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Modelling an econometric regional equations for avian influenza outbreaks in Egypt under current climate conditions

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Abstract

Highly pathogenic avian influenza (HPAI) H5N1 infection has been reported in domestic poultry, and human populations in Egypt since 2006. Despite of this, there is no clearly paper studied the Egyptian climate risk factors that associated with avian influenza outbreaks. Therefore, this paper aimed to construct the regional equation models for Egypt, which will represent a solid ground for future forecasts of avian influenza outbreaks and its patterns in relation to climate change. The results revealed that, 1. Climate factors (temperature, relative humidity and wind speed) were considered as highly risk factors in its orders in the outbreak of avian influenza and the degree of their risks differed regionally. 2. Also, the degree of avian influenza outbreak decreased gradually from north to south direction in Egypt and the effect of wind speed decreased and has no effect in disease outbreaks in south area of Egypt (Upper Egypt). 3. The validation process of the constructed equation model for each domain in Egypt indicated higher confidence level, which was 99.21%, 99.5% and 99 % for Upper, Middle and Delta region, respectively; therefore these equations can be used for forecasting of the outbreaks depending on the future climate change. 4. In addition, it exhibits seasonality, which peaks during the winter and fall months.

1. Introduction

Arab Republic of Egypt enjoys a strategic location in the northeast corner of the African continent. Egypt lies primarily between latitudes 22° and 32°N, and longitudes 25° and 35°E. Therefore, its climate is desert; hot, dry summers with moderate winters. Egypt shares its boundary with the Mediterranean Sea in the North, Sudan in the South, Gaza Strip and Israel in the northeast and the Red Sea and Gulf of Aqaba in the East and Libya in the West. The approximate land area of Egypt is around 1 million square km and water area is 6.000 square km.

Avian influenza virus (AIV) is one of the causative agents of avian diseases. It can be classified in the family of Orthomyxoviridae, and belong to type A. The type A can further subdivided by Glycoprotein, Hemagglutinin (H) and Neuraminidase

(N) (Fouchier et al.,2005). Large of majority of AIV are low pathogenic avian influenza viruses (LPAIV) and the LPAIV belong to H5 can mutate into highly pathogenic one which classified as type A, H5N1. Since the first report in 1997 on Hong Kong Island of H5N1 infection in poultry, this virus has infected poultry and wild bird, leading to a great number of deaths, and the virus rapidly spread across Asia, Europe, and Africa (WHO, 2006). In December 2005, the first case of H5N1 in Egypt was found in a migrating bird in Damietta province. In February 2006, evidence of the first H5N1 case involving domestic poultry was found (World Report, 2007). In March 2006, the first human case of H5N1 in Egypt was detected (Saad et al., 2007). From 2006 to January 2014, the number of confirmed human cases attacked with HPAI is 173 cases and 63 died (WHO, 2014).

Recently, the impact of climate change on avian influenza outbreak has attracted considerable attention. Climatic factors like temperature, humidity and wind speed may influence the onset, magnitude, virus survival outside the host and seasonality of influenza. Climate could affect the abundance of virus reservoirs; reactivate a latent infection, the virulence of circulating strains relative to population immunity (Gilbert et al., 2008). In addition, climate may affect human-human contact patterns, susceptibility and infectiousness. The ability to predict epidemic patterns using climate forecasts could have important public health implications (Miyamoto et al., 2004). The association between temperature and poultry outbreaks has been previously found in China (Li et al., 2004) where out-breaks occur when the temperature is low. Furthermore, Fang et al., (2008) found that each 100 mm increase in total annual precipitation correlates to a 0.9-fold reduction in odds of H5N1 poultry outbreaks in China.

The aim of this study firstly is finding answer to this question; do the climatic variables such as temperature, relative humidity or wind speed play a role in HPAI (H5N1) outbreaks and can be used as equation modeling for future predictors of disease seasonality in Egypt? Secondly, construction of a regional model for Egypt to become the solid ground for future forecasts of avian influenza outbreak according to climate change.

2. Materials and Methods

2.1. Study Area

In this paper, Egypt has been classified into three domains according to the topography and altitudes (Fig.1). Domain (A) represents the Nile Delta region (the northern area of Egypt), which is the triangular area that formed by two branches of Nile river called Rosetta and Dumyat. Domain (B) represents the Middle area of Egypt (Lower Egypt) that extended from Minya at the south to Giza and Cairo provinces at the north. Domain (C) represents the Upper Egypt (the southern area of Egypt) which, extended from Aswan Province at the south to Asyut provinces at the north.

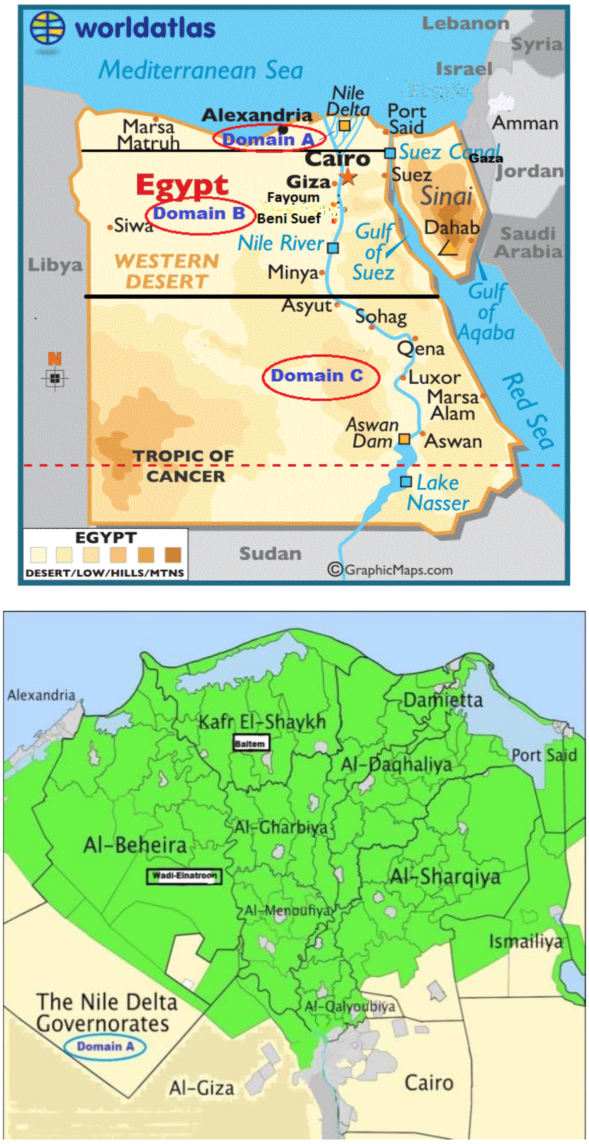

Fig. 1. *Map of Egypt showing area of study (source: www.worldatlas.com).*

2.2. Data Source and Preparation

2.2.1. Avian Influenza Data

Numbers of highly pathogenic avian influenza (HPAI) H5N1outbreaks on domestic poultry were obtained from the database of the World Animal Health Information Database (WAHID) (OIE: animal health Egypt) and Ministry of Agriculture and Land Reclamation of Egypt during 1 January, 2006 to 31 December, 2010. During this period, the numbers of outbreaks were collected and summarized, and then the average numbers of outbreaks of avian influenza for each month all over the period are calculated.

2.2.2. Meteorology Data

Daily data of climate conditionsinEgyptfrom1 January, 2006 to31 December, 2010 was taken from the report of the weather underground of Egypt website http://www.wunderground.com and freemeteo.com websites database. After that, the average monthly data were calculated for each year. The meteorological data included temperature (C^0), relative humidity (%) and wind speed (Km/h). The meteorological data is taken from monitoring stations near the areas of disease outbreaks within a radius of about 100 kilometers. The average values of the collected data are calculated per month for the years.

According to table (1, 2 and 3) of data summery in delta, middle and upper regions of Egypt, it was observed that, the number of outbreaks of avian influenza exhibits seasonality, which peaks during the winter and fall months and this, may be due to low temperature and high humidity which survive the virus for long period outside the host. Also, regarding to the number of avian influenza outbreaks, the Delta region was the highest infected area (152.33), then the Middle (136.14), then the Upper Egypt (122.92), respectively. This variation in the outbreaks among regions with obvious increased in the Delta region probably referred to increase of human population density, backyard poultry and cultivation lands combined with close proximity to irrigation, and vegetation which enhances wild bird migration.

Table (1). *Descriptive data summery for avian influenza outbreaks and climate factors in Delta region from 2006-2010*

Months	**Mean Outbreaks (No)**	**Mean values of climate factors**		
		Temp (C^0)	**Wind (km/h)**	**RH (%)**
January	35.35	14.79	11.20	73.12
February	*17.24*	16.56	11.95	64.78
March	14.03	18.35	12.58	66.01
April	8.22	20.77	12.14	64.23
May	4.13	23.65	11.24	64.54
June	3.36	26.85	12.14	67.29
July	2.72	29.27	12.62	70.08
August	3.45	29.55	12.16	71.38
September	3.41	27.37	10.95	67.45
October	*5.78*	*24.59*	*11.53*	*66.29*
November	21.54	19.98	9.04	66.14
December	33.10	16.27	11.09	74.72

Table (2). *Descriptive data summery for avian influenza outbreaks and climate factors in Middle region*

Months	**Mean Outbreaks (No)**	**Mean values of climate factors**		
		Temp (C^0)	**Wind (km/h)**	**RH (%)**
January	25.31	15.77	16.49	59.87
February	16.45	17.34	18.83	53.17
March	14.00	19.87	19.01	53.08
April	7.23	23.56	18.88	49.23
May	4.01	25.36	19.24	48.72
June	2.70	27.75	18.74	51.73
July	2.10	29.21	16.25	56.62
August	3.57	30.53	15.37	60.56
September	3.00	28.42	17.15	57.71
October	9.32	25.81	17.60	55.53
November	20.00	20.30	14.95	63.85
December	28.45	16.13	17.05	62.38

Table (3). *Descriptive data summery for avian influenza outbreaks and climate factors in Upper region from 2006-2010*

Months	**Mean Outbreaks (No)**	**Mean values of climate factors**		
		Temp (C^0)	**Wind (km/h)**	**RH (%)**
January	19.34	15.98	16.52	49.00
February	15.70	18.38	17.81	39.05
March	10.87	21.53	19.04	31.14
April	10.02	24.94	18.47	28.49
May	4.05	29.27	19.56	23.62
June	2.33	32.61	20.13	23.38
July	2.22	32.20	21.34	26.11
August	2.69	33.55	20.52	28.70
September	3.40	30.93	18.04	30.68
October	8.76	25.98	15.37	33.71
November	21.00	18.48	15.07	46.78
December	22.54	15.37	16.72	51.05

2.3. Equations Modeling Construction

Process of modeling was undertaken by using the average number of avian influenza outbreaks and meteorological data, which available from 1 January 2006 to 31 December 2010. Construction of an equation model for each domain was undertaken by using regression model analysis. Before using of regression analysis, the correlation analysis was firstly applied to investigate the degree of relationship between the outbreaks and other climate variables. After that, the regression analysis (multiple, forward, stepwise, backward and block) was done to determine the best regression equation, which represents the risk degree of climate factors on incidence of avian influenza outbreaks for each domain.

The empirical model was generated based on the multiple regression model defined as:

$$Y= \beta_0+ \beta_1 X_{1+} \beta_2 X_2+ \beta_i X_i$$

Where Y is the number of disease outbreaks, β_0 is the constant and equal zero value in this study. $X_1,\ldots X_i$ are the key environmental factors, and $\beta_1,\ldots\beta_i$ are their regression coefficients.

2.4. Validation and Evaluation of Equation Models

Process of validation was done using data about the number of avian influenza outbreaks and the meteorological data for each domain, which available from 1 January 2011 to 31 December 2012. The meteorological data of these years was used in the model related to each domain, and the expected number of outbreaks were calculated, and then compared with the values that actually observed. There are two statistical methods are used for determining the accuracy and efficiency of the constructed empirical model of each domain, which are the root mean square error (RMSE) and mean bias (MB) (Gamal El Afandi et al., 2013). Root mean square error (RMSE) is one of the very important statistical tools, which give a good overall measure of model performance. It is a frequent measure the differences between the values of outbreaks predicted by the model and the values of outbreaks actually observed. The more approach of root mean square error to zero the higher, the accuracy of model.

On the other hand, the mean bias (MB) is considered also to evaluate the model performance, which represents the degree of correspondence between the mean prediction and the mean observation. Lower numbers are best and values less than Zero indicate under prediction.

The equations for RMSE, MB and its percentages are given as follows:

$$\mathrm{RMSE} = \left(\sum_{i=1}^{n} \frac{(X_p - X_o)^2}{n} \right)^{0.5},$$

$$\mathrm{RMSE}\ \% = \left(\frac{\mathrm{RMSE}}{\overline{X_o}} \right) * 100,$$

$$\mathrm{MB} = \sum_{i=1}^{n} X_p - \frac{X_o}{n},$$

$$\mathrm{MB}\ \% = \left(\frac{\mathrm{MB}}{\overline{X_o}} \right) * 100,$$

Where n is number of observations, x_p and x_o are the predicted and observed values, respectively, and $\bar{x}_o$ is the average of observed values. These statistical measures are used extensively for evaluation of model forecasts of avian influenza outbreak.

3. Results and Discussion

3.1. Equation Model for Avian Influenza Outbreaks in Delta Region of Egypt

Table 5, explained that, the outbreaks were negatively correlated with temperature and wind speed (r= -0.86 and –0.41, respectively), but positively correlated with relative humidity r= 0.52.

Referring to table 6, the regression analysis of domain A, which representing the Delta region of Egypt, it was observed that, an increasing of temperature by one degree centigrade causing 1.76 % decrease in avian influenza outbreaks (*P-value* < 0.0001). Also, any increase of wind speed by 1 kilometer per hour, resulting in decrease of outbreaks by 2.94 % (*P-value*=0.0001). On the other hand, there was a positive relationship (*P-value* < 0.0001) observed between avian influenza outbreaks and the relative humidity. As, increasing of relative humidity by 1% leading to increase of avian influenza outbreaks by 1.26 %. The coefficient of determination, R^2 of the regression equation was 0.98 indicated that, the 98 % of changes in avian influenza outbreak related to climate factors in the Delta region. Wood et al. (2010), also, observed similar correlation between survival of H5N1 and temperature and humidity.

So, the equation model for delta region was

$$Y = \beta_0 - 1.76\mathrm{Temp} - 2.94\mathrm{Wind} + 1.26\mathrm{RH}$$

Adjusted R^2=0.98
Where,
Y= No. of outbreaks
Temp= Temperature in C^0
Wind= Wind speed Km/h
RH= Relative humidity%
R^2= Coefficient of determination

Table (4). *Monitoring stations for each domain that used for the meteorological data*

Domains	Stations
A (Delta region)	Wadi-Elnatroon and Baltem
B (Middle Egypt)	Cairo airport
C (Upper Egypt)	Aswan and Asyut

Table (5). *Correlation coefficients of avian influenza outbreaks and climate factors in Delta region*

	Outbreak	Temp	Wind	RH
Outbreak	1			
Temp	-0.86	1		
Wind	-0.41	0.26	1	
RH	0.52	-0.09	-0.01	1

Table (6). *Regression analysis for outbreaks in Delta region*

	Multiple R	R-Square	Adjusted R-Square	St Err of Estimate		
	0.991	0.983	0.980	1.66		
Regression Table	Coefficient	Standard Error	t-Value	p-Value	Confidence Interval 95% Lower	Upper
Constant	0	NA	NA	NA	NA	NA
Temp.	-1.76	0.09	-17.84	< 0.0001	-1.98	-1.54
Wind	-2.94	0.47	-6.25	0.0001	-4.00	-1.87
RH	1.26	0.07	17.01	< 0.0001	1.09	1.43

3.2. Equation Model for Avian Influenza Outbreaks in Middle Area of Egypt

As shown in table 7, the outbreaks in middle region of Egypt was strongly negative correlated with ambient temperature (r= -0.93), also weakly negative correlated with wind speed (r= -0.20) and highly positive correlated with relative humidity (r= 0.53). Moreover, there was negative interrelationship between climate factors in this region.

According to an equation model of domain B in table (8), which representing the middle area of Egypt, there was a significantly negative relationship (*P-value* < 0.0001) between environmental temperature and the outbreaks, as the increasing of temperature by one degree centigrade causing 1.48% decrease in outbreak. On the other hand, a significantly positive relationship (*P-value* < 0.0001) was observed between avian influenza outbreak and relative humidity; this means that an increase in relative humidity by 1% may be led to increase of outbreak by 0.73 %. From the analysis there was doubtful effect of wind speed (*P-value*= 0.087) on disease outbreaks in this area. The coefficient of determination, denoted $R^2$was 0.97 indicates how well data points fit a statistical empirical model and 97 % of changes in avian influenza outbreak related to climate conditions in the area of middle Egypt.

The equation model for outbreaks in middle region can be expressed in this form

$$Y= \beta_0 -1.48Temp+0.30Wind+0.73RH$$

Adjusted R^2=0.97
Where,
Y= No. of outbreaks
Temp= Temperature in C^0
Wind= Wind speed Km/h
RH= Relative humidity%
R^2= Coefficient of determination

Table (7). *Correlation coefficients of avian influenza outbreaks and climate factors in Middle Egypt.*

	Outbreak	Temp	Wind	RH
Outbreak	1.00			
Temp	-0.93	1.00		
Wind	-0.20	-0.11	1.00	
RH	0.53	-0.22	-0.89	1.00

Table (8). *Regression analysis for outbreaks in Middle Egypt.*

	Multiple R	R-Square	Adjusted R-Square	St Err of Estimate		
	0.990	0.9805	0.976	1.44		
					Confidence Interval 95%	
Regression Table	Coefficient	Standard Error	t-Value	p-Value	Lower	Upper
Constant	0	NA	NA	NA	NA	NA
Temp.	-1.48	0.07	-19.24	< 0.0001	-1.66	-1.31
Wind	0.30	0.15	1.91	0.087	-0.05	0.66
RH	0.73	0.04	15.25	< 0.0001	0.06	0.83

Table (9). *Correlation coefficients of avian influenza outbreaks and climate factors in Upper Egypt.*

	Outbreak	Temp	Wind	RH %
Outbreaks	1.00			
Temp	-0.97	1.00		
Wind	-0.76	0.72	1.00	
RH	0.94	-0.89	-0.76	1.00

3.3. Equation Model for Avian Influenza Outbreaks in Upper Area of Egypt

Regarding to table 9, There were strong negative relationship between the outbreaks in upper region of Egypt was strongly negative correlated with ambient temperature (r= -0.93), also weakly negative correlated with wind speed (r= -0.20) and highly positive correlated with relative humidity (r= 0.53). Moreover, there was negative interrelationship between climate factors in this region.

Regarding to regression analysis model of domain C which representing the upper area of Egypt, in table 7, A. the multiple regression analysis explore non-significant effect of wind speed on the outbreaks of the disease in upper Egypt (P=0.1649), and to exclude the wind speed a backward stepwise regression analysis was done to reach accurate significant climate factors which shown in table 7,B. it observed a moderate negative relationship (*P-value*< 0.0001) between environmental temperature and the outbreaks. This means, any increase of temperature by one degree centigrade causing 0.35 % decrease in outbreaks. Otherwise, there was a high positive relationship (*P-value*< 0.0001) observed between the outbreaks and each and relative humidity. As, increasing of relative humidity by 1% resulted in increasing of the outbreaks by 0.55 %. In addition, The coefficient of determination, R^2 was 0.95 indicated that 95 % of changes in avian influenza outbreaks related to temperature and relative humidity in Upper Egypt and other factors represent 5%.

The equation model for outbreaks in middle region can be expressed in this form

$$Y= \beta_0 - 0.35\ Temp+0.55RH$$

Adjusted R^2=0.95

Where,

Y= No. of outbreaks

Temp= Temperature in C^0

RH= Relative humidity%

R^2= Coefficient of determination

Table (10, A). *Multiple regression analysis for outbreaks in Upper Egypt.*

	Multiple R	**R-Square**	**Adjusted R-Square**	**St Err of Estimate**		
	0.9807	0.9618	0.9533	1.662338		
	Coefficient	Standard	t-Value	p-Value	Confidence Interval 90%	
Regression Table		Error			Lower	Upper
Constant	0	NA	NA	NA	NA	NA
Temp	-0.54551	0.134617	-4.0523	0.0029	-0.79228	-0.298
Wind speed	0.400855	0.265164	1.5117	0.1649	-0.08522	0.886931
RH %	0.481084	0.053993	8.9101	< 0.0001	0.382108	0.58006

Table (10, B). *Backward Stepwise Regression for Avian influenza outbreaks in Upper Egypt.*

	Multiple R	**R-Square**	**Adjusted R-Square**	**St Err of Estimate**		
	0.975	0.955	0.95	1.77		
	Coefficient	Standard	t-Value	p-Value	Confidence Interval 90%	
Regression Table		Error			Lower	Upper
Constant	0	NA	NA	NA	NA	NA
Temp.	-0.35	0.04	-8.6094	< 0.0001	-0.42	-0.27
RH %	0.55	0.02	18.6221	< 0.0001	0.49	0.60

Table (11). *The percentages of root mean square error and mean bias for the three regional empirical models validation using observed and predicted outbreak values.*

Regions	**RMSE%**	**MB%**
Delta Region	1.6	1
Middle Egypt	1.34	0.5
Upper Egypt	2.1	0.79

3.4. Validation of the Three Equation Models

Regarding to results outlined in the table.8, the validation process of the equation model in the Delta region of Egypt revealed that, RMSE% and MB% were 1.6% and 1%, respectively meaning that, the difference between the values of avian influenza outbreak predicted by this equation and the values of outbreak actually observed was 1.6% and the confidence level for this model was 99 %. Also, the validation process of the equation model in the Middle Egypt revealed that, RMSE% and MB% were 1.34% and 0.5%, respectively meaning that, the difference between the values of avian influenza outbreaks predicted by equation and the values of outbreak actually observed was 1.34% and the confidence level for this model was 99.5%. Otherwise, the validation process of the equation model in Upper Egypt revealed the RMSE% and MB% were 2.1% and 0.79%, respectively meaning that, the difference between the values of avian influenza outbreaks predicted by this equation and the values of outbreak actually observed was 2.1% and the confidence level for this equation was 99.21%.

4. Conclusion

This paper discusses the interrelationship between some environmental factors and outbreaks of highly pathogenic avian influenza and construction of equation model of the outbreaks by using of climate variable that significantly influence the outbreaks. The constructed equation models of this paper revealed significantly relationship between the outbreaks of avian influenza and each of temperature, relative humidity and wind speed for the Delta and middle area of Egypt. On the other hand, there was significant effect of wind speed on the outbreaks of avian influenza in Upper Egypt and has mild doubtful effect in Middle and strong obvious significant in Delta regions, this may be attributed to the character of topography of Delta regions, in addition to increase of human population density, backyard poultry and cultivation lands combined with close proximity to irrigation, and vegetation which enhances wild bird migration.

The validation process of the equation model for each domain in Egypt revealed a higher confidence level, which was 99.21%, 99.5% and 99% for Upper, Middle and Nile Delta region, respectively. It was noted that, the degree of avian influenza outbreaks in Egypt increased in the north (Delta region) and decreased toward the south (Upper Egypt) direction. In addition, the number of outbreaks of avian influenza exhibits seasonality, which peaks during the winter and fall months. Therefore, it was think that, these models represent the solid ground to predict the future outbreak of avian influenza in each domain in Egypt related to climate changes.

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