Original Article

Multicriteria geospatial analysis of the risk of occurrence of highly pathogenic avian influenza in Guyana

Análisis multicriterio geoespacial del riesgo de ocurrencia de influenza aviar altamente patógena en Guyana

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ABSTRACT: The objective of this investigation was to establish the geospatial risk of occurrence of highly pathogenic avian influenza (HPAI) in Guyana at the Neighborhood Democratic Council (NDC) level. Knowledge based multicriteria analysis was used taking into account various risk factors adjusted to the spatial resolution of the administrative districts of the country. First the risk of introduction of the causing virus was deduced and then the risk of exposure. From these two risks, by means of algebra of maps with the geographic information system QGIS version 2.18.10, the risk occurrence of disease was deduced. Equivalent proportions of districts with very high or high risk were highlighted, with 28 of 116 (24.1 %) in each category. The remainder of the districts in descending order of risk classes grouped as low and negligible in 34 (29.3 %) NDC. The regions that corresponded to high risk were: Barima-Waini with 2 out of 5 districts in this category; Pomeroon - Supenaam with 2 out of 7 districts; Essequibo Islands - West Demerara with 5 out of 19 districts (26 %); Demerara-Mahaica with 5 out of 19 districts (26 %); East Berbice - Corentyne with 8 out of 21 districts (38 %) and Upper Takutu - Upper Essequibo with 2 out of 8. The geospatial risk of occurrence of HPAI was not distributed evenly in Guyana, which presents an opportunity for prioritization strategies including the development and implementation of a risk-based surveillance system.

Key words: highly pathogenic avian influenza, multicriteria disease analysis, risk, surveillance, prioritization.

RESUMEN: El objetivo de esta investigación fue establecer el riesgo geoespacial de ocurrencia de influenza aviar altamente patógena (IAAP) en Guyana a nivel del Consejo Democrático Vecinal (CDV). Se aplicó análisis multicriterio basado en conocimiento teniendo en cuenta diversos factores de riesgo ajustados a la resolución espacial de los distritos administrativos del país. Se establecieron de forma independiente el riesgo de introducción y de exposición al virus causal. A partir de estos dos riesgos, mediante el álgebra de mapas con el sistema de información geográfica QGIS versión 2.18.10, se dedujo el riesgo de ocurrencia de la enfermedad. Se destacaron proporciones equivalentes de distritos con riesgo muy alto o alto, con 28 de 116 (24,1 %) en cada categoría. El resto de los distritos en orden descendente de clases de riesgo, se agrupó como bajo y despreciable en 34 (29,3 %) CDV. Las regiones que correspondieron a alto riesgo fueron: Barima-Waini con 2 de 5 distritos en esta categoría; Pomeroon -Supenaam con 2 de 7 distritos; Islas Esequibo - West Demerara con 5 de 19 distritos; Demerara-Mahaica con 5 de 19 distritos; East Berbice - Corentyne con 8 de 21 distritos y Upper Takutu - Upper Essequibo con 2 de 8. El riesgo geoespacial de ocurrencia de IAAP no se distribuyó de manera uniforme en Guyana, lo que presenta una oportunidad para estrategias de priorización, incluido el desarrollo e implementación de un sistema de vigilancia basado en el riesgo.

Palabras clave: influenza aviar altamente patógena, análisis multicriterio, riesgo, vigilancia, priorización.

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INTRODUCTION

Avian influenza (AI), given its impact on poultry farming (the livestock sub-sector that provides the most affordable source of animal protein worldwide) has important implications for global food security. On the other hand, the zoonotic nature of some strains and the underlying risk of causing a pandemic has resulted in it being given priority attention by relevant international organizations (1).

AI can be markedly cross-border and is extremely difficult to eradicate particularly in developing countries where it can become endemic (2). In the last 10 years, more than 200 million birds distributed in more than 70 countries have been destroyed as a result of highly pathogenic avian influenza (HPAI) outbreaks (3).

In the Cooperative Republic of Guyana, the poultry subsector is the most developed and integrated in livestock Industry, and it generates jobs for approximately 18,000 people (Fernandes, 2019; personal communication). Local poultry population exceed 15 million, distributed in 717 farms (3). On the other hand, annual production of chicken (41 922 MT) and eggs (32.08 million) guarantee self-sufficiency in the national consumption of these products and a slight export margin in the case of eggs (4). The poultry production model involves the importation of fertile eggs that are incubated locally, and the chicks are sold to poultry farmers (5).

Additionally, Guyana is very rich in biodiversity (6) which is commercially exploited and constitutes an important economic activity locally (7). The wildlife trade provides 439 direct jobs and temporary income to some 7,540 trappers and national traders, while the total number of people who benefit economically from this activity can be approximately 20,000, particularly indigenous people from the interior of the country; almost all communities are involved in the business (8).

The devastating consequences of AI on the poultry sector, given the significant economic losses caused by both the slaughter and destruction of birds and the closure of export markets (9-11) and the potential Implications for public health justify continued attention to this disease. Since most countries prohibit imports from those affected by AI, the presence of the disease in Guyana would impact both poultry and wild bird trade that constitute livelihoods for a significant proportion of the population.

On the other hand, the possibility of interaction between wildlife and domesticated animals is considered an important disease emergency factor (12-15) when promoting translocation of pathogens in the wildlife-domestic animal interface. AI is one of the most recent examples of hazards in this interface, even with implications for public health (16,17).

Guyana is outside the main routes of migratory waterfowl, but it has several sites where there are populations of resident wild ducks. It is recognized that ducks can excrete large amounts of influenza virus without manifesting symptoms (18), while the virus may have high persistence in aquatic ecosystems (19-22). On the other hand, rice production which is vital to the country's economy (23) also favors the occurrence of AI outbreaks (24-27).

The above factors could favor the occurrence of AI in Guyana, but its territorial distribution and importance are unknown. Until now, AI surveillance in the country has a passive component dependent on the willingness of farmers to report mortality and additionally veterinarians and technicians visit farms to observe clinically if there are sick birds, deaths, etc. In addition, blood samples are collected and sent to the laboratory for evaluation (28).

Although risk-based surveillance is the most efficient and effective alternative for rapid alert to the introduction of AI (26,29,30) this type of surveillance is not yet applicable in Guyana and could be an alternative to increase the efficiency of the human and financial resources dedicated to surveillance. Guyana reports a population of more than 15 million poultry, distributed in 717 establishments, while the local veterinary technical force is 170 professionals of which only 31 are from the public service (3).

Moreover, the territorial extension of the country (214,970 km^2), the dispersion of poultry establishments and the existence of other forms of production such as backyard, represent a demand for the development and implementation of risk-based surveillance systems. The objective of this study was to establish the geospatial risk occurrence of highly pathogenic avian influenza in Guyana at the Neighborhood Democratic Council (NDC) level.

MATERIALS AND METHODS

Study area

The analysis covered the entire Cooperative Republic of Guyana located in the northeastern part of South America and part of the South American Caribbean, bordering the north with the Atlantic Ocean, east with Suriname, west with Venezuela and south with Brazil (Fig. 1).

Collection of fundamental data and generation of geospacial layers of risk factors

The relevant database of commercial poultry farms, ducks, backyard chickens, poultry slaughterhouses, fighting cock arenas, sites and average number of domestic wild ducks and live bird markets were collected from the Guyana Livestock Development Authority (GLDA). Subsequently, the collected data was transferred to Microsoft Excel spreadsheet and there after georeferenced via the program QGIS 2.18.10. using Open Street map. Data for which geo-referencing was not available, geographical coordinates were obtained via the Gazetteer of Guyana. Shape files were created for each risk factor collected and georeferenced in the program QGIS 2.18.10.

Unofficial ports of entry, land border crossing sites and illegal cross-border trade points were collected from the Animal Health Unit of the GLDA. The same procedure of georeferencing and the creation of shape file was followed for these risk factors as mentioned earlier.

Other important cartographic data such as the administrative division of Guyana and road density were obtained from the public site http://www.diva-gis.org-data. The official ports and airports were obtained through the site's natural land data: naturalearthdata.com <cultural large scale> airports and ports. In the case of road density, vector <street map > download data> from layer was used.

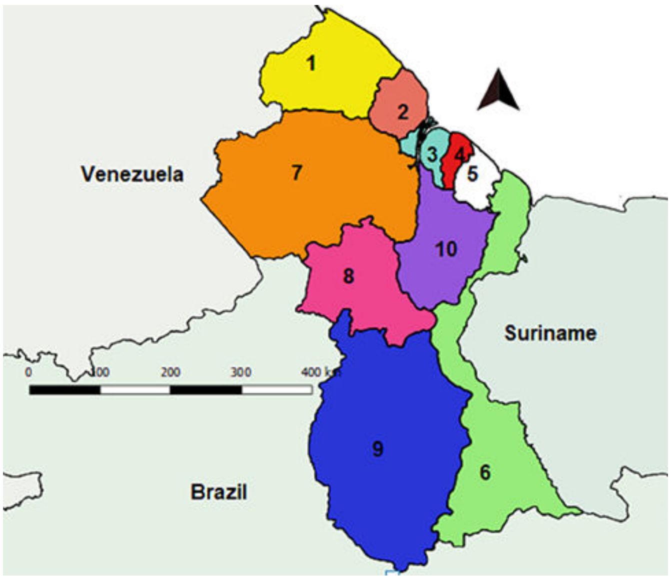

Figure 1. Location of Guyana and administrative division by regions (1 - Barima Waini; 2 - Pomeroon-Supenaam; 3 - Essequibo Islands - West Demerara; 4 - Demerara - Mahica; 5 - Mahica - Berbice; 6 - East Berbice - Corentyne; 7 - Cuyini - Mazaruni; 8 - Potaro - Siparuni; 9 - Upper Takutu - Upper Essequibo; 10 - Upper Demerara - Upper Berbice). Self-developed map using QGIS./ *Ubicación de Guyana y división administrativa por regiones (1 - Barima Waini; 2 - Pomeroon-Supenaam; 3 - Essequibo Islands - West Demerara; 4 - Demerara - Mahica; 5 - Mahica - Berbice; 6 - East Berbice - Corentyne; 7 - Cuyini - Mazaruni; 8 - Potaro - Siparuni; 9 - Upper Takutu - Upper Essequibo; 10 - Upper Demerara - Upper Berbice). Mapa de desarrollo propio usando QGIS.*

Preparation and unification of the thematic layers

The HPAI risk occurrence was established based on the estimation of the risks of introduction and exposure in independent thematic layers and their subsequent standardization and unification in a single map. The geoprocessing of the data was performed using the geographic information system QGIS version 2.18.10 in the coordinate system WGS 84 projected in UTM 21N. The thematic layers were elaborated and unified by overlapping with the algebra map tool.

Risk for the introduction of HPAI

The risk for the introduction of HPAI was based on the semi-quantitative multicriteria risk analysis methodology based on knowledge described by León (31). For the determination of the risk factors to be included in the model, the following assumptions were considered:

- The country is free of the disease.
- The virus can enter through wild migratory birds.
- The virus can enter through the legal or illegal trade of live birds or their products.
- The virus can enter through the legal or illegal trade of wild birds.
- The virus can enter through the movement of people.
- Backyard chickens are a potential source of local multiplication and spread of the virus.
- Commercial production backyard chickens constitute a potential source for mass dissemination of the disease.
- The areas where wild domestic ducks, backyard chickens and commercial poultry coexist are those with the highest risk of disease occurrence.

Modifications were made to the methodology of León (31) described by Coste (32). Other considerations were that Guyana is outside the migratory waterfowl route, so this factor was ruled out. In the case of wetlands, given the rich hydrography of the country, this factor is present with similar distribution throughout the national territory, so it was discarded from processing as a factor because it would not have changed the importance of the variable. Similar consideration was made with regards to rice fields. Domestic wild ducks sites and the average number of ducks at these sites were used. Unofficial ports and land border crossings were considered as places where there is illegal trade of poultry, poultry products and wild birds.

Ponderation and addition of the risk of introduction

The procedure consisted of preparing thematic maps from a setting of weight for each risk factor considering values of 0 or 1 that were assigned by polygons if the factor was absent or present, respectively. In each case, the value obtained was multiplied by the weighting factor that appears in Table 1 and the final value of the polygon was the sum of the weighting products of each factor.

Table 1. Ponderation of risk factors for introduction. /*Ponderación de los factores de riesgo para la introducción.*

Risk Factor	Ponderation
Official Ports	4
International Airports	4
Land border crossing	7
Unofficial ports	6
Total	**21**

The risk was performed using the raster calculator, the new map was generated, based on the following equation:

[(Offical ports × 4) + (International Airports × 4) + (Land border crossing × 7) + (Unofficial Ports × 6)] / 21

HPAI exposure risk

The determination of the risk factors for exposure was based on the review of bibliographies relating to the subject (26,27,29). Hence, the ponderation of the risk factors was realized by way of expert opinion from the Caribbean Animal Health Network (CaribVET), The French Agriculture Centre for International Development (CIRAD), and the United States Department of Agriculture Animal and Plant

Health Inspection Service (USDA APHIS). Farms with less than 100 chickens were considered equivalent to backyard production; due to the low levels of biosecurity and the rearing of various species. In each case, the value correspond to presence or absence was multiplied by ponderation of the risk factor shown in Table 2. The final value of the polygon was the sum of the ponderation results of each factor.

Table 2. Ponderation of exposure risk factors. / *Ponderación de los factores de riesgo de exposición.*

Risk Factors	Ponderation
Live bird Markets	10
Domestic wild ducks sites	9
Duck farms	8
Fighting cocks arenas	7
Poultry slaughter houses	7
Roads	6
Backyard chicken	6
Commercial poultry	5
Total	**58**

Risk of HPAI in Guyana

In all cases the results were normalized by the equation:

$$Zi = \frac{Xi - Xmin}{Xmax - Xmin}$$

where Z was the standardized value of Xi, i is the index of X, while Xmax and Xmin are respectively the maximum and the minimum value that the variable X took.

The distribution of values was divided into quantiles assigned in descending order into very high risk (1st quantile), high risk (2nd quantile), low risk (3rd quantile) and negligible risk (4th quantile).

The risk calculation was performed using the raster calculator, and the new map was generated, based on the following equation:

[(Official Ports 4) + (International Airports × 4) + (Land border crossing × 7) + (Unofficial Ports × 6) (Live birds markets × 10)+(Wild Anatidae × 9) + (Duck farms × 8) + (Fighting cocks arenas × 7) + (Slaughter houses × 7) + (Roads × 6) + (Backyard chickens × 6) + (Commercial farms × 5)] / 80

RESULTS AND DISCUSSION

HPAI risk occurrence in Guyana

The geospatial combination of the introduction and exposure risks revealed a variable distribution of the risk occurrence (Figure 2), modeled by multicriteria analysis. Equivalent proportions of districts with very high or high risk with 28 of 116 NDC's (24.1 %) in each category stand out. The rest of the districts in descending order of risk classes grouped as low in 34 (29.3 %) and negligible in the rest.

The regions that corresponded to very high risks were: Pomeroon-Supenaam with four (4) out of seven (7) NDCs in this category; Essequibo Islands - West Demerara with 13 of 19 NDCs and Mahaica-Berbice with five (5) out of 11 of the NDCs .

The regions that corresponded to high risk were: Barima -Waini with two (2) out of (5) NDCs in this category; Pomeroon-Supernaam with two (2) out of (7) NDCs; Essequibo Islands - West Demerara with five (5) out of 19 NDCs; Demerara-Mahaica with five (5) out of 19 NDC's; East Berbice - Corentyne with 8 out of 21 NDCs and Upper Takutu - Upper Essequibo with 2 out of 8 NDCs. In four (4) of these six (6) regions there are entry points or risk factors for introduction that include ports (official and unofficial), airports and land border crossing areas.

Three of these six regions (50 %) have vast borders shared with other countries. In particular, land border crossings and unofficial ports which are not well regulated and are recognized as enabling factors for unofficial movement of animals (33). Exposure risk factors were also present in these regions, but their densities were lower and did not change the distribution of the risk occurrence. These factors included: the presence of domestic wild ducks sites and number, duck farms, poultry slaughterhouses and backyard poultry.

In the Demerara-Mahaica Region, there is the Georgetown municipality which is the capital of the country with very high risk. This is due to the fact that the major official-ports of entry and one unofficial port are present in this district. These factors, together with the presence of live bird

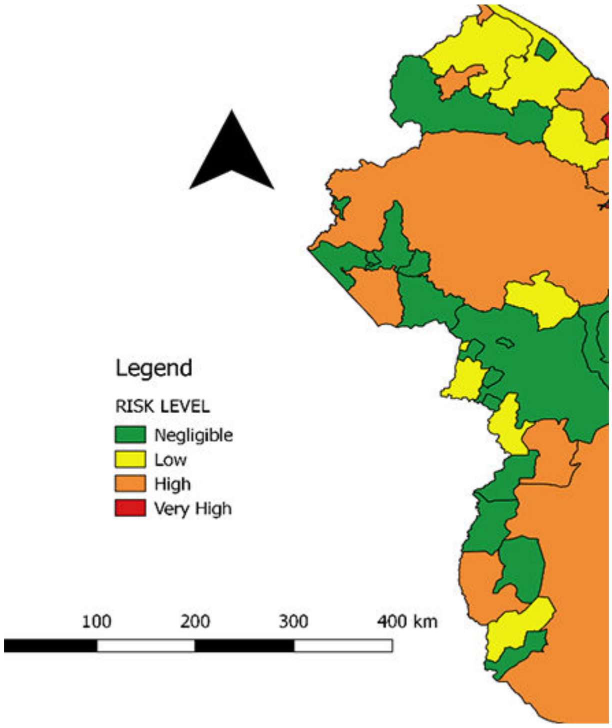

Figure 2. Highly pathogenic avian influenza risk occurrence in Guyana, October 2019. / *Ocurrencia de riesgo de influenza aviar altamente patógena en Guyana, octubre de 2019.*

markets (LBM's) in Georgetown, which have very high ponderation for the exposure risk according to Biswas (34) and Khan (35).

LBM's are essential for marketing poultry in many developing countries and are the preferred place for many people to buy poultry for consumption worldwide (36). LBM's are typically urban and have a permanent structure in which poultry can stay until they are sold. Such practice encourages the mixing of poultry species to meet the preferences of their customers however, these birds are commonly farmed by multiple suppliers. The mixing of species, the lack of comprehensive management and multiple suppliers are characteristics that make the LBM's a potential source of influenza viruses, especially in their supply lots. LBM's have been linked to many outbreaks of avian influenza internationally (37).

Henning (2) added that the high prevalence of the HPAI virus observed in LBM's is probably related to the duration of the poultry that remain in the commercial chain before being sold in LBM and is influenced by the number and frequency of susceptible bird contacts with infected birds or with surfaces contaminated with the HPAI virus. LBMs are given high importance because in addition to promoting the maintenance of AIV (38,39) they have been associated with the occurrence of human infections (40,41).

In the distribution of the risk occurrence realized in this investigation, the presence of backyard chickens was given an average weight in comparison with the other risk factors. However, the importance of this factor has been variable in epidemics that occurred in various countries (36,42-44). However, this type of poultry can be important for the livelihoods of some small producers.

This research is the first of its kind done in Guyana to estimate HPAI risk occurrence, which was achieved by combining the risk of introduction of the agent and that of exposure of the susceptible population through map algebra. The use of multicriteria analysis for the modeling of geospatial risk of disease occurrence recognizes several advantages related to the possibility of considering in the same geographical space the presence and importance of various risk factors (26,45,46).

Knowledge-based multicriteria analysis methods were also utilized (26) as an alternative in the absence of disease data because it is a disease-free country. The study is focused on the HPAI because for this form of the disease, there is more available data on diffusion and risk factors to establish knowledge-based models through multicriteria analysis (26,29,47,48). However, the identified risk areas are useful in general to increase the effectiveness of surveillance in both forms of the disease (HPAI and low pathogenic avian influenza (LPAI)).

Given the territorial extension of Guyana (214,970 km^2), as well as the presence and dispersion of multiple forms of poultry production, including the commercialization of live birds that must be controlled with a limited number of veterinary and paraveterinary personnel, the present study constitutes the possibility of prioritizing resources for early warning and prevention based on scientific evidence of risk. In particular, risk-based surveillance combines the ability to increase the sensitivity of the system with the optimization of the use of both human and financial resources, so it's the best cost-effective method to guarantee rapid alert and timely response (49).

Being the wild bird trade an important activity in Guyana, it was not considered in the AIV introduction risk. Nonetheless, most of the wild birds that are usually traded are macaws and parrots (7), hence do not belong to the orders (Anseriformes and Charadriiformes) in which the main AIV reservoirs have been identified (24-27). Moreover, more precise data on the flow of wild birds and the potential spatio-temporal coincidence of their catching and commercialization with the raising of poultry will be needed for risk assessment.

The present study responds to a demand for development of surveillance in the country and lays the foundation for the implementation of a risk-based rapid alert system. Additionally, the capacities for risk management are benefited, through the priority strengthening of biosecurity. This is important because avian influenza viruses can remain in their reservoirs as low pathogenic (LP) strains (50) which makes it more difficult to detect using passive surveillance. However, the circulation of LP H5 and H7 subtypes when they infect poultry, they have the ability to mutate to HPAI in variable and indeterminate time (51).

In fact, reports of outbreaks of avian influenza in the Caribbean so far involve LP strains and have affected three countries; Haiti, Belize and the Dominican Republic, with recurrences and an event currently active in the latter (3). Coincidentally, all reported outbreaks in the Caribbean have been caused by the H5N2 subtype for which phylogenetic relationship has also been reported between isolates and even with the virus of the same subtype that circulated previously in Mexico (52). There is no clarity with respect to the origin of outbreaks in the Caribbean, while the phylogenetic relationship exists between isolates in different and distant countries. This could be due to a common origin of the strains from their natural reservoir which could also be indicative of contact between countries using different routes.

CONCLUSION

The geospatial risk occurrence of highly pathogenic avian influenza is distributed in a variable manner in Guyana, which constitutes an opportunity for the development and implementation of a risk-based surveillance system and prioritized the allocation of resources to reduce vulnerabilities.

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