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Spread of Avian Influenza- A Mathematical Approach

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Abstract

Avian Influenza is a highly contagious respiratory disease, caused by infection with avian (bird) influenza (flu). The mathematical model constraints are the number of susceptible (S), Infected with Avian Influenza (I), Recovered (R), and Cross-immune (C) in constant human population size (N). The stability analysis represented in this work. This mathematical model concludes that the present situation of treatment is successful, but some necessary actions are required in this direction. In conclusion, mathematical simulations are carried out to validate analytical results. The model is compact in structure, and it effectively catches the course of the avian influenza transmission, and hence reveals insight into understanding its epidemiology.

Keywords: Avian Influenza, Mathematical Modeling, Differential equation, Bio-Mathematics.

I. INTRODUCTION

A brief on Influenza A viruses (Avian Influenza)

Living beings have a tendency to catch the infection more when the season gets changed every year because of low immunity at that time [7]. Influenza [Flu] is a periodic seasonal infection that diffuses due to the inadequacy of an essential understanding of the virus. Influenza is triggered through virus that could be Type A, Type B, and Type C [8].

Influenza A virus relates to the family of Orthomyxoviridae. Depending on the virulence factors of hemagglutinin (HA) and neuraminidase (NA) glycoproteins, bacterial Infections are described as 17HA and 10NA subtypes. Numerous substituents of influenza A pathogen also reported in migratory animals that reflects a primary host of influenza A virus [25].

Currently influenza ‘A’ infections are proven to affect spontaneous outbreaks in birds, but pathogens of all 15 β -lactamase enzymes from all nine neuraminidase influenza A syndromes have also been extracted from avian species in the variety of possible combinations. Influenza A viruses infecting animals can be segregated into two categories based of your intent to promote disease. Particularly virulent bacterial diseases contagious bacterial infection (HPAI) in which the risk of death could be as higher than 100%. Those same viruses The above pathogens have indeed been confined to H5 and H7 subtypes, even though not all pathogens of such syndromes trigger HPAI. Certain other infection causes something much duller, particularly bacterial infection, that might be triggered by several other pathogens or climatic conditions [26].

The continued distribution of elevated / low pathogenic AIV in migratory animals, ones resulting spread worldwide answered a concern more about importance of migratory animals as a worldwide contamination mechanism. H1N1 is an AIV subcategory which spreads amongst migratory animals but also has the flexibility to cope to humans and other vertebrates [27].

Transmission

It can be any type of virus that can be generated from the infected species and contaminated areas and transmitted to the susceptible compartment. Individuals could get infected by avian, swine, and other contagious viruses' types directly by one another.

The influenza mainly transmitted by respiratory tract of respiratory droplets or bacterial biophysical properties and, probably, by unintentional (fomite) communication accompanied by auto-inoculation of the respiratory epithelium or mucocutaneous epidermal layer. The perceived importance of all these pathways is being explored and there is evidence to support both of them, including the prevention of transmission illness to universal healthcare facilities. The propagation of avian flu virus is likely to block certain pathways along with others. Living beings conjunctiva and epithelial cells respiratory vascular endothelial cells comprise bacterial antibodies which are already identified generally by avian hemagglutinin (5-0072.3 interconnections among transitional sialic acid residues and galactose) instead of just individual (Δ2.6 linkages), flu viruses [29].

The viruses cause disease with mild symptoms to the respiratory infection to the severity of the infection sometimes leads to death and not eradicated. Some deadly infections in living beings would be continuing until long even though essentials planning for prevention are highly based on risk factors. Over the past ten years, numerous analytical solutions have already been used utilized for the transmittable Illness globally and Influenza in particular. [8,11,13,14].

RISK FACTORS

The major risk factor for parasitic infections, or avian flu viruses, likely to be explicit or implicit proximity to contaminated direct contact with an infected poultry or infected environments, including such large bird supermarkets.

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mass slaughter, beating, treating droppings of contaminated livestock and livestock preparation for intake , particularly in domestic environments, are indeed considered as possible causes. there seems to be no documentation suggesting which a(H5), a(H7N9) or other avian flu pathogen could've been released from person to person via way of correctly handled poultry or eggs.few more human infections of flu a(H5N1) have also been traced to the intake of traditional dishes from fresh, contaminated bird meat. trying to control the spread of pathogens in birds is essential to reduce the risk of infectious disease. in consideration of the emergence of a(H5) or a(H7N9) pathogens in certain bird species, regulation may require long-term contributions among governments and strong coordination amongst livestock and human health agencies .

PRIMARY FEATURES:

- People may indeed be contaminated with zoonotic bacterial spores like syndromes 'a(H5N1), a(H7N9) or a(H9N2)' and subclasses 'a(H1N1), a(H1N2) and a(H3N2)' respectively.
- Infectious diseases are mainly caused by contact with infected animals or polluted conditions, and all these viruses really haven't developed the capacity to survive human transmission.
- Viruses like avian, swine, zoonotic flu infections are caused through prevent illnesses range from a mild active infection including mild fever as well as cough), respiratory infection development resulting to rheumatic fever, panic septicemia, congestive cardiac failure, and sometimes even mortality. Corneal abrasions, respiratory problems, pneumonia and cardiomyopathy have indeed been identified in various extents dependent upon this genotype.
- Numerous cases of human of virus (H5N1) and (H7N9) bacterial infection are being correlated through contact with a person between freshly killed livestock contaminated. The management of epidemic at the beginning including its species is essential to the removal of environmental hazard.
- Syndrome is a genetic, with just a massive invisible stockpile. of marine birds, can not be eradicated. Infection with zoonotic influenza can keep on taking place in humans. To mitigate human health threats, quality monitoring in living beings, a comprehensive analysis of all human infections and risk-based pandemic preparation are necessary.

DIAGNOSIS, TREATMENT AND PREVENTION:

Rapid and Laboratory tests are needed to identify infectious disease with pathogen influenza.Research shows that certain antiretroviral medications, specifically neuraminidase receptors (oseltamivir, zanamivir), may minimize the latency of disease progression and enhance survival prospects, nevertheless current human trials may even be required [25]. With the exception of antiretroviral treatment, health promotion policy involves actual preventive measures such as:

- washing hands
- wearing masks
- Quarantine
- Social distancing
- avoidng frequent touchnig nose mouth and eyes.
- As a basic preventive measure, people should avoid migratory birds and examine them mostly from a distance.
- Prevent dealing with poultry birds (dairy) that might seem infected or have expired.
- Prevent contact with objects that happen to be infected with contaminants from migratory animals or native birds

Disease indications and managemnet

Influenza is an intensely epizootic disease of the respiratory system caused by the "Ribonucleic Acid" [RNA] virus from birds and beasts. The appearances that can be noticed at the outset are suddenly the rise in temperature of the body with severe headache, runny nose with coughing and discomfort in breathing in addition. As the belongingness of influenza to epidemiology [The branch of science which deals with the study of unpredictable pandemic diseases] and consequences of transmittance, living beings are prone to catch contamination from the affected poultry either live or dead and afterward to few other humans. To minimize the threat of the expansion of the infection, the spread of avian influenza viruses in poultry should be essentially controlled or mitigated with contributions from worldwide, and strong solidarity between animal and health officials. Moreover by maintaining personal hygiene including washing of hands frequently, covering mouth and nose while sneezing and coughing, staying away from the infected individuals can be helpful to prevent such viruses apart from anti-viral remedy.

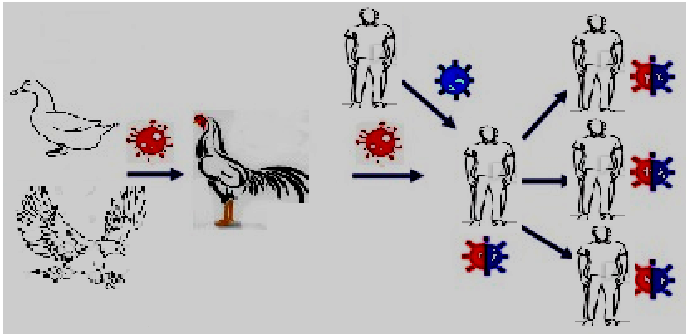

Figure 1: Spreadness of avian influenza epidemiology

Epidemic incidences

An outbreak of pandemic in India : In the second month of 2006, the first case of avian influenza was reported in Maharashtra state followed by a second outbreak in the state MP [28]. Enormous flocks of birds were elected to monitor and normalize the situation and after successful actions, the virus had been eliminated in the month of august and subsequently, the trend of an outbreak of the infectious disease has been reporting in India in almost every state whether privileged or unprivileged till date with different characteristics of the virus [15]. The principal cause of the expansion of the disease is utterly dependent on the migration of the birds from one location to another. The fundamental source for the outbreak of a virus in India is the heavily populated poultry. In the meantime, Europe has not reported any fresh cases of avian virus over the past week [16].

Introduction to Mathematical model

Various mathematical models (SIR) are intended in the literature to outline the inter-pandemic habitat of influenza 'A' type in living beings [19]. The SIRC model has been introduced with ordinary differential equation system of equations to examine the patterns of conduct. The evolution is exceptionally ordinary by excluding the accountability for seasonality nevertheless distinct from the traditional SIR ones. The study of the strained SIRC model exhibits that a broad range of compound temporal patterns can be predicted that is pragmatic for influenza 'A' type.

II. MATHEMATICAL MODELTHE MATHEMATICAL MODEL IS REPRESENTED BY THE DIFFERENTIAL CONDITIONS FOR HUMAN AND BIRD CREATURE POPULACE:

$$\frac{dS}{dt} = \omega - \left(\mu + \beta\left(I_0/N_0\right)\right)S + \delta R + nC \qquad (1)$$

$$\frac{dI}{dt} = \beta\left(I_0/N_0\right)S - \left(\mu + \gamma + \alpha\right)I + mC\left(I_0/N_0\right) \qquad (2)$$

$$\frac{dR}{dt} = (\omega - m)C\left(I_0/N_0\right) + \gamma I - \left(\mu + \delta\right)R \qquad (3)$$

$$\frac{dC}{dt} = \delta R - mC\left(I_0/N_0\right) - \left(\mu + n\right)C \qquad (4)$$

$$\frac{dN}{dt} = \omega - \mu N - \alpha I \qquad (5)$$

For Bird population:

$$\frac{dS_0}{dt} = \mu_0 N_0 - \left(\mu_0 + \beta_0\left(I_0/N_0\right)\right)S_0 \qquad (6)$$

$$\frac{dI_0}{dt} = \beta_0\left(I_0/N_0\right)S_0 - \mu_0 I_0 \qquad (7)$$

For the system of equation in the $SIRCS_0I_0N$ space is positively constant. as $N'(t) < 0$, $N > \omega/\mu$, all paths in the first approach, enter or stay inside Ω given by:

$$\Omega = \{\left(S, I, R, C, S_0, I_0, N\right)/0 \le S_0; 0 \le I_0; 0 \le I; 0 \le S; \\ S + I + R + C = N \le \omega/\mu; S_0 + I_0 = N_0\}$$

The continuity of the above including R.H.S and diffrentials suggests that one of a type of solutions exist on a maximal stretch. However solutions indicates the boundedness - enter, or remain. Subsequently, the defined model is numerically well presented. Now taking the ratios:

$$s = \frac{S}{\omega/\mu}, i = \frac{I}{\omega/\mu}, r = \frac{R}{\omega/\mu}, c = \frac{C}{\omega/\mu}, s_0 = \frac{S_0}{N_0}, i_0 = \frac{I_0}{N_0}$$

Where the sum $S + I + R + C = N$ and $s_0 + i_0 = N_0$, we get:

$s + i + r + c = n$ and $s_0 = 1 - i_0$

The updated equations are as follows:

$$\frac{ds}{dt} = \omega - \left(\mu + \beta i_0\right)s + \delta r + nc \qquad (8)$$

$$\frac{di}{dt} = \beta i_0 s + m i_0 c - \left(\mu + \gamma + \alpha\right)i \qquad (9)$$

$$\frac{dr}{dt} = \gamma i - \left(\mu + \delta\right)r + m i_0 c \qquad (10)$$

$$\frac{dc}{dt} = \delta r - m i_0 s - \left(\mu + n\right)c \qquad (11)$$

$$\frac{di_0}{dt} = \beta_0 i_0 (1 - i_0) - \mu_0 i_0 \qquad (12)$$

In the set

$$\Omega' = \{\left(s, i, r, c, i_0\right)/0 \le i; 0 \le s; 0 \le r; 0 \le c; \\ s + i + r + c \le n \le 1; 0 \le i_0 \le 1\}$$

III. NUMERICAL RESULTS AND DISCUSSION

For trivial state $E_1(1,0,0,0,0)$ Jacobian Matrix is defined as follows:

$$J_{E_1} = \begin{pmatrix} -\mu & 0 & \delta & n & -\beta \\ 0 & -M & 0 & 0 & 0 \\ 0 & \gamma & -\mu-\delta & 0 & 0 \\ 0 & 0 & \delta & -\mu-n & -m \\ 0 & 0 & 0 & 0 & \beta_0-\mu_0 \end{pmatrix}$$

To check the stability of Jacobians matrix, we have to find the characteristics polynomial of $\det(J_{E_1} - \lambda I)$

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$$P(\lambda) = \mu_0(R-1-\lambda)(-\mu-\lambda)(-M-\lambda)$$
$$(-\mu-\delta-\lambda)(-\mu-n-\lambda) = 0$$

Thus the eigen values are:

$$\lambda_1 = R-1, \lambda_2 = -\mu, \lambda_3 = -M,$$
$$\lambda_4 = -(\mu+\delta), \lambda_5 = -(\mu+n)$$

So E_1 is stable because eigen values are negative if $R<1$ For stable $E_2(\bar{s},\bar{i},\bar{r},\bar{c},\bar{i_0})$ the matrix of linearization (Jacobians Matrix) is given as

$$J_{E_2} = \begin{pmatrix} -\mu-\beta i_0 & 0 & \delta & n & -\beta s \\ \beta i_0 & -M & 0 & -mi_0 & mc \\ 0 & \gamma & -\mu-\delta & -mi_0 & mc \\ -mi_0 & 0 & \delta & -\mu-n & -ms \\ 0 & 0 & 0 & 0 & \beta_0-\mu_0-2\beta_0 i_0 \end{pmatrix}$$

To check the stability of Jacobian Matrix, we have to find the characteristics polynomial of $\det(J_{E_2}-\lambda I)$

$$P(\lambda) = (\beta_0-\mu_0-2\beta_0 i_0-\lambda)(\lambda^4+A\lambda^3+B\lambda^2+C\lambda+D) = 0$$

Thus eigen values are: $\lambda_1 = -(\beta_0-\mu_0-2\beta_0 i_0)$ .And the roots of biquadratic equation

$$\lambda^4+A\lambda^3+B\lambda^2+C\lambda+D$$

$$A = M+\mu_0+\beta i_0$$
$$B = (\mu+\delta)^2+M\mu_0+Mi\beta_0+m^2 i^2{}_0\delta-nmi_0$$
$$C = -M(\mu+\delta)^2-mi_0+(\mu_0+i\beta_0)(\mu+\delta)^2$$
$$+\beta i_0\gamma\delta+mi_0 M+nmi_0\mu+nmi_0\delta$$
$$D = M(\mu+\delta)^2(\mu_0+i\beta_0)-mi_0\gamma\delta(\mu_0+i\beta_0)$$
$$-\beta i_0\delta\gamma(\mu+n)+m^2 i^2{}_0\delta\gamma-n\beta i_0\gamma\delta-nMi_0 m\mu$$
$$-nmi_0 M\delta$$

So E_2 will be stable if all given eigen values are negative. It is clear that $\lambda_1<0$.To check the stability of remaining eigen values. We will apply the Routh-Hurwitz criterion of stability

It is clear that

$$A>0, B>0, C>0, D>0, AB>C, A^2D-C^2$$

So E_2 is stable. To test the behavior of the differential equation model, it was utilized to solve sirci0 model with the parameters in Table I.

TABLE I. PARAMETERS ESTIMATION

S. No.	Parameters	Value	Reference
1	β	0.01, 0.025, 0.075	[1]
2	β_0	0.035	[1]
3	δ	0.1	[1]
4	α	0.02	[1]
5	γ	0.25	[1]
6	μ	0.00004	[1]
7	μ_0	0.0004	[1]
8	n	0.035	estimated
9	m	[0.01, 0.1]	estimated

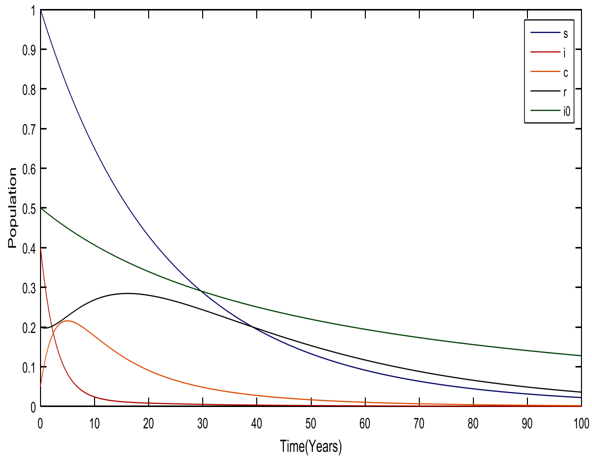

Figure 2: Graphical representation of Model for avian influenza ($\beta = 0.01$).

In Figure (2), the graph shows that Susceptible to avian Influenza in human class is going down with time and completely recovered in human population class is going up with time because of treatment on schedule, when the transmission rate of avian Influenza, bird to human($\beta = 0.01$).

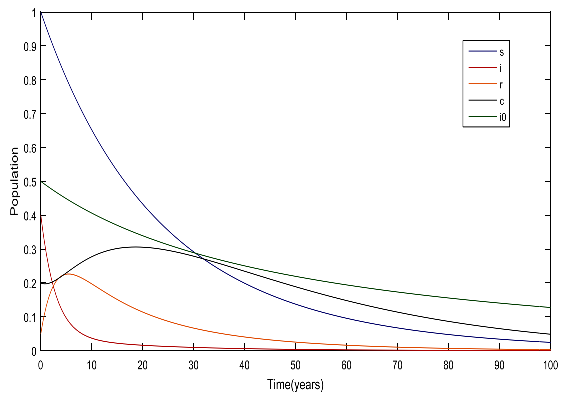

Figure 3: Graphical representation of Model for avian influenza ($\beta = 0.025$).

In Figure (3), the graph shows that Susceptible to avian Influenza in human class is going down with time and completely recovered in human population class is going up with time because of treatment on schedule, when Transmission rate of avian Influenza, bird to human ($\beta = 0.025$).

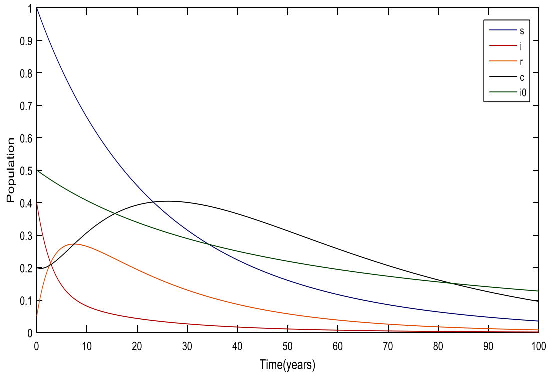

Figure 4: Graphical representation of model for avian influenza ($\beta = 0.075$).

In Figure (4), the graph shows that Susceptible to avian Influenza in human class is going down with time and completely recovered in human population class is going up with time because of treatment on schedule, when Transmission rate of avian Influenza, bird to human ($\beta = 0.075$).

The Force of Infection

In the study of epidemiology, the force of infection (f) and defined as the rate at which susceptible individuals gain an epidemic situation. Therefore the force of infection receives the amount of susceptibility, which can be used to distinguish the rate of transmission among various groups of the human population for communicable disease.

A Crude Approximation

A crude approximation β which is the function of time for the disease is to assume that the rate of transmission varies, and it is given by the formula:

$$\beta(t) = \beta_0(1 + \alpha \cos 2\pi t)$$

Where β means a crude approximation, α is an amplitude of the seasonal variation and 't' is the time period.

Table-II: Transmission rate of avian Influenza, bird to human

Time(1 to 12) months	0.01	0.025	0.075	0.035
1	0.00102	0.025499997	0.076499992	0.035699996
2	0.00102	0.02549999	0.07649997	0.035699986
3	0.001019999	0.025499977	0.076499932	0.035699968
4	0.001019998	0.025499959	0.076499878	0.035699943
5	0.001019997	0.025499937	0.07649981	0.035699911
6	0.001019996	0.025499909	0.076499726	0.035699872
7	0.001019995	0.025499876	0.076499627	0.035699826
8	0.001019994	0.025499838	0.076499513	0.035699773
9	0.001019992	0.025499795	0.076499384	0.035699712
10	0.00101999	0.025499746	0.076499239	0.035699645
11	0.001019988	0.025499693	0.076499079	0.03569957
12	0.001019985	0.025499635	0.076498904	0.035699489

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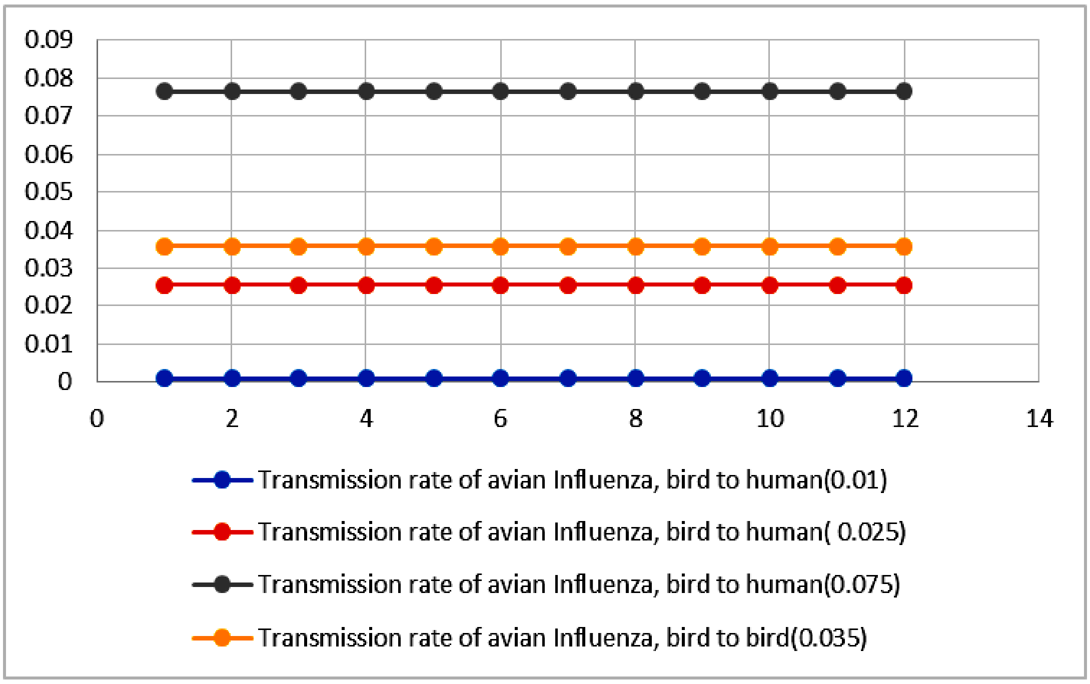

Figure 5: Graphical representation transmissions rate of avian influenza for a year.

In Figure (5), the graph shows different growths of different forces of infection for a year. It represents the transmission rate of avian influenza from bird to human with different force of infections and bird to bird force of infection.

IV. CONCLUSIONS

Avian influenza 'A' type is a threatening disease for the living population that is liable to produce severe infection amongst individuals and lead causalities if not treated well in time. The pathological conditions, contagion, medical traits, and pharmacologic remedies, therapies' and ways of handling stoppage of further spread of the virus to avoid its likely catastrophic implications. The work changes the traditional perspective of stability of a framework concerning epidemic disease modeling. The work touched numerical difficulties concerned with creating a differential equations model based on four classes of living beings termed - "Susceptible, Infected, Recovered and Cross immune "compartments. The impact of various outlines of epidemiological requirements on the reiteration of outbursts of the virus has made the discussions quite simple with the help of the SIRC model. Through the stability analysis of the proposed model the work exhibits that after receiving proper medical attention, the condition is more likely to be stable in future endeavors. We have an interesting topic for further discussions, such as the stochastic Avian influenza model with delays. We conclude that environmental warrants genuine thought in the investigation of avian influenza ecology and advancement.

Table III: Nomenclature of Parameters

Parameters	**Description**
S	"Susceptible to avian Influenza in human"
I	"Infected with avian Influenza in human"
C	"Cross-immune individuals in human population"
R	"Completely recovered in human population"
ω	"Birth and Immigration rate"
β	"Transmission rate of avian Influenza, bird to human"
β_0	"Transmission rate of avian Influenza, bird to bird"
δ	"Loss of immunity rate"
α	"Avian influenza -death rate"
γ	"Recover rate from avian influenza"
$1/\mu$	"Average life time of human"
$1/\mu_0$	"Average life time of birds"
$1/n$	"Cross-immune life time of human"
$1/m$	"Average time passed since last infection for cross-immune individuals"
S_0	"Susceptible to avian Influenza in birds"
I_0	"Infected with avian Influenza in birds"

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