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Forecasting Measles in the European Union Using the Adaptive Neuro-Fuzzy Inference System

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BACKGROUND/AIMS
Measles is one of the diseases that cause child mortality. The measles forecasting is essential in planning the fight against the disease and reducing the risk of the vaccine stocks expiration. Governments and health institutions estimate the measles vaccine requirements using certain equations, which are generally based on the size of the target population and the past consumption records. There are several studies that have examined the measles forecasting and conducted a vaccine requirement assessment.

MATERIAL and METHODS
This study uses a forecasting model that employs an adaptive neuro-fuzzy inference system (ANFIS) based on clustering. In this study, the measles data were derived using the World Health Organization (WHO) Measles and Rubella Surveillance Data, which cover the period from January 2011 to March 2018 and include 28 European Union member countries. Out of total 87 monthly measles cases, 80% were used for training, and 20% were chosen for testing.

RESULTS
In addition to the mean square error, the root mean square error, normalized root mean square error, mean absolute error, and mean absolute percentage error were calculated.

CONCLUSION
The model created for this purpose has demonstrated that the predictions made for the data collected between January 2011 and March 2018 were successful.

Keywords: Measles, forecasting, European Union

INTRODUCTION

Measles is still one of the leading causes of child mortality. The measles forecasting is essential in planning the fight against the disease and reducing the risk of the vaccine stocks expiration.

Governments and health institutions estimate the measles vaccine requirements using certain equations, which are generally based on the size of the target population and the past consumption records. There are several studies that have examined the measles forecasting and conducted a vaccine requirement assessment using tools, such as the Statistical Analysis System (1), the World Health Organization (WHO) Measles Programmatic Risk Assessment Tool (2-7), Statistical Package for the Social Sciences (8), nonlinear forecasting and chaos (9), and Markov Chain Monte Carlo methods (10).

Measles cases in the European Union (EU)/European Economic Area principally occur in unvaccinated populations, affecting both adults and children (11). The European Centre for Disease Prevention and Control annual report shows that as many as 80% of teenagers and young adults who contracted measles in 2017 had not been vaccinated (11, 12).

MATERIAL and METHODS

According to the WHO Measles and Rubella Surveillance Data showing the distribution of measles cases by country and by month between January 2011 and March 2018 (Table 1), there were a total of 1,353,222 measles cases worldwide,

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TABLE 1. Part of the World Health Organization measles and rubella surveillance data distribution of measles cases by country and month, 2011–2018

				Month											
Region	**ISO3**	**Country**	**Year**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
EUR	AUT	Austria	2011	13	11	10	19	34	61	41	7	4	1	12	6
EUR	AUT	Austria	2012	6	8	5	2	3	4	2	2	1	2	0	0
EUR	AUT	Austria	2013	4	8	8	13	10	4	2	4	7	8	2	9
EUR	AUT	Austria	2014	32	13	6	4	12	16	4	0	0	4	11	17
EUR	AUT	Austria	2015	33	29	49	65	69	40	9	2	0	0	3	1
EUR	AUT	Austria	2016	0	0	0	2	1	2	9	1	5	3	1	4
EUR	AUT	Austria	2017	33	29	7	2	7	0	2	2	1	2	8	1
EUR	AUT	Austria	2018	7	6	0	0								
EUR	BEL	Belgium	2011	18	46	291	212	250	184	88	20	20	6	25	3

EUR: European Region; ISO3: International Standards Organization 3 - digit country code - AUT: ISO3 of Austria; BEL: ISO3 of Belgium

TABLE 2. Total monthly number of measles cases in the European Union between January 2011 and March 2018

	Month											
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2011	2407	3441	5860	6246	5770	3208	1873	919	752	567	911	927
2012	1439	1281	1422	1420	1352	1072	817	481	376	612	617	432
2013 435	651	793	905	1130	1365	1398	1394	704	656	662	447	
2014	1270	761	1027	641	388	245	185	142	104	104	147	303
2015	586	588	801	717	586	296	146	54	41	48	62	79
2016	117	181	237	276	326	364	377	412	377	588	761	635
2017	997	1739	2825	2525	2290	975	871	537	439	493	593	743
2018	1137	1305	63									

EUR: European Region; ISO3: International Standards Organization 3 - digit country code - AUT: ISO3 of Austria; BEL: ISO3 of Belgium

TABLE 3. Results

	Train	**Test**	**Overall**
MSE	79671.423	253835.159	114918.846
RMSE	282.261	503.821	338.997
NRMSE	0.045	40.908	18.520
MAE	196.618	352.406	228.146
MAPE	47.503	136.486	65.512

MSE: mean square error; RMSE: root mean square error; NRMSE: normalized root mean square error; MAE: mean absolute error; MAPE: mean absolute percentage error

as reported by the member countries (13). The WHO indicates that many cases are not reported. For the same period, a total of 86.246 measles cases (Table 2) were reported by the EU member states (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom).

This study uses a forecasting model in MATLAB (MathWorks Inc., USA) (14) that employs an adaptive neuro-fuzzy inference system (ANFIS) based on clustering that was applied to the EU measles cases. Fuzzy clustering is a data-clustering technique wherein each data point belongs for a cluster to some degree that is specified by a membership grade. ANFIS uses a hybrid learning algorithm to tune the parameters of a Sugeno-type fuzzy inference system. The algorithm uses a combination of the least-squares and back-propagation gradient descent methods to model a training dataset. ANFIS also validates the models using a checking dataset to test for overfitting of the training data.

Out of the total 87 monthly EU measles cases (Table 3), 67 (80%) were used for training, and 17 (20%) of them were chosen for testing. In this study, the mean square error (MSE), root mean square error (RMSE), normalized root mean square error (NRMSE), mean absolute error (MAE), and mean absolute percentage error (MAPE) were calculated using the following equations, which are the indexes of forecasting accuracy:

$$MSE = \frac{1}{N}\sum_{i=1}^{N}\left(Y_i - P_i\right)^2, \quad (1)$$

$$RMSE = \sqrt{\left(\frac{1}{N}\sum_{i=1}^{N}\left(Y_i - P_i\right)^2\right)}, \quad (2)$$

$$NRMSE = \frac{RMSE}{Y_{max} - Y_{min}}, \quad (3)$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|Y_i - P_i|, \quad (4)$$

$$MAPE = \left(\frac{1}{N}\sum_{i=1}^{N}\frac{|Y_i - P_i|}{Y_i}\right)\times 100\%, \quad (5)$$

where Y_i is an actual value, P_i is the forecasted value of the i-th data obtained, and N is the number of data. In our forecasting model, we assumed the relationship as

$$y(k) = F(y(k-3), y(k-2), y(k-1)), \quad (6)$$

where *y(k)* are the measles cases by *k*-th month, *y(k-1)* is the measles cases by *(k-1)*-th month, *y(k-2)* is the measles cases by *(k-2)*-th month, and *y(k-3)* is the measles cases by *(k-3)*-th month.

Since this study was based on merely a statistical dataset freely available online (13), we did not use any human materials. So, an ethic committee approval and informed consent were not necessary. This study was performed in accordance with the principles of the Declaration of Helsinki.

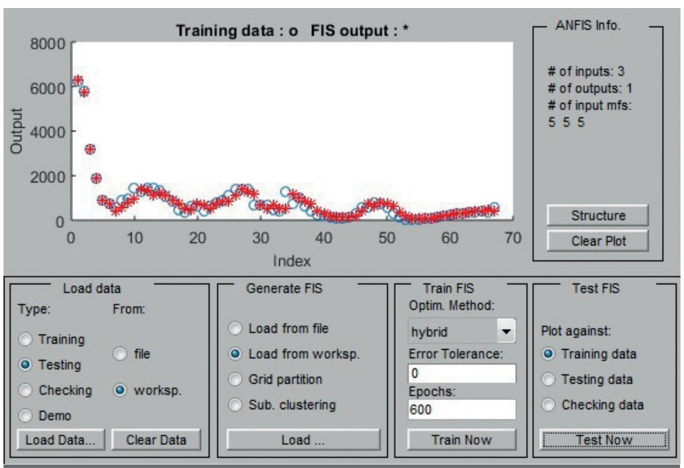

FIGURE 1. Adaptive neuro-fuzzy inference system training

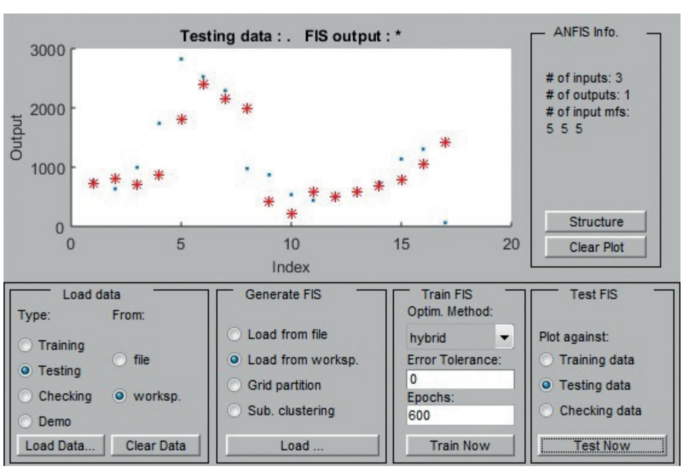

FIGURE 2. Adaptive neuro-fuzzy inference system Testing

RESULTS

The study was aimed at predicting the number of measles cases expected in the following month given the data for previous three months. The data cover all measles cases in the EU area between January 2011 and March 2018 by month. The data collected for March 2018 are not complete, but we included them because they were listed.

The client data were subjected to the subtractive clustering procedure using MATLAB. The algorithm was repeated for the cluster radii 0.1 through 0.9, while keeping the accept ratio, reject ratio, and squash factor constant at 0.5, 0.15, and 1.25, respectively. The training and testing of the FIS with the radius 0.2 at 600 epochs resulted in the lowest training error of 282.261 and testing error of 503.821. The ANFIS graphical outputs show the training points in Figure 1 and testing points in Figure 2.

The input membership functions obtained from the subtractive clustering using MATLAB are of the Gaussian type. Each input space shown in Figure 3 generalizes the input data submitted to the ANFIS training.

The model is constructed with five clusters, hence five rules as shown in Figure 4. The model structure has three inputs, each made of five Gaussian membership functions. The five rules determined as a result of the training of the network. The first order Sugeno-type reasoning was conducted on the forth layer where the firing strengths were obtained.

The crisp output was received on the 6th layer after the aggregation process. Figure 5 shows the crisp input data and the crisp

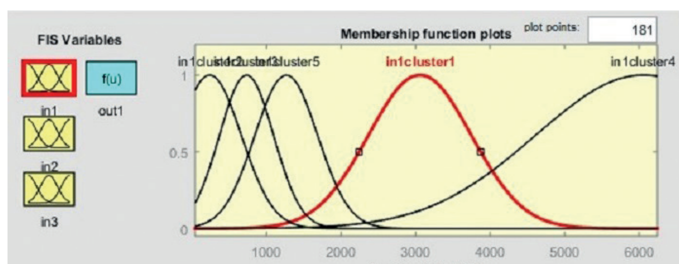

FIGURE 3. Membership Functions

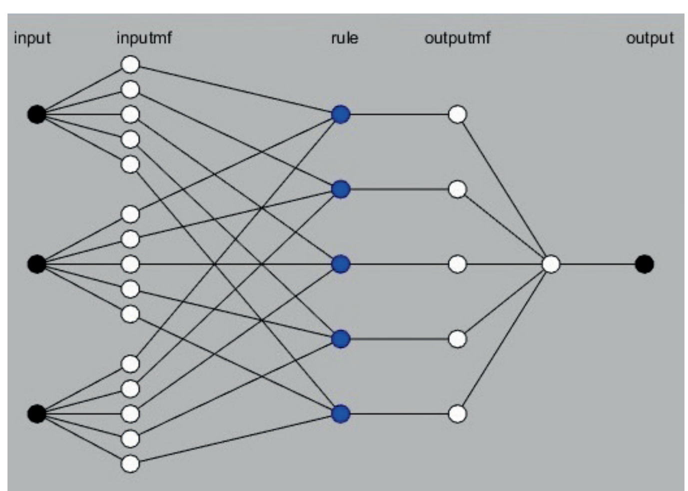

FIGURE 4. Adaptive neuro-fuzzy inference system Model

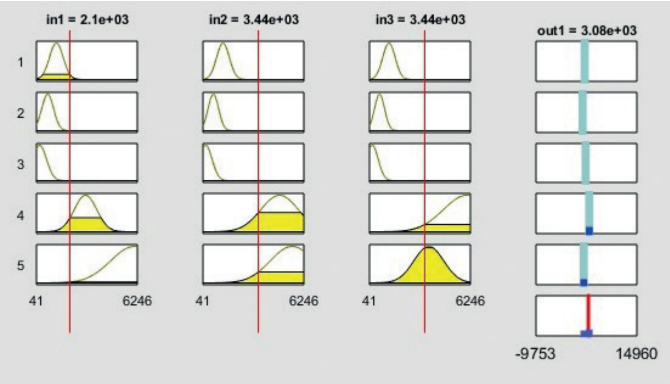

FIGURE 5. Fuzzy Rules

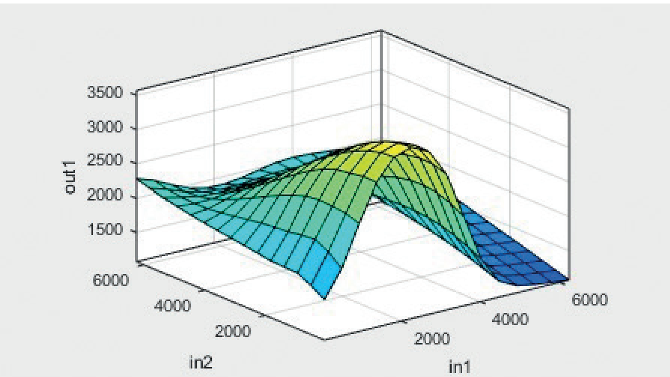

FIGURE 6. Surface

output of the number of expected measles cases for the following month.

The surface plot is a three-dimensional graphics tool in MATLAB that shows the shape of the FIS with three-dimensional plots at a time. A particular instance of the three consecutive months is shown in Figure 6. A general idea can be obtained from the surface plot by observing the shape of the relationship between the given parameters.

DISCUSSION

Measles cases are considered to be epidemiologically linked, confirmed by laboratory findings and clinical cases as reported to the WHO. Some countries report measles cases at irregular intervals, providing multiple months of data in a single month period, and missing future months are reported as no cases; hence, they are expected to be updated as data becomes available (11).

In this study, a forecasting model was created using ANFIS to predict the number of future measles cases in the EU area. Such a work was particularly required to control the vaccine stocks and organize an effective distribution through the member countries. The model created for this purpose demonstrated that the predictions made for the data collected between January 2011 and March 2018 were successful.

Ethics Committee Approval: The authors declared that the research was conducted according to the principles of the World Medical Association Declaration of Helsinki "Ethical Principles for Medical Research Involving Human Subjects" (amended in October 2013).

Informed Consent: N/A.

Peer-review: Externally peer-reviewed.

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Conflict of Interest: The authors have no conflicts of interest to declare.

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