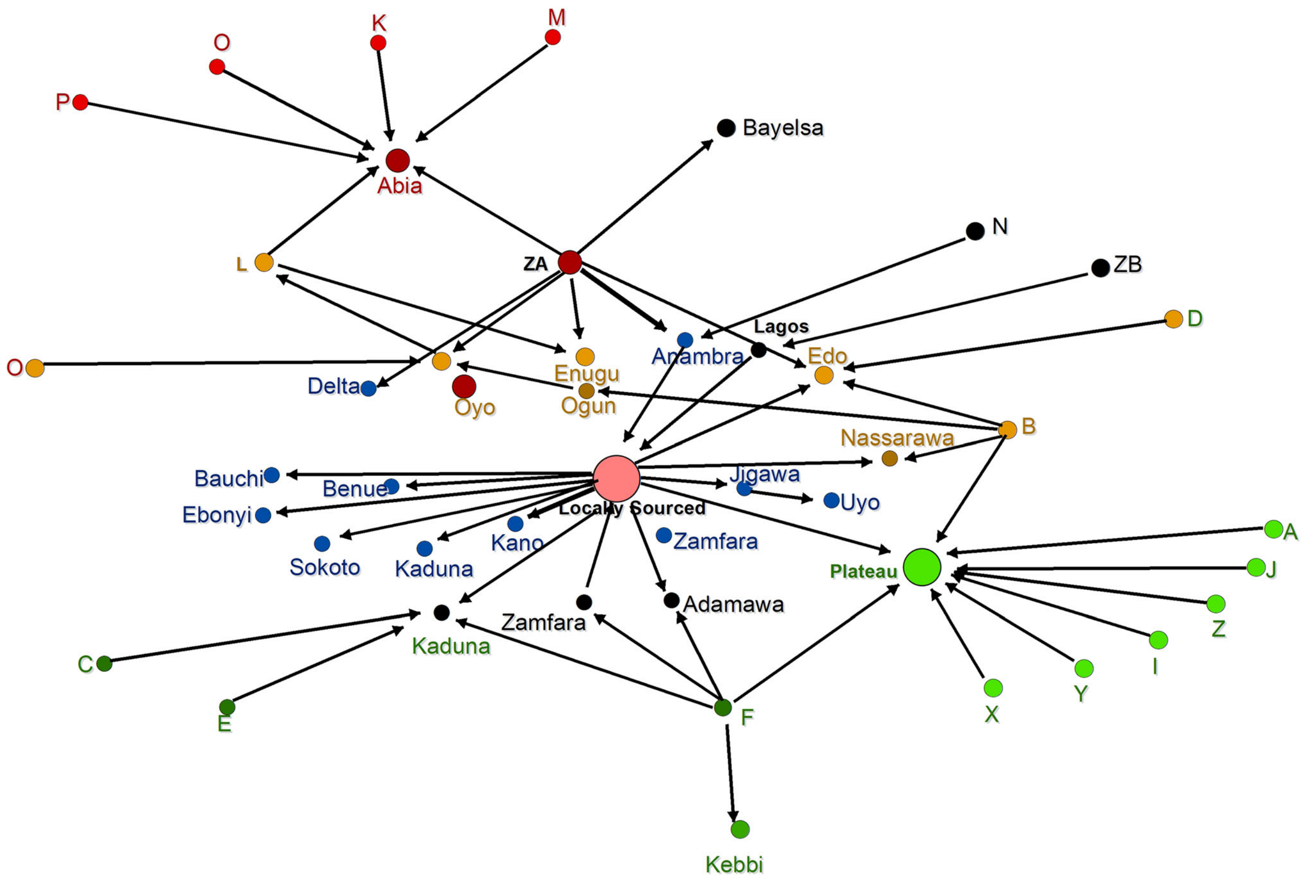

Fig. 1 Interstate poultry market network following HPAI-H5N1 outbreaks in Nigeria (December 2014–November 2016). Outbreak data for the period were obtained from the Office International des Epizooties (OIE 2016a, b). Data were formatted for analysis on NodeXL Basic template 2014 (Social Media Research Foundation, California, USA). Network nodes and corresponding vertices were used to identify individual and central players within the local poultry market chain. Each node represented a hatchery, farm known for poultry (broilers, point-of-lay pullets, or spent layers) distribution or proximate state where HPAI was reported. The corresponding arrows on the other hand indicated poultry transport network with subsequent incoming and out-going infections. Harel–Koren Fast multiscale layout algorithm was used to analyze the relationships giving a spring-embedded visualization. Networks were grouped into clusters using Clauset–Newman–Moore cluster algorithm while graph density and average geodesic distance between nodes were used as informative tools to describe the presenting graphical network connections.

states were more able to respond rapidly and effectively following occurrence of the index cases, as well as in implementing biosecurity and other control measures including enforcement of movement restrictions, slaughter of infected birds and decontamination of infected farms and LBMs.

An interesting epidemiological scenario was observed during this period with the first reports of outbreaks in two poultry farms in Enugu and Abia States, southeast Nigeria. Remarkably, in the process of tracing back the infection source(s), we discovered that both farms purchased point-of-lay pullets from a commercial farm in Ibadan, Oyo State, southwest Nigeria (Fig. 2). Subsequent testing of biological specimens from birds in the source farm confirmed they were HPAI-H5N1-infected. This finding highlights the critical role of poultry market chain actors such as suppliers of point-of-lay pullets and day-old chicks in the interstate transmission of HPAI-H5N1. It also emphasizes the need for regulation of both interstate and intra-state movements of poultry and poultry products/inputs in Nigeria. Consequently, it is instructive to equip existing animal control posts across Nigeria with rapid influenza antigen detection kits so that birds that test positive can be quarantined and their specimens sent to zonal/national reference laboratories for confirmatory diagnosis. Thus, we have shown that trade-movement networks are an important risk factor for the dissemination of AIV to poultry flocks in Nigeria where poultry movement data is generally unavailable. We recommend enforcement of movement restrictions on poultry and other birds, issuance of veterinary permit before movement of birds and restructuring of poultry marketing networks across the country, as has been used successfully elsewhere (Fasina *et al.* 2015).

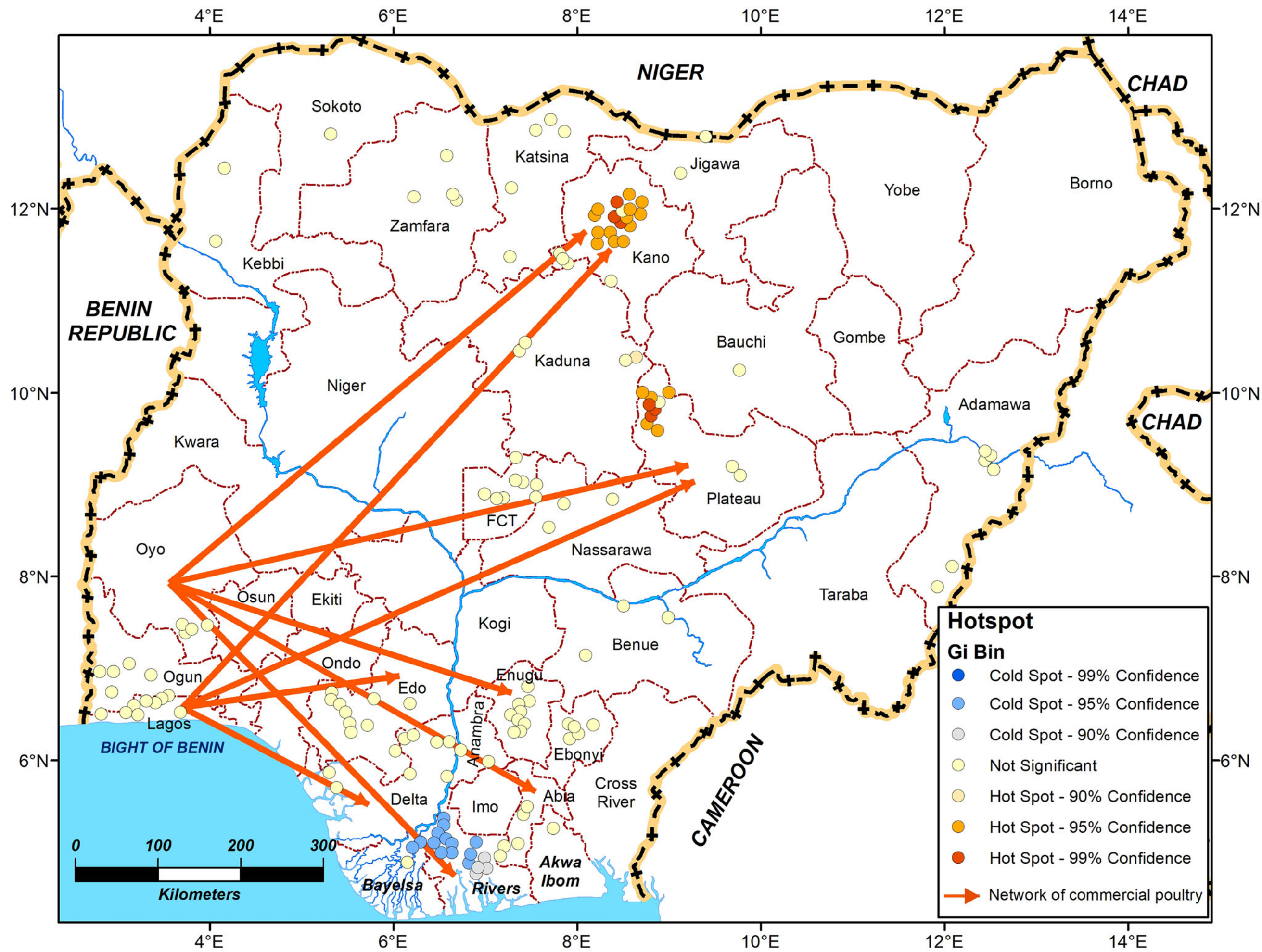

Fig. 2 Point locations and hotspots of HPAI-H5N1 outbreaks with interstate network of commercial poultry movement in Nigeria. Coordinates of point locations of HPAI outbreaks within states in Nigeria were generated using Google Earth Pro. Data were collated on Microsoft Excel sheet and exported into ESRI's ArcGIS 10.1 software. Cartographical outputs were visualized on ArcView® and results displayed as points symbolizing locations of resultant outbreaks. Hotspot analysis was used to identify statistically significant hotspots and cold spots, respectively. A hotspot was defined as a geographical area or location with high risk of HPAI occurrence (Grubesic and Murray 2001). Conversely, a cold spot referred to a geo-location with less likelihood of HPAI occurrence.

Further, social network and value chain analyses can be applied within an epidemiological context to assist in identifying persistence of HPAI infections or points of concentration along the poultry value chain in order to aid description of the disease transmission patterns and guide control policies (Kitsak *et al.* 2010). As shown in this study, the role of interstate transport of day-old chicks and point-of-lay pullets (in the southwest-north and southwest-southeast/south-south directions) as well as indigenous chickens (in the north–south direction) in spread and persistence of the December 2014 to November 2016 HPAI-H5N1 outbreaks in Nigeria cannot be underestimated.

In order to forestall future outbreaks of HPAI in Nigeria, surveillance efforts should not only be targeted at preventing emergence of new cases, they should also be risk-based and focused on stopping dissemination in order to avoid farm-to-farm transmission, and medium- or long-distance jumps due to agro-commercial practices. Transportation of indigenous poultry with domestic ruminants from northern Nigeria to live animal markets in the south should also be discouraged. We advocate the use of social network and value chain analyses combined with epidemiological surveillance for identifying high risk areas along Nigeria's poultry value chain where knowledge of poultry trading patterns and the LBM network structure, and their capacity for maintaining HPAI-H5N1 infection may be employed to enhance the success of existing control measures. This novel approach will also facilitate contact trace back in future HPAI emergencies.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Animal and Human Rights Statement This article does not contain any studies with human or animal subjects performed by any of the authors.

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