**Methods:**

To determine the trend of rabies cases, two time-series forecasting models were used: the auto-regressive integrated moving average (ARIMA) and the auto-regressive integrated moving average with explanatory factors (ARIMAX).

As the primary outcome variable for rabies cases is influenced by reported cases in the near past, we chose the ARIMA model (time-series events). The ARIMA model is a data-focused, exploratory technique that enables the user to construct an appropriate model based on the data's actual structure. This model attempts to extract regional trends while filtering out high-frequency noise from the data and assumes a linear correlation between the time series values (1). By updating the model to forecast the system's future state based on current occurrences, ARIMA models have the advantage of being able to adapt to dynamically oriented systems that change over time. The R package "forecast" was used to run the ARIMA model for this study (2).

Numerous researchers have recently used time series to study the trend of rabies (including additive models (3), (4), autoregressive time series models (5), and wavelet time series models (6)), but most of them use the ARIMA model with one-time series because it is a useful method for analyzing time series with one-time series in systems (7) (8) (9) (10) (11). However, as ARIMA only considers one variable, it was unable to provide light on the connections between system variables. To extract nearby designs while reducing high-frequency turbulence, ARIMA models accept a direct relationship between the time-series values and seek to leverage these straight circumstances in perceptions. More than one variable is always used to define the ARIMAX model. The ARIMA model with a single time series cannot capture the changing rules of the multivariate time series. Consequently, it is essential to develop a model using the multivariate ARIMAX model (12, 13). Mass Dog Vaccination (MDV) and Anti Rabies vaccination (ARV) were considered explanatory variables in the ARIMAX model.

We predicted trends for the upcoming nine years (up to 2032) using both time series models with the data on rabies cases and showed them in the figure. R version 3.5.2.2, a statistical software, was used for all studies.

**Empirical evaluation**

To assess the relevance of the predictions, we analyzed and compared the performance of the time series models using some of the generally used measures, including coefficient of determination (R2), root mean square error (RMSE), and mean absolute error (MAE).

**Results**

Table 1: The summary of the Auto-Regressive Integrated Moving Average (ARIMA) and Auto-Regressive Integrated Moving Average with explanatory variable (ARIMAX) model.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **RMSE** | **MAE** | **R2** |
| **ARIMA (1,2,1)** | 14.89 | 12.50 | 86.75% |
| **ARIMAX (1,2,1)** | 14.87 | 12.31 | 86.87% |
| **ARIMAX (1,2,1) with a 50% increase in MDV** | 15.08 | 12.58 | 71.75% |

With R2, RMSE, and MAE values of 86.75%, 86.87%, 71.75%, and 14.89, 14.87, and 15.08, and 12.50, 12.31, and 12.58, respectively, we found a continuous trend between observed and predicted rabies cases in three models (Table 1). In terms of accuracy, the ARIMA model performed better than the ARIMAX model (with better R2, RMSE, and MAE values). In comparison to the ARIMAX model with sensitivity, the ARIMAX model without sensitivity has a greater coefficient of determination and fewer errors. However, all these three models indicate a considerable decrease in rabies cases during the following ten years. Figure 1 displays the predicted rabies cases for each model.

**Table 2: A forecasting of annual rabies cases in Bangladesh for the period of 2022-2032 using ARIMA and ARIMAX models.**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **ARIMA (1,2,1)** | **ARIMAX (1,2,1)** | **ARIMAX with a 50% increase of MDV** |
| Year | **Point forecast (95% CI)** | **Point forecast (95% CI)** | **Point forecast (95% CI)** |
| 2023 | 36 (3 to 73) | 31 (-3 to 72) | 32 (-9 to 74) |
| 2024 | 31 (-9 to 80) | 32 (-15 to 90) | 32 (-25 to 91) |
| 2025 | 26 (-25 to 86) | 37 (-26 to 112) | 36 (-38 to 111) |
| 2026 | 21 (-40 to 91) | 33 (-46 to 125) | 31 (-59 to 123) |
| 2027 | 16 (-56 to 96) | 26 (-70 to 136) | 24 (-83 to 132) |
| 2028 | 11 (-72 to 101) | 26 (-87 to 155) | 24 (-100 to 149) |
| 2029 | 6 (-88 to 105) | 21 (-112 to 169) | 18 (-124 to 160) |
| **2030** | **2 (-104 to 110)** | **8 (-149 to 172)** | **2 (-158 to 162)** |
| 2031 | 0 (-120 to 114) | 3 (-177 to 186) | 0 (-183 to 174) |
| 2032 | 0 (-136 to 118) | 0 (-206 to 202) | 0 (-208 to 187) |

The forecasting found that if the declining trend of rabies cases continues, Bangladesh would obtain 2, and 8 cases in the year 2030, according to ARIMA and ARIMAX models. However, if we increased MDV about to 50%, we would reach zero rabies cases in the year 2031.

**Figure 1: Top: Observed and predicted annual rabies cases using Auto-Regressive Integrated Moving Average (ARIMA) model. Middle: Observed and predicted annual rabies cases using Auto-Regressive Integrated Moving Average with Explanatory Variables (ARIMAX) model. Bottom: Observed and predicted annual rabies cases using an Auto-Regressive Integrated Moving Average with Explanatory Variables (ARIMAX) model with a 50% increase in MDV.**

|  |
| --- |
| **ARIMA** |
|  |
| **ARIMAX** |
|  |
| **ARIMAX with 50% increase of MDV** |
|  |



Many other factors can influence occurrence of rabies cases including literacy rate, GDP, awareness of rabies, access and availability of post-exposure vaccines, access to primary care, and primary contact related to sickness. However, reliable data on these parameters or proxy variables are not available. Thus, we decided to keep MDV in the model as the key determinant of the occurrence of human rabies cases (please add a Ref).

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