Forecasting of the wind speed under uncertainty

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In this paper, the semi-average method under neutrosophic statistics is introduced. The trend regression line for the semi-average method is given in the presence of Neutrosophy in the data. The application of the semi-average method under indeterminacy is given with the help of wind speed data. The efficiency of the semi-average method under the neutrosophic statistics is discussed over the semi-average method under classical statistics. From statistical analysis, it is concluded that the proposed method is effective, informative, and flexible for the forecasting of wind speed.

In business situations, the experimenters are interested to estimate the nature’s estimated sales, prices of the commodity, and energy produced through winds. This estimation is done on the basis of information on past data. Data that is collected in accordance with the time is known as the time-series data. For example, the minimum and maximum values of wind speed recorded on a daily basis. There are four popular methods to measure the secular trends in the time series data. The method of semi-averages is very popular due to its simplicity, easy to apply, relatively objective, and easy to understand as compared to the method of least square and method of moving averages. In this method, a time series data is divided into two halves. The average of each half is computed and a coded variable is generated corresponding to each average. A regression line is used to forecast the values for the future. Discussed are applications of time series in organizational research presented methods of the time series analysis. Applied the time series method in geography. Worked on the time series method using the local Wilcoxon statistic.

The statistical methods have been widely for estimation and forecasting of energy through wind. Applied the statistical analysis on the wind speed data. Worked on the distribution for the wind speed. Worked on the estimation of wind speed using the time series method. Introduced various distribution to model the wind speed. The estimation of parameters of wind data was studied. The application of statistical analysis can be seen in. Most applications of statistical methods in the field of energy can be seen in.

The existing statistical methods are applied for the estimation of wind energy when the parameters or the data is determined or exact. In practice, usually, the wind speed data is recorded in the interval; therefore, the existing methods under classical statistics (CS) cannot be used for estimation and forecasting of wind speed data. In this paper, the methods using the fuzzy logic are applied for estimation and forecasting of the energy.

Introduced time series methods using fuzzy logic. Introduced an analysis method using the fuzzy logic. Presented a detailed review of time-series application in deep learning also discussed the applications of the neutrosophic logic. The neutrosophic logic is more informative than the fuzzy logic. The neutrosophic logic which is a generalization of fuzzy logic gives information about the measure of indeterminacy. Provided several applications of the neutrosophic logic in the various fields. Proved the efficiency of neutrosophic statistical analysis over CS. The neutrosophic statistics (NS) reduces to CS when no uncertainty is found in the data. Some statistical tests using NS was introduced.

Although a rich literature is available on time series methods under CS. According to the best of our knowledge, no work on semi-average method under neutrosophic statistics is developed. To fill this gap, in this paper, we will present the semi-average method in the presence of indeterminacy in the data. The application of the proposed method will be given using wind speed data. The necessary measures to estimate/forecast the wind speed will be introduced. It is expected that the proposed method will be quite effective to forecast the wind speed. The proposed method will help the energy experts to estimate the energy on the basis of energy when neutrosophic numbers are present in the data.

Preliminaries
Suppose that $Y_{iN} = Y_{iL} + Y_{iU} I_{iN}$; $Y_{2N} = Y_{2L} + Y_{2U} I_{2N}$; $Y_{N} = Y_{N} + Y_{U} I_{N}$; $I_{N} = I_{NL, U}$ be a neutrosophic time series random variable of size $n_{c} = n_{L, U}$; the measure of indeterminacy $I_{N} = I_{NL, U}$. The values $Y_{iL}, Y_{2L}, ..., Y_{NL}$ represents the time series values under CS. Let...
\[ X_{1N} = X_{1L} + X_{1U}I_N; \quad I_N \in [I_{1L}, I_{1U}] \] \[ X_{2N} = X_{2L} + X_{2U}I_N; \quad I_N \in [I_{2L}, I_{2U}] \] are the codes values corresponding to neutrosophic averages of the first and second halves. The neutrosophic average for the first half is computed as.

**Step-1:** Compute the means of lower values of the first half of time-series data

**Step-2:** Compute the means of upper values of the first half of time-series data

**Step-3:** The neutrosophic averages for the first and second are given by

\[ \bar{Y}_{1N} = \frac{1}{n_{1N}} \sum_{i=1}^{n_{1N}} Y_i \]

\[ \bar{Y}_{2N} = \frac{1}{n_{2N}} \sum_{i=1}^{n_{2N}} Y_i \]

**Semi-average method under indeterminacy**

In the method of semi-average under indeterminacy, the time series data having neutrosophic numbers is divided into two equal or nearly equal halves. The neutrosophic average of each half is computed and placed them at the center of time spans. Suppose that \( \bar{Y}_{1N} \in [\bar{Y}_{1L}, \bar{Y}_{1U}] \) and \( \bar{Y}_{2N} \in [\bar{Y}_{2L}, \bar{Y}_{2U}] \) be the neutrosophic averages of the first and the second half, respectively. Suppose also that \( X_{1N} \) and \( X_{2N} \) are the coded values corresponding to the first and second half, respectively. The neutrosophic trends values using this method can be obtained as follows

\[ \left( \hat{Y}_N - (\bar{Y}_{1L} + \bar{Y}_{1U}I_N) \right) = \left( \frac{\left(\bar{Y}_{2L} + \bar{Y}_{2U}I_N\right) - \left(\bar{Y}_{1L} + \bar{Y}_{1U}I_N\right)}{X_{2N} - X_{1N}} \right)(X_N - X_{1N}); \quad \hat{Y}_N \left[ \hat{Y}_L, \hat{Y}_U \right] \]

where \( \hat{Y}_N \) and \( \hat{Y}_{2N} \) are the neutrosophic averages of the first and the second halves.

**Note here that Eq. (1) is used to estimate the following regression line under indeterminacy**

\[ \hat{Y}_N = a_N + b_NX_N; \quad \hat{Y}_N \left[ \hat{Y}_L, \hat{Y}_U \right] \]
where \( a_N[a_L, a_U] \) is neutrosophic intercept which can be calculated as follows

\[
a_N = (\overline{Y}_L + \overline{Y}_U) \overline{X}_N - b_N X_N; a_N[a_L, a_U], b_N[b_L, b_U], I_N[I_L, I_U]
\]

where \( b_N[b_L, b_U] \) is the rate of change per unit in the presence of indeterminacy and computed as follows

\[
b_N = \left( \frac{(\overline{Y}_L + \overline{Y}_U) I_N - (\overline{Y}_L + \overline{Y}_U) I_N}{X_N - X_N} \right); b_N[b_L, b_U]
\]

### Application using wind speed data

The application of the proposed semi-average method under indeterminacy is given using real wind speed data. The data of the year 2020 is collected from the Pakistan Meteorology department. The last available data of the first three months have been used to explain the proposed method. The wind speed (mph) data having the minimum value and the maximum value is taken. The energy expert is interested to forecast the wind speed on the basis of the given data. As the wind speed (mph) data is recorded in the interval, therefore, the use of the existing semi-average method under CS is not suitable. The proposed semi-average method under indeterminacy is suitable to apply for such wind speed data. The necessary calculations for the wind speed data of month January, February, and March 2020 using the proposed method are explained.

| January | Wind speed (mph) | Trend values | Neutrosophic form | Indeterminacy |
|---------|------------------|--------------|-------------------|--------------|
| 1       | 0 6 0           | 5.85         | \( Y_N = 0 + 5.85 I_N \) | \( I_N [0, 1] \) |
| 2       | 0 7 0           | 6.28         | \( Y_N = 0 + 6.28 I_N \) | \( I_N [0, 1] \) |
| 3       | 0 6 0           | 6.71         | \( Y_N = 0 + 6.71 I_N \) | \( I_N [0, 1] \) |
| 4       | 0 3 0           | 7.14         | \( Y_N = 0 + 7.14 I_N \) | \( I_N [0, 1] \) |
| 5       | 0 7 0           | 7.57         | \( Y_N = 0 + 7.57 I_N \) | \( I_N [0, 1] \) |
| 6       | 0 12 0          | 8            | \( Y_N = 0 + 8 I_N \) | \( I_N [0, 1] \) |
| 7       | 0 7 0           | 8.43         | \( Y_N = 0 + 8.43 I_N \) | \( I_N [0, 1] \) |
| 8       | 0 7 0           | 8.86         | \( Y_N = 0 + 8.86 I_N \) | \( I_N [0, 1] \) |
| 9       | 0 8 0           | 9.29         | \( Y_N = 0 + 9.29 I_N \) | \( I_N [0, 1] \) |
| 10      | 0 12 0          | 9.72         | \( Y_N = 0 + 9.72 I_N \) | \( I_N [0, 1] \) |
| 11      | 0 9 0           | 10.15        | \( Y_N = 0 + 10.15 I_N \) | \( I_N [0, 1] \) |
| 12      | 0 14 0          | 10.58        | \( Y_N = 0 + 10.58 I_N \) | \( I_N [0, 1] \) |
| 13      | 0 21 0          | 11.01        | \( Y_N = 0 + 11.01 I_N \) | \( I_N [0, 1] \) |
| 14      | 0 8 0           | 11.44        | \( Y_N = 0 + 11.44 I_N \) | \( I_N [0, 1] \) |
| 15      | 0 6 0           | 11.87        | \( Y_N = 0 + 11.87 I_N \) | \( I_N [0, 1] \) |
| 16      | 0 9 0           | 12.3         | \( Y_N = 0 + 12.3 I_N \) | \( I_N [0, 1] \) |
| 17      | 0 5 0           | 12.73        | \( Y_N = 0 + 12.73 I_N \) | \( I_N [0, 1] \) |
| 18      | 0 6 0           | 13.16        | \( Y_N = 0 + 5.85 I_N \) | \( I_N [0, 1] \) |
| 19      | 0 10 0          | 13.59        | \( Y_N = 0 + 13.16 I_N \) | \( I_N [0, 1] \) |
| 20      | 0 9 0           | 14.02        | \( Y_N = 0 + 14.02 I_N \) | \( I_N [0, 1] \) |
| 21      | 0 10 0          | 14.45        | \( Y_N = 0 + 14.45 I_N \) | \( I_N [0, 1] \) |
| 22      | 0 100 0         | 14.88        | \( Y_N = 0 + 14.88 I_N \) | \( I_N [0, 1] \) |
| 23      | 0 15 0          | 15.31        | \( Y_N = 0 + 15.31 I_N \) | \( I_N [0, 1] \) |
| 24      | 0 12 0          | 15.74        | \( Y_N = 0 + 15.74 I_N \) | \( I_N [0, 1] \) |
| 25      | 0 9 0           | 16.17        | \( Y_N = 0 + 16.17 I_N \) | \( I_N [0, 1] \) |
| 26      | 0 12 0          | 16.6         | \( Y_N = 0 + 16.6 I_N \) | \( I_N [0, 1] \) |
| 27      | 0 10 0          | 17.3         | \( Y_N = 0 + 17.3 I_N \) | \( I_N [0, 1] \) |
| 28      | 0 0             | 17.46        | \( Y_N = 0 + 17.46 I_N \) | \( I_N [0, 1] \) |
| 29      | 0 0             | 17.89        | \( Y_N = 0 + 17.89 I_N \) | \( I_N [0, 1] \) |
| 30      | 0 0             | 18.32        | \( Y_N = 0 + 18.32 I_N \) | \( I_N [0, 1] \) |
| 31      | 0 0             | 18.75        | \( Y_N = 0 + 18.75 I_N \) | \( I_N [0, 1] \) |
Table 2. Neutrosophic form of wind speed in February.

| February | Wind speed (mph) | Trend values | Neutrosophic form | Indeterminacy |
|----------|------------------|--------------|------------------|---------------|
|    1     | 0.0028           | 9.24         | $\tilde{Y}_N = 0.0028 + 9.24I_N$ | $I_N [0, 1]$ |
|    2     | 0.0228           | 9.43         | $\tilde{Y}_N = 0.0228 + 9.43I_N$ | $I_N [0, 1]$ |
|    3     | 0.0428           | 9.62         | $\tilde{Y}_N = 0.0428 + 9.62I_N$ | $I_N [0, 1]$ |
|    4     | 0.0628           | 9.81         | $\tilde{Y}_N = 0.0628 + 9.81I_N$ | $I_N [0, 0.99]$ |
|    5     | 0.0828           | 10           | $\tilde{Y}_N = 0.0828 + 10I_N$ | $I_N [0, 0.99]$ |
|    6     | 0.1028           | 10.19        | $\tilde{Y}_N = 0.1028 + 10.19I_N$ | $I_N [0, 0.99]$ |
|    7     | 0.1228           | 10.38        | $\tilde{Y}_N = 0.1228 + 10.38I_N$ | $I_N [0, 0.99]$ |
|    8     | 0.1428           | 10.57        | $\tilde{Y}_N = 0.1428 + 10.57I_N$ | $I_N [0, 0.99]$ |
|    9     | 0.1628           | 10.76        | $\tilde{Y}_N = 0.1628 + 10.76I_N$ | $I_N [0, 0.98]$ |
|   10     | 0.1828           | 10.95        | $\tilde{Y}_N = 0.1828 + 10.95I_N$ | $I_N [0, 0.98]$ |
|   11     | 0.2028           | 11.14        | $\tilde{Y}_N = 0.2028 + 11.14I_N$ | $I_N [0, 0.98]$ |
|   12     | 0.2228           | 11.33        | $\tilde{Y}_N = 0.2228 + 11.33I_N$ | $I_N [0, 0.98]$ |
|   13     | 0.2428           | 11.52        | $\tilde{Y}_N = 0.2428 + 11.52I_N$ | $I_N [0, 0.98]$ |
|   14     | 0.2628           | 11.71        | $\tilde{Y}_N = 0.2628 + 11.71I_N$ | $I_N [0, 0.98]$ |
|   15     | 0.2828           | 11.9         | $\tilde{Y}_N = 0.2828 + 11.9I_N$ | $I_N [0, 0.98]$ |
|   16     | 0.3028           | 12.09        | $\tilde{Y}_N = 0.3028 + 12.09I_N$ | $I_N [0, 0.97]$ |
|   17     | 0.3228           | 12.28        | $\tilde{Y}_N = 0.3228 + 12.28I_N$ | $I_N [0, 0.97]$ |
|   18     | 0.3428           | 12.47        | $\tilde{Y}_N = 0.3428 + 12.47I_N$ | $I_N [0, 0.97]$ |
|   19     | 0.3628           | 12.66        | $\tilde{Y}_N = 0.3628 + 12.66I_N$ | $I_N [0, 0.97]$ |
|   20     | 0.3828           | 12.85        | $\tilde{Y}_N = 0.3828 + 12.85I_N$ | $I_N [0, 0.97]$ |
|   21     | 0.4028           | 13.04        | $\tilde{Y}_N = 0.4028 + 13.04I_N$ | $I_N [0, 0.97]$ |
|   22     | 0.4228           | 13.23        | $\tilde{Y}_N = 0.4228 + 13.23I_N$ | $I_N [0, 0.97]$ |
|   23     | 0.4428           | 13.42        | $\tilde{Y}_N = 0.4428 + 13.42I_N$ | $I_N [0, 0.97]$ |
|   24     | 0.4628           | 13.61        | $\tilde{Y}_N = 0.4628 + 13.61I_N$ | $I_N [0, 0.97]$ |
|   25     | 0.4828           | 13.81        | $\tilde{Y}_N = 0.4828 + 13.81I_N$ | $I_N [0, 0.97]$ |
|   26     | 0.5028           | 13.99        | $\tilde{Y}_N = 0.5028 + 13.99I_N$ | $I_N [0, 0.96]$ |
|   27     | 0.5228           | 14.18        | $\tilde{Y}_N = 0.5228 + 14.18I_N$ | $I_N [0, 0.96]$ |
|   28     | 0.5428           | 14.37        | $\tilde{Y}_N = 0.5428 + 14.37I_N$ | $I_N [0, 0.96]$ |
|   29     | 0.5628           | 14.56        | $\tilde{Y}_N = 0.5628 + 14.56I_N$ | $I_N [0, 0.96]$ |

The fitted neutrosophic regression equation for January 2020 is given by

$$\tilde{Y}_N = [0.87, 1.53] + [0.04, 0.43]X_N$$

The fitted neutrosophic regression equation for February 2020 is given by

$$\tilde{Y}_N = [0.1428, 10.57] + [0.02, 0.19]X_N$$

The fitted neutrosophic regression equation for March 2020 is given by

$$\tilde{Y}_N = [1.4, 15.33] + [0.87, -0.29]X_N$$

The actual wind speed (mph) and the trended values for January, February, and March 2020 are plotted and shown in Fig. 1. The left figure shows the values of the trend of January, the middle figure shows the values of February month and the right figure shows the trended values of March. From Fig. 1, it can be noted that there is a big gap between the actual wind speed data and the fitted data. The larger width of the indeterminacy interval clear affects the forecasting of the wind speed. In the month of January, only three trended points are near the line of actual values. The middle figure shows that still, several points are above the line of actual values. In the month of March, there is an irregular trend in wind speed. From Fig. 1, we also note that for the month of January, several plotted points are close to the trend line. Therefore, the trend line for this month can be used to forecast the wind speed. From Fig. 1, it can be noted that the presence of Neutrosophy in the wind speed data can affect the forecasting analysis of the wind speed. The proposed method has some limitations that it can be...
applied for the forecasting of the wind speed only when the data has Neutrosophy. The proposed method can be applied for a variety of fields where the forecasting is needed using the data under indeterminate environment.

### Competitive study based on wind speed data

As discussed earlier, the proposed semi-average method under indeterminacy is the generalization of the existing semi-average method under CS. The proposed method reduces to existing method when \( I_L = 0 \). We will compare both methods in terms of trended values for the three months of the year 2020. The neutrosophic form of trended values and measure of indeterminacy of January 2020 is given in Table 1. The neutrosophic form of trended values and measure of indeterminacy of February 2020 is given in Table 2. The neutrosophic form of trended values and measure of indeterminacy of March 2020 is given in Table 3. From Table 1, it is quite clear that the measure of indeterminacy is 1. Further, the determined part of the neutrosophic form is 0. It means that the presence of a high measure of indeterminacy will affect the forecasting of wind energy. From Table 2, it can be seen that the indeterminacy measure for the first three days is around 1. For the last four days, this measure is 0.96. For example, for day seven, the neutrosophic form of trended value is \( \hat{Y}_N = 0.1228 + 10.38I_N; I_N \in [0.99] \). The trended value 0.1228 presents the value under CS. From this neutrosophic form, it can be seen that for seven days, the forecasting value of wind energy will be from 0.1228 to 10.38. We note a big gap between these values, the gap between these values is based on the difference between the lower and upper values of wind speed. The gap may be narrow if lower and upper values of wind speed are close. From this study, it can be noted that the

| March | Wind speed (mph) | Trended values | Neutrosophic form | Indeterminacy |
|-------|------------------|----------------|-------------------|--------------|
|       | \( Y_L \) | \( Y_C \) | \( \hat{Y}_L \) | \( \hat{Y}_C \) | \( Y_N = 0 + 17.36I_N \) | \( I_N \in [0, 1] \) |
| 1     | 0               | 12             | 0                 | 17.36        | \( Y_N = 0 + 17.36I_N \) | \( I_N \in [0, 1] \) |
| 2     | 0               | 6              | 0                 | 17.07        | \( Y_N = 0 + 17.07I_N \) | \( I_N \in [0, 1] \) |
| 3     | 0               | 6              | 0                 | 16.78        | \( Y_N = 0 + 16.78I_N \) | \( I_N \in [0, 1] \) |
| 4     | 0               | 12             | 0                 | 16.49        | \( Y_N = 0 + 16.49I_N \) | \( I_N \in [0, 1] \) |
| 5     | 3               | 25             | 0                 | 16.2         | \( Y_N = 0 + 16.2I_N \) | \( I_N \in [0, 1] \) |
| 6     | 2               | 25             | 0                 | 15.91        | \( Y_N = 0 + 15.91I_N \) | \( I_N \in [0, 1] \) |
| 7     | 0               | 13             | 0.53              | 15.62        | \( Y_N = 0.53 + 15.62I_N \) | \( I_N \in [0.09, 0.97] \) |
| 8     | 0               | 10             | 1.4               | 15.33        | \( Y_N = 1.4 + 15.33I_N \) | \( I_N \in [0.09, 0.91] \) |
| 9     | 5               | 15             | 2.27              | 15.04        | \( Y_N = 2.27 + 15.04I_N \) | \( I_N \in [0.08, 0.85] \) |
| 10    | 0               | 12             | 3.14              | 14.75        | \( Y_N = 3.14 + 14.75I_N \) | \( I_N \in [0.07, 0.79] \) |
| 11    | 0               | 13             | 4.01              | 14.46        | \( Y_N = 4.01 + 14.46I_N \) | \( I_N \in [0.07, 0.72] \) |
| 12    | 3               | 37             | 4.88              | 14.17        | \( Y_N = 4.88 + 14.17I_N \) | \( I_N \in [0.06, 0.66] \) |
| 13    | 5               | 23             | 5.75              | 13.88        | \( Y_N = 5.75 + 13.88I_N \) | \( I_N \in [0.05, 0.59] \) |
| 14    | 3               | 14             | 6.62              | 13.59        | \( Y_N = 6.62 + 13.59I_N \) | \( I_N \in [0.05, 0.51] \) |
| 15    | 0               | 7              | 7.49              | 13.3         | \( Y_N = 7.49 + 13.3I_N \) | \( I_N \in [0.04, 0.44] \) |
| 16    | 0               | 12             | 8.36              | 13.01        | \( Y_N = 8.36 + 13.01I_N \) | \( I_N \in [0.03, 0.35] \) |
| 17    | 0               | 7              | 9.23              | 12.72        | \( Y_N = 9.23 + 12.72I_N \) | \( I_N \in [0.02, 0.21] \) |
| 18    | 0               | 9              | 10.1              | 12.43        | \( Y_N = 10.1 + 12.43I_N \) | \( I_N \in [0.01, 0.19] \) |
| 19    | 0               | 8              | 10.97             | 12.14        | \( Y_N = 10.97 + 12.14I_N \) | \( I_N \in [0, 0.01] \) |
| 20    | 0               | 7              | 11.84             | 11.85        | \( Y_N = 11.84 + 11.85I_N \) | \( I_N \in [0, 0.001] \) |
| 21    | 0               | 16             | 12.71             | 11.56        | \( Y_N = 12.71 + 11.56I_N \) | \( I_N \in [0, 0.09] \) |
| 22    | 0               | 8              | 13.58             | 11.27        | \( Y_N = 13.58 + 11.27I_N \) | \( I_N \in [0, 0.17] \) |
| 23    | 0               | 6              | 14.45             | 10.98        | \( Y_N = 14.45 + 10.98I_N \) | \( I_N \in [0, 0.24] \) |
| 24    | 0               | 7              | 15.32             | 10.69        | \( Y_N = 15.32 + 10.69I_N \) | \( I_N \in [0, 0.30] \) |
| 25    | 0               | 21             | 16.19             | 10.4I         | \( Y_N = 16.19 + 10.4I_N \) | \( I_N \in [0, 0.36] \) |
| 26    | 0               | 12             | 17.06             | 10.11        | \( Y_N = 17.06 + 10.11I_N \) | \( I_N \in [0, 0.41] \) |
| 27    | 0               | 17             | 17.93             | 9.82I         | \( Y_N = 17.93 + 9.82I_N \) | \( I_N \in [0, 0.45] \) |
| 28    | 3               | 1              | 18.8I             | 9.53I         | \( Y_N = 18.8 + 9.53I_N \) | \( I_N \in [0, 0.49] \) |
| 29    | 3               | 19.67           | 9.24I             | 19.67        | \( Y_N = 19.67 + 9.24I_N \) | \( I_N \in [0, 0.53] \) |
| 30    | 0               | 12             | 8.95              | 20.54        | \( Y_N = 20.54 + 8.95I_N \) | \( I_N \in [0, 0.56] \) |
| 31    | 4               | 21.4I           | 8.66I             | 21.41        | \( Y_N = 21.41 + 8.66I_N \) | \( I_N \in [0, 0.60] \) |

Table 3. Neutrosophic form of wind speed in March.
Conclusions
The semi-average method under neutrosophic was introduced in this paper. The proposed semi-average method is the extension of the semi-average method under classical statistics. The trend line under the indeterminacy was the extension of the semi-average method under classical statistics. The proposed semi-average method provides the forecasting values in an interval. In addition, the proposed method gives information about the measure of indeterminacy. In an uncertain environment, the use of the existing method under CS will mislead the energy experts. The use of the proposed method to forecast the wind speed in the presence of indeterminacy is quite suitable and effective.

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**Author contributions**

Design and conduct of the study (M.A.); collection of data (M.A); management, analysis, and interpretation of data (M.A.).

**Competing interests**

The author declares no competing interests.

**Additional information**

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