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Analysis of risk factors in the management of foot-and-mouth disease in Turkey

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Abstract: The aim of this study was to perform a risk analysis of the management of foot-and-mouth disease (FMD) epidemics in Turkey. The relationship between disease outbreaks and risk was analyzed by evaluating 11 disease risk factors related to the input, processing, production, movement, and marketing infrastructure aspects of the animal production chain. A progressive (hierarchical) clustering analysis method was employed to group the quantitative data obtained for each of the risk variables. The total risk scores were grouped in a dendrogram. There was a strong positive relationship (72%) between risk variables and total outbreak numbers (P < 0.01). Results showed the districts in which the FMD risk is high and indicate where the appropriate measures should be taken to eradicate or at least minimize outbreaks.

Key words: Disease management, clustering, risk analysis, foot-and-mouth disease

1. Introduction

Strategic plans have been put in place on a global scale in order to decrease the risk from animal diseases (1). These studies include risk-based and people-centered approaches (2). Foot-and-mouth disease (FMD) is an important animal disease worldwide and causes major financial losses to livestock enterprises (3). The economic impact of the disease at the sectoral and national level is also very high (4). This is due to the international trade in animals and animal products from the countries/regions where FMD is present (5,6).

Studies that attempted to estimate the economic losses due to FMD worldwide reported that these losses vary, depending on the type of animal production and livestock system (7,8). For instance, the production losses and the costs of vaccination are between 6.6 to 21 billion dollars in countries where FMD is endemic, whereas these costs are about 1.5 billion dollars for countries where the disease is nonendemic (7). Even though the number of outbreaks of the disease can be reduced, the costs of protection measures are very high. Therefore, new approaches that reduce the number of outbreaks and improve the control of any outbreaks should be thoroughly investigated.

In Turkey, the average annual number of outbreaks of FMD was 1046 between the years 2006 and 2013 (9) and they have continued in recent years. In addition to the high number of outbreaks, the production losses due to disease are in the tens of millions of Turkish lira (8).

In the literature, there have been no scientific studies that investigated risk evaluation in FMD management in Turkey. The current study applied the disease risk evaluation approach to FMD and the specific circumstances prevailing in Samsun Province, Turkey.

2. Materials and methods

2.1. Research data and data sources

The data for outbreak numbers of FMD in Samsun Province between 2003 and to 2013 were obtained from the Turkish Ministry of Food, Agriculture, and Livestock. The number of animals coming to the province in 2012 and 2013 and the data on the number of veterinary clinics were obtained from the Directorate of Samsun Study Report (10,11). The number of veterinarians and animal health workers, feed dealers, animals susceptible to the disease, and size of the human population were obtained from official data, road map data, and data on the number of artificial inseminations and pastures (10,11).

2.2. Field situation analysis

Risk factors for the production process were as follows: the input infrastructure of the livestock production chain (feed mills and feed dealers), process infrastructure (slaughterhouses and processing plants, cold stores),

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production infrastructure (the species and the number of animals), focus products (milk and meat), scale of enterprise/business, and movement and marketing infrastructure. All animals susceptible to FMD in the districts of Samsun Province, namely cattle (pure breeds and cross breeds), buffalo, sheep, and goats, were included in the livestock count.

2.3. Statistical analyses

A progressive (hierarchical) clustering analysis method was used to evaluate the total risks and group the quantitative data that were obtained from each of the risk variables. The total risk scores were grouped by using the dendrogram method. Spearman correlation analysis was used to determine the strength of the relationship between the risk variables and total outbreak numbers. Furthermore, linear regression analysis was performed to specify the effect of the risk score on the total number of outbreaks. The NCSS 2009 (Version 9.0.5) software package was used for all statistical analyses (12).

By combining the risk factors for FMD with quantitative findings and location in the value chain, the equation for the risk of FMD was formulated as follows:

$(Y) = f(X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11})$.

In the formula, the variables are as follows:

- Y: Outbreak number
- X_1: Sensitive animal species ratio (heads/km^2)
- X_2: Rural human population ratio
- X_3: The number of feed dealers
- X_4: The number of veterinary clinics
- X_5: The number of veterinary health professionals
- X_6: Pasture area (hectares)
- X_7: The number of animals being transported (heads)
- X_8: The number of artificial inseminations (heads)
- X_9: Condition of roads
- X_{10}: The presence of animal market
- X_{11}: The presence of slaughterhouse

The total risks of FMD in Samsun Province were divided into risk groups that were calculated by taking into account the quantitative data for each risk variable. The United Kingdom Department for Environment, Food, and Rural Affairs (DEFRA) standards were used to determine the risk scores (13). Risk was defined by four categories: very low, low, medium, and high risk groups. According to the DEFRA system (13), the quantitative values of the risk scores are divided into 4 groups. In the present study, a progressive (hierarchical) clustering method employing median link aggregation and squared Euclidean distance was used. The districts of Samsun Province were clustered into four groups by using hierarchical clustering analysis. The clusters were defined as very low (risk score: 1), low (risk score: 2), moderate (risk score: 3), and high (risk score: 4) risk groups, depending on the mean values.

For the risk scores for the districts in Samsun Province, the same categories as above were determined and the total risk scores were calculated by summing the risk score for each risk variable.

In this study, the districts were grouped according to scaled distances, and the dendrogram method, which provides a graphic summary, was used to show the results of cluster analysis. In the dendrogram, the districts are on the vertical axis and the distance between clusters is on the horizontal axis. The horizontal lines indicate the distance and the vertical lines show the relationship of the clusters. The intersections of the clusters on the scale indicate which groups are included in the clusters, as well as the distance between these groups.

In addition, Spearman correlation coefficients were calculated to specify the association between the risk variables and the total outbreak numbers.

If the relationship between the total risk scores and the outbreak numbers is statistically significant, it can be mathematically modeled with a regression equation. In other words, it is possible to predict the number of outbreaks of FMD in the region by using the risk score. The effect of the total number of outbreaks on the risk scores was determined by using the linear regression model in Eq. (1).

$$y = \mu + \beta + \varepsilon \quad (1)$$

In this formula, 'y' is the total number of outbreaks, 'μ' is the model constant, 'β' is the total risk score, and 'ε' is the random error.

3. Results

In the present study, each risk variable was grouped as very low (risk score: 1), low (risk score: 2), moderate (risk score: 3), or high (risk score: 4), according to the average values of the clusters and the distributions, means of the clusters, and risk scores of the hierarchical cluster analysis of the risk variables (Table 1).

Secondly, the total risk scores of districts were calculated by summing the scores obtained for each of the risk variables. The risk scores of districts of Samsun Province, based on the risk variables, are provided in Table 2.

Furthermore, the 15 counties of Samsun Province were grouped by total risk scores in a dendrogram (Figure 1). In the dendrogram, five clusters were formed by combination of districts, depending on their total risk scores. Accordingly, Salıpazarı and Ayvacık were the districts that had the lowest risk scores, whereas Centrum, Çarşamba, and Bafra had the highest risk scores. As a result, Salıpazarı, Ayvacık, Yakakent, Kavak, and Asarcık were defined as the lowest risk districts and were grouped

Table 1. The average cluster and clustering results of risk variables associated with foot-and-mouth disease in Samsun Province, Turkey.

Risk variables	Variable code	Very low (risk score: 1)		Low (risk score: 2)		Medium (risk score: 3)		High (risk score: 4)	
		Cluster 1		Cluster 2		Cluster 3		Cluster 4	
		N	Mean ± SD	N	Mean ± SD	N	Mean ± SD	N	Mean ± SD
Sensitive animal species ratio (heads/km^2)	X_1	5	16.3 ± 3.9	7	29.4 ± 3.9	2	44.2 ± 2.7	1	75.2 ± 0.00
Rural population ratio	X_2	3	30.7 ± 7.6	7	52.4 ± 4.6	4	68.7 ± 4.9	1	87.0 ± 0.0
The number of feed dealers	X_3	4	6.0 ± 1.4	5	17.8 ± 4.9	4	34.5 ± 6,1	2	65 ± 4.2
The number of veterinary clinics	X_4	7	2.3 ± 0.9	3	5.3 ± 0.6	2	9.0 ± 0.0	3	18.0 ± 3.0
The number of veterinary health professionals	X_5	4	5.5 ± 1.0	8	10.9 ± 1.4	2	18.5 ± 0.7	1	27.0 ± 0.0
Pasture area (hectares)	X_6	9	2555 ± 2495	3	14,846 ± 1815	2	26,760 ± 4136	1	46,136 ± 0
The number of animals being transported (heads)	X_7	6	1008 ± 732	5	5035 ± 1039	2	9296 ± 753	2	12,076 ± 1046
The number of artificial inseminations (heads)	X_8	5	981 ± 678	4	2954 ± 205	5	4902 ± 1042	1	15,757 ± 0
Road conditions	X_9	1	Local roads	2	Interdistrict road	6	Interprovincial road	6	Interregional road
The presence of animal markets	X_{10}	6	No	9	Available				
The presence of slaughterhouses	X_{11}	3	No	12	Available				

Table 2. Risks scores by district for foot-and-mouth disease in Samsun Province, Turkey.

District	Risk variables												Total risk score
	Y	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	
Alaçam	14	2	3	2	2	2	1	1	3	3	2	2	23
Asarcık	9	3	4	1	1	1	1	1	2	2	2	1	19
Ayvacık	5	1	3	1	1	1	1	1	1	1	1	1	13
Bafra	43	2	1	3	4	3	4	2	4	3	2	2	30
Çarşamba	35	2	2	4	4	3	1	3	3	4	2	2	30
Havza	64	1	2	3	2	2	3	3	3	4	2	2	27
Kavak	40	1	2	1	1	2	1	2	2	4	2	2	20
Ladik	54	2	2	2	1	2	2	4	2	3	1	2	23
Ondokuzmayıs	10	4	2	2	1	2	1	2	1	3	2	2	22
Salıpazarı	7	1	3	2	1	1	1	1	1	1	1	2	15
Tekkeköy	5	3	1	2	2	2	1	1	3	4	1	2	22
Terme	28	2	2	3	3	3	1	2	1	4	2	2	25
Vezirköprü	30	1	3	3	3	1	2	2	3	3	2	2	25
Yakakent	1	2	2	1	1	4	1	1	1	3	1	1	18
Centrum	38	2	1	4	4	4	3	4	2	4	1	2	31

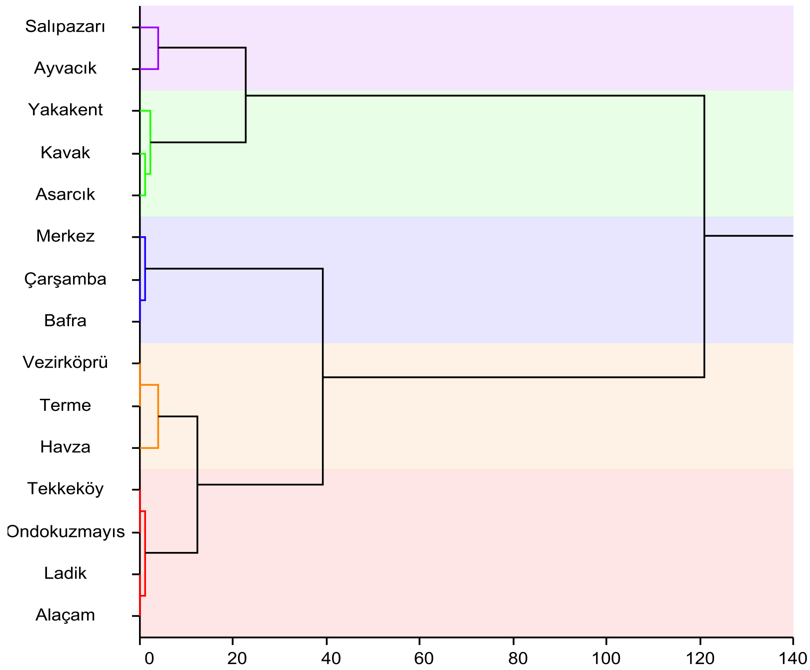

Figure 1. Dendrogram of the total risk scores for foot-and-mouth disease for the districts of Samsun Province, Turkey.

in a cluster with respect to their risk scores. In contrast, Alaçam, Bafra, Çarşamba, Havza, Lâdik, Ondokuzmayıs, Tekkeköy, Terme, Vezirköprü, and Centrum districts were grouped in a cluster and defined as high-risk districts (Figure 1).

The Spearman correlation coefficient for each variable was calculated in order to determine the strength of the association between the risk variables and the total number of outbreaks (Table 3). According to the Spearman correlation coefficients, there was a strong positive

Table 3. The relationship of the total number of outbreaks and risk variables for foot-and-mouth disease in Samsun Province, Turkey.

Risk variables	Variable code	Outbreak numbers
Sensitive animal species ratio (heads/km^2)	X_1	–0.25
Rural population ratio	X_2	–0.34
The number of feed dealers	X_3	0.55*
The number of veterinary clinics	X_4	0.42
The number of veterinary health professionals	X_5	0.23
Pasture area (hectares)	X_6	0.72**
The number of animals being transported (heads)	X_7	0.84**
The number of artificial inseminations (head)	X_8	0.51
Road conditions	X_9	0.46
The presence of animal markets	X_{10}	0.41
The presence of slaughterhouses	X_{11}	0.59*
Total risk	X_T	0.72**

* $P < 0.05$; ** $P < 0.01$.

correlation (72%) between the total risk scores, which included the score for each of the risk variables, and the number of outbreaks ($P < 0.01$).

Linear regression modeling was used to determine the effect of risk scores on the total number of outbreaks. The parameter estimation results of the linear regression model are provided in Table 4 and the regression curve is provided in Figure 2.

As an example, according to the regression model, if the risk score of a district is 25, the outbreak number is estimated to be 31 (outbreak number = −30.88 + 2.47 × 25 = 31) (Table 4).

4. Discussion

In Turkey, a history of relatively unsuccessful attempts to manage animal disease epidemics means that new strategic approaches are required. The value chain method is one possible approach and the first step is the risk analysis of livestock value chains (2). In the present study, a risk analysis for management of the epidemic disease FAM was performed in Samsun Province, Turkey. The total risk scores were calculated for different risk variables and the districts at high risk were determined. This determination provides opportunities for the implementation of higher protection and control measures in these high-risk districts. In addition, it is also beneficial to identify and analyze the stakeholders. The value of these analyses has been demonstrated in various scientific studies (14–16). Stakeholders from all sectors of the livestock industry must be included in the development and implementation of measures that reduce the risk of disease outbreak and spread.

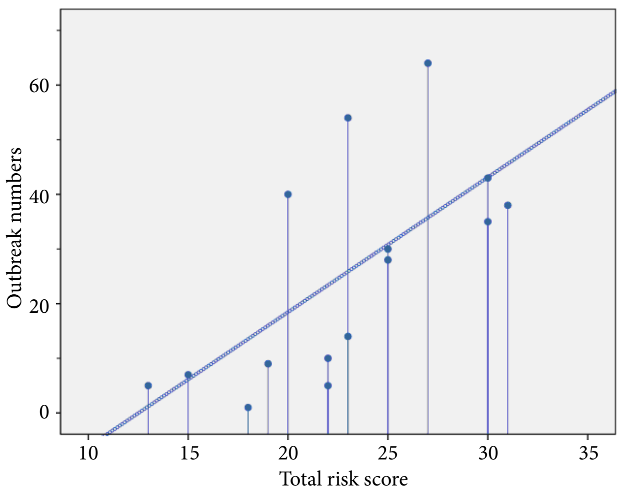

Figure 2. Linear regression model for the number of outbreaks and the total risk score for foot-and-mouth disease in Samsun Province, Turkey.

According to our results, FMD management needs to be improved and new approaches must be adopted quickly. In recent years, risk-based disease management models have been recommended and used in the animal health economy (2,17–19). According to these studies, the risks differed according to the type of disease, as well as human population density. The present study suggests that studies must initially be at the local and province scale when evaluating the different risk variables for different diseases. However, with additional resources available that approach can be extended to an integrated approach at the national level.

In our study, the relationship between the total number of outbreaks and risk variables was examined. It was determined that the correlation number increased in cases where animals were brought into the district (0.84). This finding supports the results of other studies that showed that the movement of animals facilitates the spread of epidemics (20,21). Therefore, the precise assessment of risks attached to animal movement should be performed as a priority for disease management.

In addition, factors such as geographical features of districts and the human and animal population had effects on the clusters of districts shown in the dendrogram created on the basis of total risk scores (Figure 1). For instance, the Bafra, Çarşamba, and Centrum districts have high populations, are located on the same coastline, and are at the highest level in the province of Samsun for animal numbers. Our study indicates that disease management plans should consider these risks.

In the present study, a model equation was developed and used to estimate FMD outbreak numbers by using estimated risk scores. The regional FMD outbreak numbers can be calculated with a regression equation by using the risk scores. In cases where the risk variables are known,

Table 4. Estimation of the number of outbreaks from the total risk score and the linear regression equation for foot-and-mouth disease in Samsun Province, Turkey.

Parameters	Coefficient	T value	P-value	CI (95%)
Model constant (μ)	−30.88	−1.72	0.109	−69.69; 7.93
Risk score (β)	2.47	3.22	0.007	0.81; 4.12
Coefficient of determination (R^2): 0.44				

this method can be used, particularly when there are not sufficient or reliable data on outbreak numbers.

In conclusion, FMD disease management was examined by using risk analysis and a methodology was developed for improving the management of disease outbreaks. The present study provides a mechanism for determining the high-risk districts for FMD. Moreover, it is possible to choose the appropriate stakeholders in these high-risk districts and prepare risk management plans accordingly. That process has the potential to reduce both the number and size of epidemics. More broadly, the same methodology has the potential to be applied to other epidemic diseases of livestock.

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