A Spatial Epidemiological Analysis of Foot and Mouth Disease in North Central Province, Sri Lanka

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Abstract

Foot and mouth disease (FMD) is one of the most contagious diseases of animal livestock in the world in terms of economic impact. FMD is endemic in the dry zone of Sri Lanka and considered to be a common disease among cattle and buffaloes in this area. A massive epidemic in 2014 swept through all the Provinces, resulting in 58,645 cases and 1,265 deaths, the largest number recorded since 1987. In Sri Lanka, currently there is no regular, nationwide vaccination programme devised to control FMD. One of the major obstacles in meaningful economic analysis has been the lack of substantive data on the relationship between vaccination strategies and the resultant incidence of FMD. Therefore, the objectives of this study were to estimate the transmission coefficient of FMD and the critical vaccination coverage required to prevent outbreaks. Employing the Susceptible–Exposed–Infectious–Recovered (SEIR) model, the transmission coefficient for FMD incidence was quantified. The transmission coefficient was estimated to be 0.618 by the SEIR model. The vaccination coverage at 6 months was found to be 35% in North Central Province. The number of infected animals was 10,676, corresponding to a vaccination coverage of 35% (Under a condition of 85% vaccine efficacy). The actual number of reported cases was 8,384 during the same period; the model over estimated cases by +21.5%.

ABBREVIATIONS

FMD: Foot-and-Mouth Disease; SEIR: Susceptible–Exposed–Infectious–Recovered; DAPH: Department of Animal Production and Health

INTRODUCTION

Foot-and-mouth disease (FMD) has been considered the oldest cattle disease in Sri Lanka and was found to be endemic in various parts of the country, particularly in the eastern part of Northern and Eastern Provinces. These areas hold more than half of the national cattle and buffalo population and make a substantial contribution to the total milk production in the country.

There was only a single epidemic of FMD recorded during the first decade of the 21st century in the country (Figure 1). During this epidemic, which occurred in 2003, a total of 36,340 cases were recorded, of which 96% were confined to the endemic zones (Department of Animal Production and Health, 2003). Since then, FMD appeared to be well under control, and the total number of cases recorded annually was less than 2000. However, a massive epidemic in 2014 swept through all the Provinces, resulting in 58,645 cases and 1,265 deaths, the largest number recorded since 1987 (Department of Animal Production and Health, 2014). A Majority of the FMD cases were observed in North Central Province, with some spill over in other Provinces.

In Sri Lanka, there is currently no regular, nationwide vaccination programme devised to control FMD. Vaccination for FMD in the country has always been limited to the endemic and buffer zones and ring vaccination during an outbreak to prevent further spread of the outbreak to other areas. Therefore, the objective of this study was to estimate the transmission coefficient (β) for FMD. Policy makers can use this knowledge to identify the required vaccination coverage to prevent an outbreak, while farmers can use this information to improve their animal health, and economic status, which ultimately leads

towards the eradication of FMD.

MATERIALS AND METHODS

Data from the FMD epidemic that took place in North Central Province in 2014 was obtained from the North Central Province DAPH.

Firstly, \( \beta \) was estimated for each divisional secretariat. Since heterogeneity varied widely among divisional secretariats, the number of FMD-infected animals at the end of the epidemic was adjusted by the duration of the outbreak using the following formula:

\[
C_a = \frac{C}{t}
\]

(1)

Where \( C \) is the number of new cases identified in the FMD epidemic, \( C_a \) is the adjusted number of cases, and \( t \) is the duration of the outbreak in days; therefore, \( C_a \) is an estimate of the expected number of cases caused by an individual FMD-infected animal in a single day [1]. Consequently, \( \beta \) was estimated as:

\[
\beta = \frac{NC_a}{St}
\]

(2)

Where \( N \) is the number of animals (cattle and buffalo) in the divisional secretariat, which was assumed to be constant through the duration of the epidemic, justified by the zero mortality and by the prohibition of all animal movement susceptible for FMD imposed at the beginning of the epidemic. \( I \) denotes the number of animals infected at the time of outbreak detection, and \( S \) is the number of susceptible animals at the beginning of the epidemic, \( S = N - I \).

In addition, the transmission coefficient \( \beta_{ij} \) between divisional secretariats \( i \) and \( j \) decreased exponentially with increase of the Euclidean distance of their respective divisional secretariat centroids [2]. Therefore, the elements of the “mixing” or “contact” matrix \( \beta_{ij} \) [3] were therefore described as:

\[
\beta_{ij} = \beta(t) e^{-q d_{ij}}
\]

(3)

Where \( \beta \) is the average transmission coefficient of each infectious divisional secretariat at time \( t \), \( d_{ij} \) is the distance between the centroids of divisional secretariat \( i \) and \( j \), and the parameter \( q (\text{km}^{-1}) \) indicates the extent of the average spread in each secretariat. Additionally, for simplicity, homogeneous mixing within each divisional secretariat was assumed, that is, \( d_{ii} = 0 \). In addition, this parameter \( (d_{ij}) \) is able to capture the effect of local transmission factors, such as animal density within the divisional secretariat and wind direction [2]. Secondly, \( \beta_{ij} \) were calculated for each of the 18 FMD-affected divisional secretariats.

The above explanations and assumptions led to the following SEIR model:

\[
\frac{dS}{dt} = -\frac{S\beta I}{N}
\]

(4)

\[
\frac{dE}{dt} = -\frac{S\beta I}{N} - \frac{E}{\sigma}
\]

(5)

\[
\frac{dI}{dt} = \frac{E}{\sigma} - \gamma I
\]

(6)

\[
\frac{dR}{dt} = \gamma I
\]

(7)

Where \( S, E, I \) and \( R \) respectively indicate the number of susceptible, exposed, infectious and recovered animals in the all divisional secretariats. The incorporation of vaccination led to the following modified model:

\[
\frac{dS}{dt} = -\frac{S\beta I}{N} - \frac{E}{\sigma} + v + \alpha R
\]

(8)

\[
\frac{dV}{dt} = \frac{E}{\sigma} - v + \frac{S}{\sigma}
\]

(9)

\[
\frac{dI}{dt} = \frac{E}{\sigma} - \gamma I
\]

(10)

\[
\frac{dR}{dt} = \gamma I - \alpha R - \frac{S}{\sigma}
\]

(11)

Thirdly, the compartmental model was simulated in using a daily time interval. Definitions of variables and initial parameter estimates used in the SEIR model are given in (Table 1). The
SIR model assumes that an individual becomes infectious immediately after infection. FMD has a latent phase which individuals are infected but not yet infectious. Thus, SEIR model is more appropriate for FMD. Finally, a sensitivity analysis was conducted to assess the robustness of the modelling results by changing selected input parameters in the model. The major assumptions used in the model are as follows: Uniform mixing of individuals within each divisional secretariat; no external introduction of FMD from surrounding countries; FMD outbreak is located in the center of each corresponding divisional secretariat. The coefficient of transmission $\beta_{ij}$ between divisional secretariats $i$ and $j$ decayed exponentially fast with the Euclidean distance of their respective divisional secretariat centroids; Vaccine efficacy is 85%; age, breed, sex and management system do not affect the probability of being infected.

RESULTS AND DISCUSSION

The efficacy of the FMD vaccine has not been field tested in Sri Lanka. Many previous studies have assumed [4,5] the efficacy of FMD vaccines to be 80–90% in cattle and buffalo. Thus, the present study modelling catch-up FMD vaccination assumed 85% efficacy and six months of immunity [6].

The transmission coefficient was estimated to be 0.618 by the SEIR model [2], modelled the epidemiology of FMD in Uruguay in 2011 and found transmission coefficients of 0.77 and 0.33 for the non-spatial epidemic model and spatial epidemic model, respectively. The numbers of infected animals tend to decrease with increasing vaccination coverage. Indeed, effective vaccination acts as though the number of susceptible animals were reduced; this will therefore affect the contact rate and the reproduction number $R$ [7]. Ultimately, vaccination against FMD reduced the number of infected animals.

For the number of vaccinated animals in the 2013 vaccine season in North Central Province, there was no regular (bi-annual) vaccination programme in the study areas, and a vaccine was offered for cattle only. The vaccination coverage at 6 months was found to be 35% in North Central Province. The number of infected animals was 10,676, corresponding to a vaccination coverage of 35% (Under a condition of 85% vaccine efficacy). The actual number of reported cases was 8,384 during the same period; the model over estimated cases by +21.5%.

CONCLUSION

Employing the Susceptible–Exposed–Infectious–Recovered (SEIR) model, the link between vaccination coverage and change of FMD incidence was quantified. The transmission coefficient was estimated to be 0.618 by the SEIR model.

REFERENCES


Cite this article