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Time series modeling of animal bites

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ABSTRACT

Objective: To explore the modeling of time series of animal bite occurrence in northwest Iran.

Methods: In this study, we analyzed surveillance time series data for animal bite cases in the northwest Iran province of Iran from 2011 to 2017. We used decomposition methods to explore seasonality and long-term trends and applied the Autoregressive Integrated Moving Average (ARIMA) model to fit a univariate time series of animal bite incidence. The ARIMA modeling process involved selecting the time series, transforming the series, selecting the appropriate model, estimating parameters, and forecasting.

Results: Our results using the Box Jenkins model showed a significant seasonal trend and an overall increase in animal bite incidents during the study period. The best-fitting model for the available data was a seasonal ARIMA model with drift in the form of ARIMA (2,0,0) (1,1,1). This model can be used to forecast the frequency of animal attacks in northwest Iran over the next two years, suggesting that the incidence of animal attacks in the region would continue to increase during this time frame (2018-2019).

Conclusion: Our findings suggest that time series analysis is a useful method for investigating animal bite cases and predicting future occurrences. The existence of a seasonal trend in animal bites can also aid in planning healthcare services during different seasons of the year. Therefore, our study highlights the importance of implementing proactive measures to address the growing issue of animal bites in Iran.

KEYWORDS: Animal bites; Time series analysis; ARIMA modeling; Box Jenkins model; Northwest Iran

1. Introduction

Humans' vulnerability to rabies from animal bites, which are the primary means of rabies transmission to humans worldwide, makes animal bites a significant public health concern[1]. Rabies is a viral zoonotic disease, caused by infection with the rabies lyssavirus[2]. The rabies infection virus is most frequently spread through interaction with sick animals, such as being bitten or scratched by rabies-prone animals[3]. In addition to the possible transmission of rabies, animal bites can cause lasting scarring that necessitates reconstructive surgery, impairment, infection, and, in rare instances, even death[4,5]. Nearly all cases of rabies result in death[6]. Worldwide, rabies poses a threat to more than 2.5 billion people[1]. According to reports, there are 250 instances of animal bites per

Significance

Animal bites are a significant public health concern in Iran, and forecasting future occurrences is crucial for planning healthcare services. Our study explored the modeling of time series of animal bite incidence in northwest Iran using decomposition methods and ARIMA models. We found a significant seasonal trend and an overall increase in animal bite incidents during the study period. Our best-fitting model can be used to forecast animal attacks in northwest Iran over the next two years, highlighting the importance of proactive measures to address this growing issue.

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1 000 people globally and 180 cases per 100 000 people in Iran[7]. Hence, the high incidence rates raise treatment and prevention expenses and negatively impact the victims' psychological and social lives[8]. The greatest burden of animal bite injuries, mostly from dog bites, is located in Asia and Africa, where an estimated 55 000 people die from rabies each year[9]. Animal bites also incur significant financial costs for medical care, post-exposure rabies treatment, and in some cases, hospitalization, as well as harming the victims' psychological and social well-being[10]. Poor and vulnerable people who might not have access to medical services bear the brunt of animal bite injuries and their consequences, such as rabies[11]. In Iran, animal bites are widespread and have long been endemic to Iranian wildlife and frequently infect domestic animals[12]. According to the most recent incidence status of animal bites in the nation, Golestan province, along with Ardabil, North Khorasan, and Charmahal-Bakhtiari provinces, are known as provinces with high rates of animal bites. Animal bite statistics have risen in Iran over the past 30 years, from an incidence rate of 35 per 100 000 people in 1987 to 177 per 100 000 people in 2016[13]. Also, in most places in Iran, the rate of animal attacks is increasing. From 2013 to 2020, the incidence of animal bites climbed from 196 to 282[14]. The first move towards a successful intervention to contain a reportable disease outbreak is early identification of the outbreak[15]. In contrast, outbreaks frequently have already started before public health officials are made aware of them. The epidemiological incidence patterns of this illness should be looked into and evaluated in light of the rising number of animal bites and rabies cases. To strengthen the public health service's ability to make decisions for efficient targeted strategies to control and prevent rabies transmission, it is urgently necessary to develop robust and reliable predictive models[16]. Autoregressive Integrated Moving Average (ARIMA) and Seasonal Autoregressive Integrated Moving Average (SARIMA) models have been widely used for epidemic time series forecasting including hemorrhagic fever with renal syndrome[17], dengue fever[18], and tuberculosis[19].

The main objective of this study is to apply a time-series analysis to analyze incidence rate of animal biting in West Azerbaijan province during 2012-2017 using the Box-Jenkins or ARIMA method. This model considers the reported cases over time, thereby allowing for forecasts of expected numbers of reported cases and providing confidence intervals around these predictions. Time series models are relatively easy to fit and require less epidemiological information. Like many other infectious diseases, time series of animal bite incidence exhibit seasonal behavior, secular trend, and rapid fluctuations. Therefore it is reasonable to forecast epidemic incidence with time series methods[20]. Traditional time series versions come in five different varieties. Auto Regressive (AR) models express the time series' current value as a linear function of both its prior values and its current residual, while Moving Average (MA) models express the time series' current value linearly in terms of its prior and current residual series. The current value of the time series is expressed linearly in terms of its earlier values as well as in terms of the current and previous residual series in Auto Regressive Moving Average (ARMA) models, which combine AR and MA models[21]. The time series that the AR, MA, and ARMA models describe are stationary processes, which mean that they all have constant means and co-variances between their observations. For non-stationary time series, first, the series must be transformed into a fixed series. With a differencing process that successfully converts the non-stationary data into stationary data, the ARIMA model typically fits the non-stationary time series based on the ARMA model. SARIMA models, which combine seasonal differencing with an ARIMA model, are used when the time series data exhibits periodic characteristics. When data show a seasonal trend, SARIMA models have been extensively used in forecasting infectious diseases and other areas[22]. Public health officials will be better able to understand epidemic trends and initiate early interventions if time series models have good forecasting performance[23]. These models are primarily used to forecast the future and match historical data. Less research has, however, been done on the time series modeling of animal attacks and the time series correlation of these bites.

2. Subjective and methods

This descriptive cross-sectional study examined all 1 047 animal bite cases referred to the rabies prophylaxis centers in West Azerbaijan province from April 2012 to March 2018. The information was gathered based on records of animal bites of people who were referred to the health facilities in the province of West Azerbaijan for precautionary steps and treatment. The collected data were analyzed by statistics using SPSS version 21 and R studio software.

One of the most well-liked univariate time series models, the ARIMA model is frequently employed in the analysis of infectious diseases[24]. The ARMA formula is defined as:

$$y_t=\mu+y_{(t-12)}+\varphi_1 y_{(t-1)}+\varphi_2 y_{(t-2)}+\varphi_1 y_{(t-13)}-\varphi_2 y_{(t-14)}+\varphi_3 y_{(t-12)}-\varphi_1\varphi_3 y_{(t-13)}-\varphi_2\varphi_3 y_{(t-14)}-\varphi_3 y_{(t-24)}+\varphi_1\varphi_3 y_{(t-25)}+\varphi_2\varphi_3 y_{(t-26)}+Z_t-\beta_1 Z_{(t-12)}$$

where y_t refers to the value of the time series at time t and in the presented formula μ is equal to 11/4 603 and φ_1, φ_2, and φ_3 is equal to 1 and β_1 is also equal to 1. The ARMA model-based differencing procedure is used by the ARIMA model to handle non-stationary time series. The model can be expressed as ARIMA (p, d, q) (P, D, Q) s, and the SARIMA model is usually termed as SARIMA (p, d, q) (P, D, Q) S. In the expression, the seasonal order of the autoregressive component is P, the non-seasonal order of the autoregressive part is p; the regular moving average part is q, the seasonal moving average part is Q; the regular differencing order is d, and the seasonal differencing order is D. The length of the seasonal time is indicated by the subscripted letter "s"[25].

Three steps were taken into consideration for the modeling process to make predictions: model identification, parameter estimation for the chosen model, and model evaluation[26]. To determine the order of the MA and AR terms included in the ARIMA model, sample autocorrelation (ACF) and partial autocorrelation function (PACF) graphs were used. Specifically, an ARIMA model with p-AR components and q-MA components is suggested if we see statistically significant autocorrelation in the sample ACF plot at q-time lags and significant sample PACF at p lags. The goodness of fit and Akaike's Information Criterion (AIC) are combined to choose the ultimate model (order)[27,28]. Here we determined the goodness of fit using the residual autocorrelation function to guarantee that no additional autocorrelation was present in each fit.

3. Results

The monthly distribution of animal bite cases during the study period was used for time series analysis (Table 1). During the investigated period, the average animal bite cases per month were 561. The minimum and maximum number of animal bite cases observed were 408 (in December 2012) and 718 (in June 2014), respectively. The highest number of animal bite cases occurred in the first half of the year and the incidence of animal bite cases was lower in the second half of the year.

The animal bite time series data were used for future analysis (Figure 1). The series chart for the observed data is shown in Figure 1A. Figure 1B displays the data trend, which climbed until the middle of 2014, and then decreased slightly in the second half of 2015. The trend of animal bite cases then continued to rise until the end of the study period. Figure 1C shows the existence of seasonal changes in the data of this series. Figure 1D shows the residuals of the time series after removing the trends and seasonal changes in these data, and it can be seen that this part of the graph does not contain any particular pattern in the data.

The average values of the mean and variance of the data points must not change over time for ARIMA modeling to function for a specific set of data. ACF and PACF plots were created to test the series' consistency (Figure 2). The first step in time series modeling is to check whether the data series is stationary in terms of variance and mean. And the ARIMA model works best when our data has a stable or constant pattern over time, meaning that the variance and mean of the data should remain constant over time. Therefore, when the data has an upward or downward trend and has a sure (seasonal) pattern, the data is not stable. The autocorrelation graph of the data in Figure 2A shows the presence of seasonal changes in the data, and

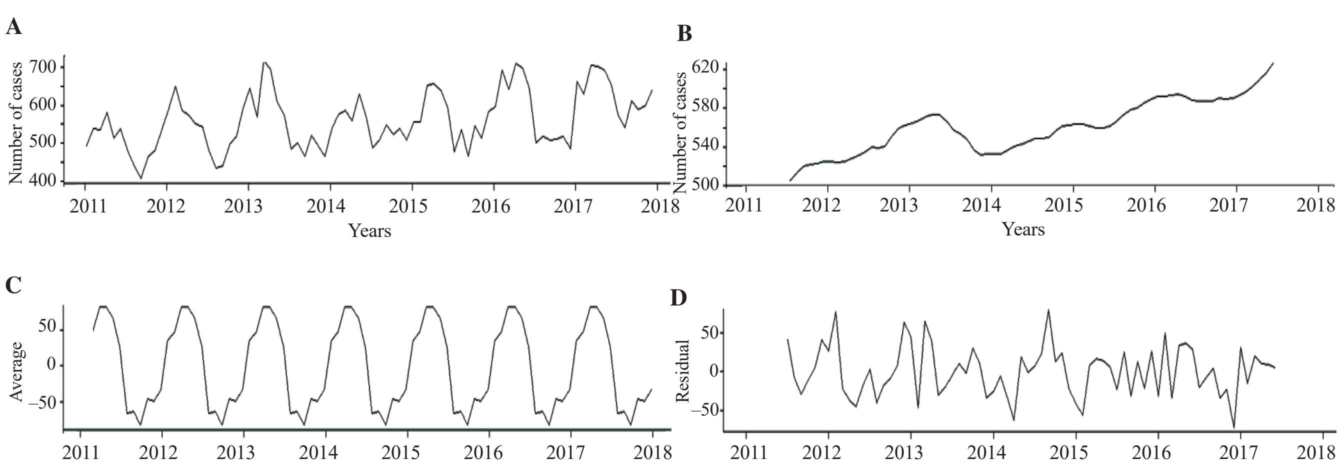

Figure 1. Decomposition of time series data of animal bite cases in West Azerbaijan province, Iran 2012-18. A: Observed data; B: Trend component; C: Seasonal change component; D: Random change.

Table 1. Monthly distribution of animal bite cases during the study period (n).

Year	April	May	June	July	August	September	October	November	December	January	February	March
2011	493	538	535	582	514	539	480	441	408	465	479	533
2012	586	650	585	573	552	543	477	434	440	497	518	594
2013	645	568	718	695	609	573	486	500	464	521	493	465
2014	542	575	585	559	628	571	489	507	548	523	537	508
2015	557	555	651	657	640	593	477	535	465	547	514	583
2016	596	691	642	710	696	643	500	517	509	510	518	485
2017	661	630	705	703	693	658	573	540	611	589	598	639

while the autocorrelations in this graph have not tended to become zero over time, the partial autocorrelation graph has become zero from the second lag onward, indicating instability in the series. The KPSS test was also employed to check for series instability, and the results showed that the series is unstable (P=0.03). To reduce the series' instability, first-order differentiation and seasonal differentiation were done on the series' data using a different approach.

After using seasonal differentiation to establish the initial parameters for Box Jenkins modeling, the parameter values for the best model are based on autocorrelation and partial autocorrelation diagrams. Identifying the AR term (p) was done by inspecting the PACF graph, which was significant in the first 20 lags of partial autocorrelation at the 13th lag (Although in lags 1 and 2 the autocorrelation slightly exceeded the significance line, this value was not considerable). As a result, p=1 was taken into account. Examining the partial autocorrelation diagram to determine the P parameter revealed that partial autocorrelation was significant in the 12th log in the first 20 logs. Therefore, P=1 was considered. According to an order of seasonal differentiation, the rank of parameter d is zero, and D=1. When the autocorrelation graph was examined to find the q parameter, it was discovered that autocorrelation was significant in lag 2 in the first 20 lags. As a result, q=1 was evaluated. In addition, the autocorrelation graph used to calculate the Q parameter revealed that autocorrelation was significant in the 12th log in the first 20 logs. As a result, Q=1 was evaluated.

Therefore, the initial model of a seasonal ARIMA model was considered as ARIMA (1,0,1) (1,1,1). Because some spikes in the autocorrelation and partial autocorrelation graphs were notable, several ARIMA models were fitted, and the results of the estimations are shown in Table 2. To begin, the suitability of all of these time series models was evaluated, and the final ARIMA model chosen was highlighted based on the criterion of minimum AIC (AICc), and according to the formula provided above, the Tier 3 model was chosen as the appropriate model for the data.

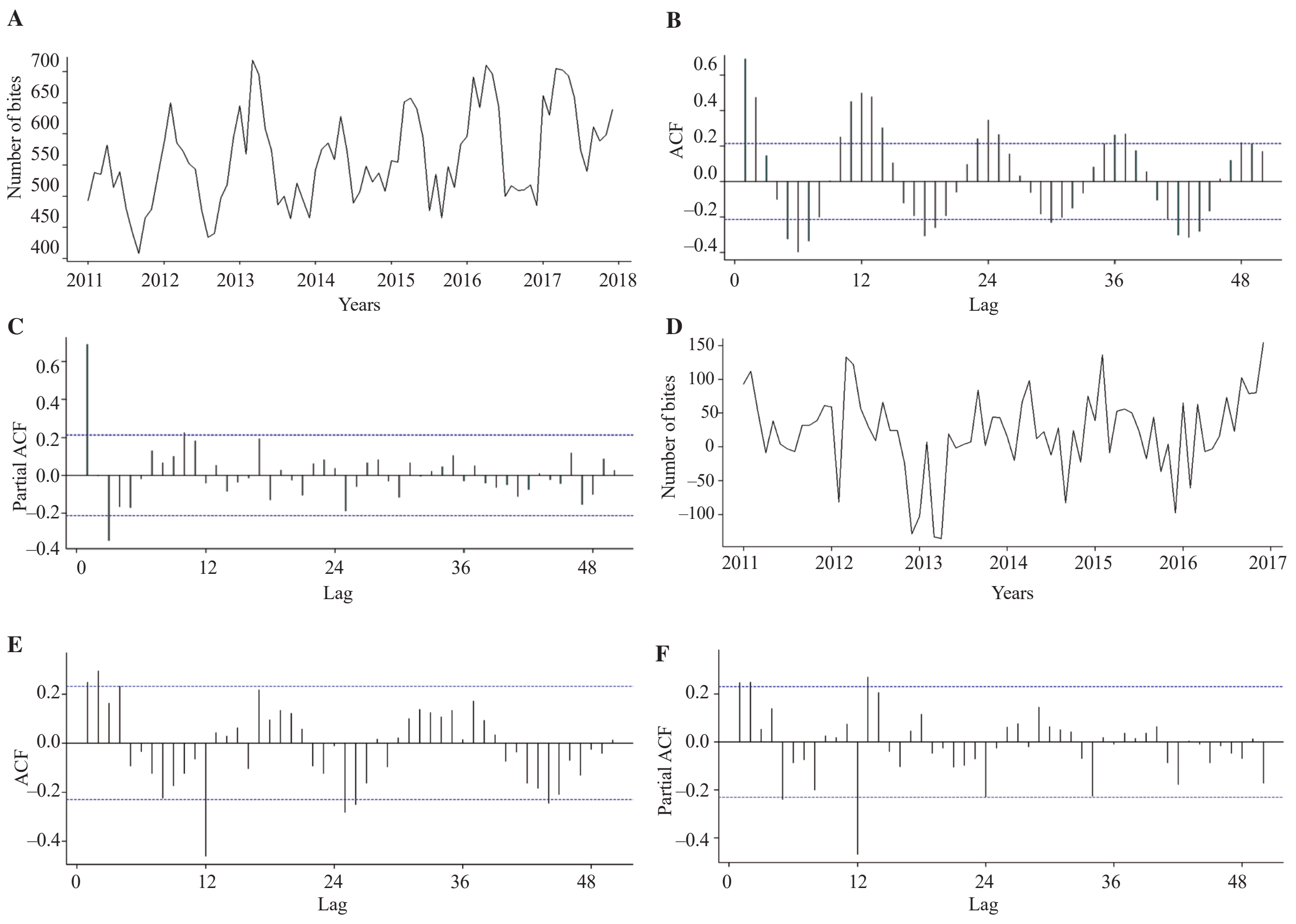

Figure 2. Time series graphs (A, D), autocorrelation function (ACF) (B, E), and partial autocorrelation function (PACF) (C, F). A, B, C: before differentiation; D, E, F: after seasonal differentiation.

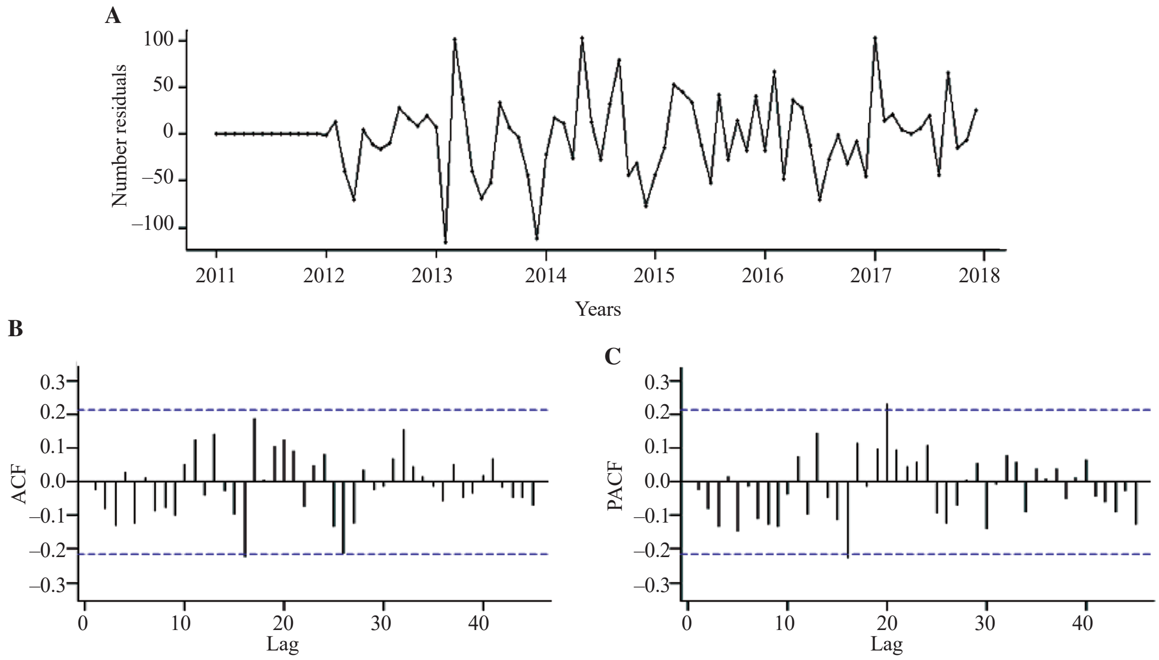

Figure 3. Residuals, autocorrelation function and partial autocorrelation function of residuals for ARIMA (2,0,0) (1,1,1).

To evaluate the appropriateness of the selected model, the residuals of the ARIMA (2,0,0) (1,1,1) model were checked by drawing the graph of the residuals and ACF and PACF (Figure 3). The results revealed that the residual distribution was random with no discernible pattern, and no substantial autocorrelation or partial autocorrelation was identified in the residuals. The Box-Ljung test, which was used to determine whether or not there was autocorrelation between the model's residuals, revealed that the distribution of the residuals was independent and that there was no autocorrelation in the data (P=0.967, df=12, and χ^2=4.712). The histogram of the distribution of the model's residuals revealed that the residuals follow a normal distribution. The Box Jenkins model for assuming residual independence is shown in Table 3 (P=0.581, df=43, and χ^2=40.5).

The selected ARIMA (2,0,0) (1,1,1) model was used to anticipate monthly animal bites cases for the next 24 months (April 2019 to March 2020). Table 3 shows the point estimate with lower and upper bounds of the uncertainty of 80% and 95% for the predicted number of animal bites in the next 24 months. Based on the predicted number of animal bites, the number of events will increase compared to the past, and the seasonal trend can also be seen in this period (Figure 4).

Table 2. ARIMA models, AIC, and log-likelihood indices.

Parameters number	AIC	Log-likelihood	ARIMA model	Tier
5	766.63	–378.32	ARIMA (1,0,1) (1,1,1)	1
6	768.05	–378.02	ARIMA (2,0,1) (1,1,1)	2
4	766.05	–384.03	ARIMA (2,0,0) (1,1,1)	3
5	766.10	–378.05	ARIMA (1,0,0) (1,1,1)	4

AIC: Akaike's Information Criterion.

Table 3. Box Jenkins model of residual independence.

Lag	χ^2	df	P
48	40.5	43	0.581
36	29.0	31	0.572
24	16.1	19	0.651
12	3.9	7	0.786

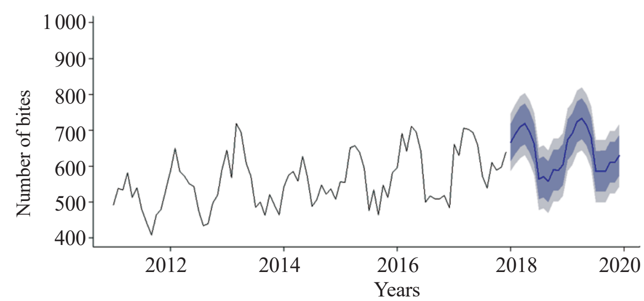

Figure 4. Prediction of animal bite cases based on ARIMA (2,0,0) (1,1,1) for the next 24 months.

4. Discussion

Animal bite cases in West Azerbaijan increased steadily between 2011 and the middle of 2013. After the first half of 2013, the incidence fell till 2014. And, from 2014 to the end of 2017, there was a gentle and steady increase in the number of animal bites. Animal bite cases increased from 1992 to 1993, then declined till 1995, according to a study conducted by Ahmed *et al*[29]. According to a study conducted in Khorramshahr, the number of animal bite cases reduced from 166 to 122 between 1992 and 1994, then grew to 130 between 1994 and 2016[30]. From 1979 to 1983, the frequency of animal bite incidents in Aq Qala progressively climbed, and then gradually declined until 1988[31]. In Ilam province, between 1373 and 1382, most cases of animal bites occurred in the summer and winter seasons, and the last cases occurred in the spring season[32]. The outcomes of this research are difficult to compare because the periods studied are not the same. Furthermore, the majority of research has only looked at a short period. This research also revealed the presence of a seasonal trend in the occurrence of animal bites. As a result, the monthly number of animal bite cases gradually increased beginning in the first month of each year, with the highest number of animal bite cases occurring between June and August, and then gradually decreasing until it was the lowest from November to January. The number reached its maximum and then steadily climbed again, a pattern that was repeated virtually every year. Previous research in Iran has paid less attention to investigating the seasonal trend in the prevalence of animal bites, instead reporting the months or seasons with the highest or lowest number of animal bite occurrences. In research conducted in Khorramshahr between 2012 and 2014, for example, the greatest cases of animal bites occurred in the spring, with June having the highest number of animal bites with 81 cases[29]. In Bojnoord between 2004 and 2010, the greatest cases of animal bites were detected in July, the least in August, and then in October and January, with no significant variation between seasons in terms of the prevalence of animal bites[33]. Seasonal variations in the incidence of animal bites in the current study can be attributed to the lengthening of the days, an increase in air temperature, and an increase in outdoor activities in both urban and rural areas during the months when the days are longest and the air temperature is highest. On the other hand, the lowest of animal bite cases has increased during the months when the length of the day is shorter and the temperature is cooler, causing people to spend less time outside.

There was no analogous study using modeling tools to evaluate the occurrence of animal bite incidents. Hosseini *et al*. used exponential smoothing to apply a basic seasonal model to data on animal bites that occurred in Bardsir between April 2009 and December 2013, but they eventually determined that this model was not optimal for animal bite data[34]. The time series modeling method was applied in this study to forecast the monthly number of animal bite cases. The modeling results using the Box Jenkins model not only verified that there was a seasonal trend in animal bite data in West Azerbaijan province but also demonstrated the growth and increase of incidents of animal bites over the study period. The best fitting model for the available data among the investigated models was a seasonal ARIMA model in the form of ARIMA (2,0,0) (1,1,1) with drift. Thus, the fitted ARIMA (2,0,0) (1,1,1) with a drift model can be used to forecast the frequency of animal attacks in West Azerbaijan over the following two years. This model, when the fitted values of the model were compared to the observed values, revealed that the model has a relatively good fit and can be used to forecast future values of the series entirely based on previous data. When the data displays a steady and stable trend across time with few outliers, the ARIMA model performs best[35]. The projected results indicate that the incidence of animal attacks in West Azerbaijan will increase during the next two years (2018-2019). However, because these models are reliant on previously observed data, they must be continually updated with fresh data to provide more accurate predictions. The increase in the incidence of animal bites can be attributed to an increase in people's awareness of the disease's dangers and referral to health centers, an increase in tourism, the shape of residential houses (without fences), an improvement in the care system and report registration, and an increase in anti-rabies treatment centers. Wildlife is also one of the reasons for the increase in animal bites, as a result of ecological changes (growth of cities and villages, destruction of forests, and dam construction) and increasing interaction with wild animals, followed by rabies transmission to domestic animals. As a result, understanding animal bite projections is essential for prompting health authorities to expand monitoring systems and reallocate resources in anticipation of rising animal bite incidence. We confirmed in this study that the ARIMA model is a valuable tool for monitoring and predicting shifting patterns in illnesses.

There is an urgent need to monitor and anticipate the occurrence of animal bites to prevent the significant morbidity and mortality caused by this disease. ARIMA models using historical animal bite incidence data are a valuable tool for animal bite surveillance. It is possible to forecast the occurrence of animal bites accurately. Our modeling approach can be used to track and predict the occurrence of animal bites in Iran. The ARIMA model could be used to optimize animal bite prevention by providing estimates on animal bite incidence trends in Iran.

Conflict of interest statement

The authors report no conflict of interest.

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Authors' contributions

FR: concept and design of a study or data acquisition, analysis, and interpretation; drafting and revising; providing final approval of the version. SM: drafting and revising; providing final approval of the version.

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