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APPLICATION OF THE AUTOREGRESSIVE INTEGRATED MOVING AVERAGE FOR THE ANALYSIS OF COVID-19 CASE SERIES IN PERU

APLICACIÓN DEL MÉTODO AUTORREGRESIVO INTEGRADO DE MEDIAS MÓVILES PARA EL ANÁLISIS DE SERIES DE CASOS DE COVID-19 EN PERÚ

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ABSTRACT

Introducción: In recent months, researchers have been using mathematical methods to predict the number of COVID-19 cases worldwide. **Objective:** To estimate an Integrated Autoregressive Moving Average model (ARIMA) for the analysis of series of COVID-19 cases, in Perul. **Methods:** The present study was based on a univariate time series analysis; The data used refer to the number of new accumulated cases of COVID-19 from March 6 to June 11, 2020. For the analysis of the fit of the model, the autocorrelation coefficients (ACF), the unit root test of Augmented Dickey-Fuller (ADF), the Normalized Bayesian Information Criterion (Normalized BIC), the absolute mean percentage error (MAPE) and the Box-Ljung test. **Results:** The prognosis for COVID-19 cases, between June 12 and July 11, 2020 ranges from 220 596 to 429 790. **Conclusion:** The results obtained with the ARIMA model, compared with the observed data, show an adequate adjustment of the values; And although this model, easy to apply and interpret, does not simulate the exact behavior over time, it can be considered a simple and immediate tool to approximate the number of cases.

Key words: Forecasting; Pandemics; Coronavirus (source: MeSH NLM).

RESUMEN

Introducción: En los últimos meses, los investigadores han venido empleando métodos matemáticos para poder pronosticar el número de casos de COVID-19 en todo el mundo. **Objetivo:** Estimar un modelo Autorregresivo Integrado de Medias Móviles (ARIMA) para el análisis de series de casos de COVID-19, en Perú. **Métodos:** El presente estudio se basó en un análisis de series temporales univariante; los datos utilizados se refieren a la cantidad de casos nuevos acumulados de COVID-19 del 06 de marzo al 11 de junio de 2020. Para el análisis del ajuste del modelo se utilizaron los coeficientes de autocorrelación (ACF), el contraste de raíces unitarias de Dickey-Fuller Aumentado (ADF), el Criterio de Información Bayesiano Normalizado (BIC Normalizado), el error porcentual medio absoluto (MAPE) y el test de Box-Ljung. **Resultados:** El pronóstico de casos de COVID-19, entre el 12 de junio al 11 de julio de 2020 oscila entre 220 596 a 429 790. **Conclusión:** Los resultados obtenidos con el modelo ARIMA, comparados con los datos observados, muestran un ajuste adecuado de los valores; y aunque este modelo, de fácil aplicación e interpretación, no simula el comportamiento exacto en el tiempo puede considerarse una herramienta simple e inmediata para aproximar el número de casos.

Palabras clave: Pronóstico; Pandemias; Coronavirus (fuente: DeCS BIREME).

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INTRODUCTION

The new coronavirus (severe acute respiratory syndrome coronavirus 2-SARS) was reported in December 2019 in Wuhan-China, with the appearance of several cases of pneumonia of unknown etiology which caused severe acute respiratory problems[1-7]. This infection is transmitted by inhalation of respiratory droplets, close contact with the infected individual, and contact with contaminated surfaces or objects[1,8].

On March 11, 2020, the World Health Organization (WHO) declared COVID19 a pandemic[9]. Cases are increasing worldwide, including Peru, where the first case was announced on March 6; As of July 12, the total number of confirmed cases was 326,326[10].

There is great concern about the Peruvian health system's response capacity to effectively meet the needs of people with COVID-19 as the number of cases increases. Despite all the measures taken by the government, it does not stop. The outcome is worst now that the government "opened the doors" for the population to a "new normal."

Mathematical models are used to understand critical epidemiological transitions[11-14], and in recent months, researchers have been using mathematical methods to forecast the number of COVID-19 cases worldwide. The Autoregressive Integrated Method of Moving Averages (ARIMA) is the one that has been used the most to make forecasts, such is the case of those proposed by Singh RK et al.[11], for the United States, Spain, Italy, France, Germany, the United Kingdom, Turkey, Iran, China, Russia, Brazil, Canada, Belgium, the Netherlands, and Switzerland; by Ceylan Z[15], for Italy, Spain, and France; by Moftakhar L and Seif M[1], for Iran; by Benvenuto D et al.[16], for Italy; by Yousaf M et al.[17], for Pakistan; by Hiteshi Tandon[18] and Rishabh Tyagi et al.[19], for India and by Perone G[20], for Italy

Time series constitute data collections in a period in which trends or patterns are observed to forecast some future values[21]. The ARIMA model has three main parameters; the parameter p: associated with the autoregressive process (AR), the number of differences that must be taken from the series to be stationary. The parameter d: associated with the integrated part (I) y; the parameter q: related to the part of the moving average (MA), which is the current value of a series, which is defined as a linear combination of past errors[11,12,18].

To estimate an ARIMA model, the Box-Jenkins methodology[11,22-23], is used, which consists of 4 stages. Identification: which consists of identifying the model that can tentatively be considered. Estimation: which consists of estimating the parameters of the model tentatively considered; validation: which consists in performing diagnostic tests to check if the model fits the data. Finally, prediction, which consists of obtaining forecasts in probabilistic terms of future values and the model's predictive capacity, is evaluated[24].

One of the concerns in Peru and any other country, is to know how many people will be infected with COVID-19 in time; and this could be answered with predictive models[25]; Therefore, the present study aimed to estimate an Autoregressive Integrated Moving Average model (ARIMA) for the analysis of series of COVID-19 cases, in Peru, t

seek an approximation between the results obtained with the model and observed data.

METHODS

Design and study area

This study was based on a univariate, descriptive, cross-sectional, retrospective time series analysis, carried out in Peru, with the number of new daily confirmed cases of COVID-19, between March 6 and March 11. June 2020.

Population and sample

The data used refers to the total number of new daily confirmed cases of COVID-19 between March 06 and June 11, 2020.

Variables and instruments

The data comes from the COVID-19 Situation Room -Peru, from Instituto Nacional de Salud y Centro Nacional de Epidemiologia, Prevención y Control de Enfermedades del Ministerio de Salud[10]; which serve to obtain the accuracy of the forecast of the spread of COVID-19.

Procedures

The data was used to obtain the forecasts of the number of cases for the next 30 days, from June 12 to July 11, 2020, creating a projected trajectory of these cases, to later compare them with the cases observed in the indicated period.

Statistical analysis

The time series method used for the forecast of COVID-19 cases was the Integrated Autoregressive Moving Averages of order (p, d, q) or ARIMA (p, d, q). The construction of the model was carried out iteratively following the 4 stages of the Box-Jenkins methodology[11,22-24] 1-Identification: in which the stationary transformation of the series was determined to obtain the appropriate model, through the analysis of autocorrelation coefficients (ACF), and the Augmented Dickey-Fuller unit root test (ADF); 2-Estimation: in which, by choosing the appropriate orders p, d, q, the model was adjusted to the time series, obtaining the ARIMA model(0,2,9); 3-Validation: in which it was analyzed if the model was appropriate, and it was valued with the Normalized Bayesian Information Criterion (Normalized BIC), the mean absolute percentage error (MAPE) and the white noise test or Box-Ljung test; 4-Prediction: in which the forecasts of the number of cases for the next 30 days were generated; and then compare the observed cases.

The statistical program used for the time series analysis was the SPSS version 22, and the STATA version 15 program was used to determine the increased Dickey-Fuller unit root contrast.

Ethical aspects

The data is public, open, and has anonymous access. Therefore, the approval of an institutional ethics committee was not required.

RESULTS

Table 1 shows the daily count of COVID 19 cases between March 6, 2020, and June 11, 2020.

In Figure 1, it is shown that the autocorrelation coefficients (ACF) slowly decrease as linear, so they correspond to a non-stationary time series, this being corroborated by the Augmented Dickey-Fuller unit root contrast ($p > 0.01$).

In Figure 2, the second-order stationary transformation is shown. The time series was stabilized by eliminating trends and obtaining the appropriate model with the orders p, d, q, which was ARIMA (0.2,9).

Table 2 shows the parameters (p, d, q) obtained in the modeling process; the Normalized Bayesian Information Criterion (BIC) which indicates that 13,475 was the lowest value obtained indicating the best ARIMA model; the mean absolute percentage error (MAPE) that indicates that the forecast of the model is wrong by 7.775%; and the Ljung-Box test that suggests that the model is capable of reproducing the systematic behavior pattern of the time series.

Figure 3 and Table 3 show the prognosis of the number of cases with 95% confidence intervals and the observed cases, from June 12 to July 11, 2020, with data from March 6, 2020, to June 11, 2020. The observed cases' values are lower than the predicted cases' values, with those observed within the minimum and maximum values of the estimates.

Table 1. Number of cases with COVID 19 per day, from March 6 to June 11, 2020. Peru .

Day	Cases	Day	Cases	Day	Cases	Day	Cases
6/03/2020	1	31/03/2020	1065	25/04/2020	25331	20/05/2020	104020
7/03/2020	6	1/04/2020	1323	26/04/2020	27517	21/05/2020	108769
8/03/2020	6	2/04/2020	1414	27/04/2020	28699	22/05/2020	111698
9/03/2020	9	3/04/2020	1595	28/04/2020	31190	23/05/2020	115754
10/03/2020	11	4/04/2020	1746	29/04/2020	33931	24/05/2020	119959
11/03/2020	17	5/04/2020	2281	30/04/2020	36976	25/05/2020	123979
12/03/2020	22	6/04/2020	2561	1/05/2020	40459	26/05/2020	129751
13/03/2020	38	7/04/2020	2954	2/05/2020	42534	27/05/2020	135905
14/03/2020	43	8/04/2020	4342	3/05/2020	45928	28/05/2020	141779
15/03/2020	71	9/04/2020	5256	4/05/2020	47372	29/05/2020	148285
16/03/2020	86	10/04/2020	5897	5/05/2020	51189	30/05/2020	155671
17/03/2020	117	11/04/2020	6848	6/05/2020	54817	31/05/2020	164476
18/03/2020	145	12/04/2020	7519	7/05/2020	58526	1/06/2020	170039
19/03/2020	234	13/04/2020	9784	8/05/2020	61847	2/06/2020	174884
20/03/2020	263	14/04/2020	10303	9/05/2020	65015	3/06/2020	178914
21/03/2020	317	15/04/2020	11475	10/05/2020	67307	4/06/2020	183198
22/03/2020	360	16/04/2020	12491	11/05/2020	68822	5/06/2020	187400
23/03/2020	395	17/04/2020	13489	12/05/2020	72059	6/06/2020	191758
24/03/2020	416	18/04/2020	14420	13/05/2020	76306	7/06/2020	196515
25/03/2020	480	19/04/2020	15628	14/05/2020	80604	8/06/2020	199696
26/03/2020	580	20/04/2020	16325	15/05/2020	84495	9/06/2020	203736
27/03/2020	635	21/04/2020	17837	16/05/2020	88541	10/06/2020	208823
28/03/2020	671	22/04/2020	19250	17/05/2020	92273	11/06/2020	214788
29/03/2020	852	23/04/2020	20914	18/05/2020	94933	-	-
30/03/2020	950	24/04/2020	21648	19/05/2020	99483	-	-

Source: COVID 19-Peru Situation Room, of the National Institute of Health and National Center for Epidemiology, Prevention and Control of Diseases of the Ministry of Health.

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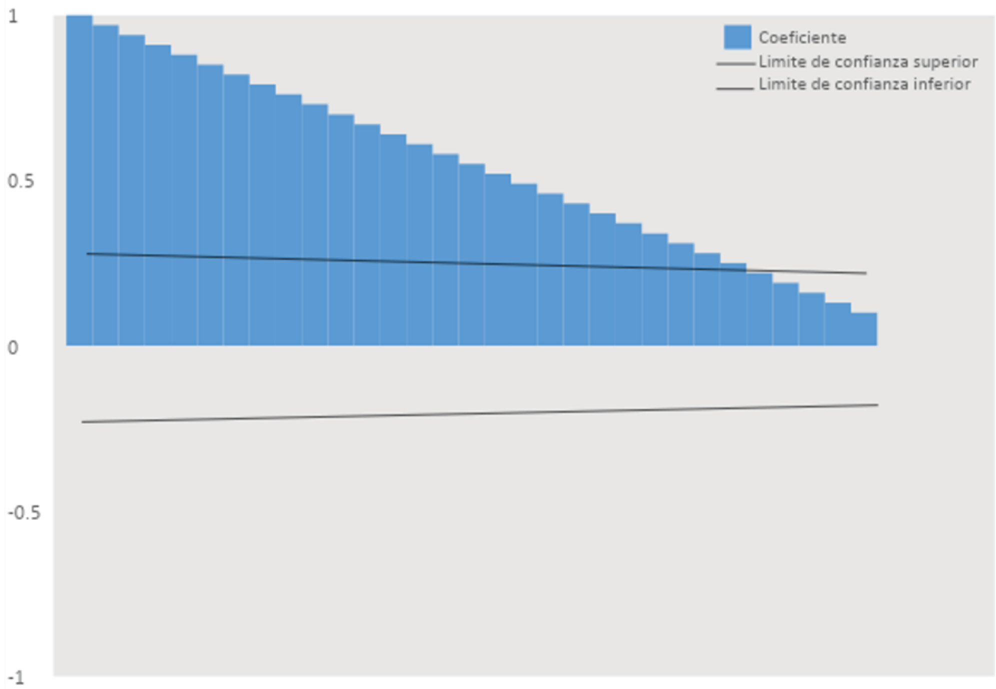
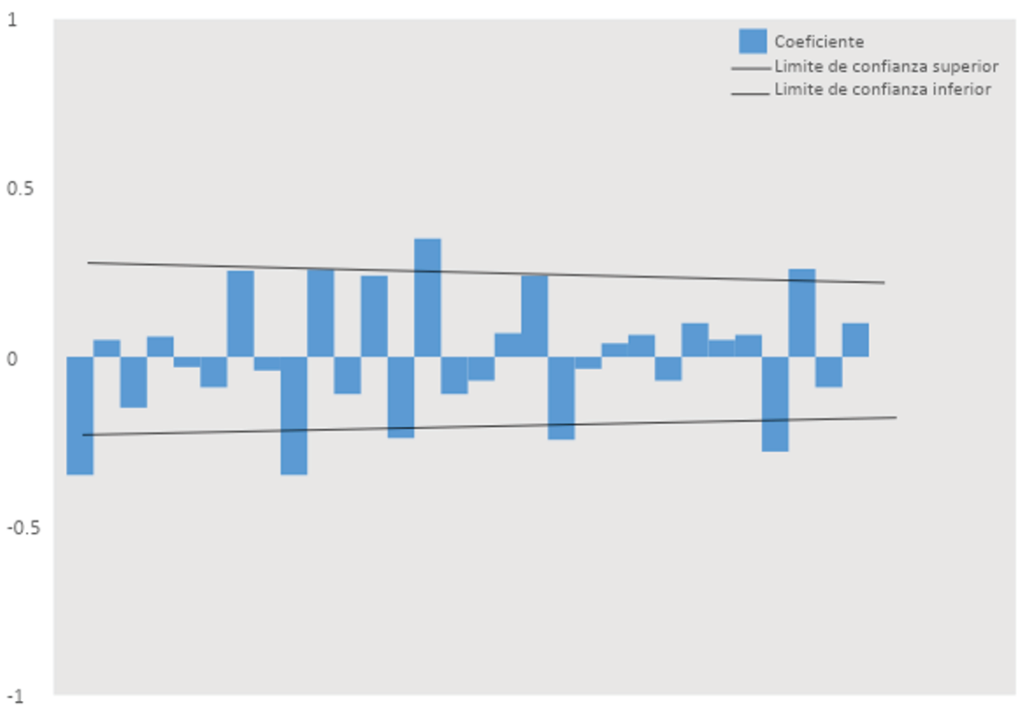


Source: COVID 19-Peru Situation Room, of the National Institute of Health and National Center for Epidemiology, Prevention and Disease Control of the Ministry of Health

Graphic 1. Autocorrelation correlogram (ACF) estimated for the time series.



Source: COVID 19-Peru Situation Room, of the National Institute of Health and National Center for Epidemiology, Prevention and Control of Diseases of the Ministry of Health

Graphic 2. Autocorrelation correlogram (ACF) estimated for the time series, with a second-order transformation.

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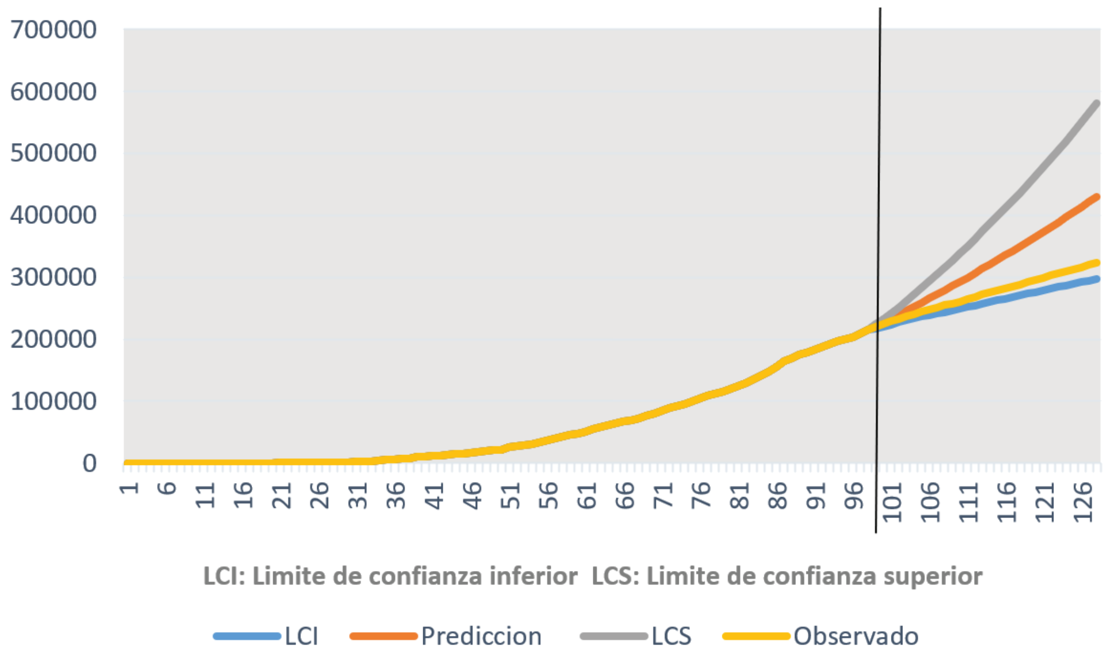
Table 2. Optimal parameters for the model

	parameters ARIMA	BIC normalized	Mean error absolute	Test Ljung-Box
Perú	(0,2,9)	13,475	7,775	0,040*

Note: * p <0.01
Normalized BIC: Standardized Bayesian Information Criterion
ARIMA: Autoregressive Integrated Method of Moving Averages



Source: COVID 19-Peru Situation Room, of the National Institute of Health and National Center for Epidemiology, Prevention and Disease Control of the Ministry of Health.

Graphic 3. Forecast of the number of COVID 19 cases, with 95% confidence intervals and observed cases of COVID 19; from June 12 to July 11, 2020.

Table 3. Observed cases and forecast of the number of COVID 19 cases, with 95% confidence intervals from June 12 to July 11, 2020

Day	Observed	ARIMA	Forecast Confidence Interval: 95 % Limit lower	Limit upper
12/06/2020	220749	220596	216821	224394
13/06/2020	225132	226675	220300	233118
14/06/2020	229736	232952	223819	242221
15/06/2020	232992	239355	227227	251717
16/06/2020	237156	245776	230401	261518
17/06/2020	240908	252499	233612	271929
18/06/2020	244388	259233	236578	282653
19/06/2020	247925	265890	239218	293600
20/06/2020	251338	272444	241516	304743
21/06/2020	254936	279083	243973	315926
22/06/2020	257447	285805	246533	327204
23/06/2020	260810	292612	249163	338615
24/06/2020	264689	299503	251840	350183
25/06/2020	268602	306478	254548	361925
26/06/2020	272364	313539	257274	373857
27/06/2020	275989	320685	260010	385988
28/06/2020	279419	327916	262748	398327
29/06/2020	282365	335232	265483	410882
30/06/2020	285213	342635	268210	423660
1/07/2020	288477	350123	270926	436665
2/07/2020	292004	357698	273628	449903
3/07/2020	295599	365359	276313	463378
4/07/2020	299080	373107	278978	477094
5/07/2020	302718	380942	281622	491054
6/07/2020	305703	388864	284244	505263
7/07/2020	309278	396873	286842	519724
8/07/2020	312911	404970	289414	534438
9/07/2020	316448	413155	291960	549411
10/07/2020	319646	421428	294478	564643
11/07/2020	322710	429790	296969	580138

Note: The forecasts with their confidence intervals are obtained with the Autoregressive Integrated Method of Moving Averages-ARIMA (0,2,9)

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DISCUSSION

This research was carried out to predict the number of cases with COVID-19 from June 12 to July 11, 2020, in Peru using the Autoregressive Integrated Method of Moving Averages (ARIMA), to later compare them with the cases observed in order to find an approximation between both results.

It must be taken into account that the forecasts obtained from a univariate time series model are extrapolations of the observed data until the time the series ends, being in many cases very effective providing a reference point to predict future values of confirmed cases. Most series are stochastic, in that their past values can partially determine the future, so accurate forecasts are impossible[24].

Various authors[1,11,15-20], worldwide, have developed models for the prognosis of COVID-19 cases based on the ARIMA method. They have used certain statistics to evaluate the goodness of fit of the model showing good results in short-term forecasts.

The modeling carried out in this study has followed all the stages of the Box-Jenkins methodology[11, 22-23], to obtain the best predictive model. Although, some researchers have applied these stages, they have only mentioned some statistical parameters used in their construction.

Moftakhar L and Seif M[1], mention the use of the analysis of the autocorrelation coefficients (ACF), partial autocorrelation (PACF) and the Box-Ljung test; Singh RK et al.[11], mention the use of the Akaike information criterion (AIC); Ceylan Z[15], mentions the use of the mean square error (RMSE), mean absolute error (MAE) and mean absolute percentage error (MAPE); Benvenuto D[16], mentions the use of the Augmented Dickey-Fuller unit root test (ADF) and the analysis of the autocorrelation coefficients (ACF) and partial autocorrelation (PACF); Yousaf M et al(17), mention the use of the analysis of the autocorrelation coefficients (ACF) and partial autocorrelation (ACF and PACF) and the Akaike information criterion (AIC); Hiteshi Tandon[18], mentions the use of the analysis of the autocorrelation coefficients (ACF) and partial autocorrelation (PACF) in addition to the variance, normality test, the mean absolute percentage error (MAPE), the Absolute Deviation of the Mean (DAM) and mean squared deviation (MSD); Rishabh Tyagi et al.[19], mention the use of the analysis of the autocorrelation coefficients (ACF) and partial autocorrelation (PACF), the Augmented Dickey-Fuller unit root test (ADF), and provide the confidence intervals (CI) 95% for point estimates; Finally, Perone G (20)mentions the use of the Akaike information criterion (AIC), the analysis of the autocorrelation coefficients (ACF) and partial autocorrelation (PACF), the Augmented Dickey-Fuller unit root test (ADF), the modified Elliott-Rothenberg-Stock (DF-GLS) unit root test, the mean absolute error (MAE), the normality test, the homoscedasticity, the Engle Lagrange multiplier test, and the Box test -Ljun, many of which coincide with those used in this investigation.

Although it is true that within the mathematical forecasting models, there are a variety of models, the ARIMA model has a higher fitting precision than the others[26]. It captures seasonal and non-seasonal forecast trends; This study focuses on a non-seasonal model to describe the growth pattern over time. On the other hand, if a model uses statistical approaches for its selection and evaluation, it must be recognized that the number of cases is not true. Since ARIMA is the only official source of information available in the country, it can lead to an inaccurate forecast. Even with this limitation, the results suggest that the method can help estimate the outbreak dynamics and provide guidelines to stop or better control the increase in infections in the country. It is also evident that any attempt to control depends on the public policies dictated by the authorities and above all. The awareness of each citizen about the spread of COVID-19 and the lethal effects that an irresponsible behavior or practice can have, as a consequence, the health of an individual, a family, and community.

Likewise, this model allows to analyze the possible evolution of the contagion curve and to be able to compare the results with those of other countries to evaluate the actions that are being taken.

It should be clarified that this estimate is strongly related to the trend of the original series data, and the result of the forecasts can help to understand any sudden change in the prognosis of COVID-19 cases.

Within the limitation of the study, it can be mentioned that the precision of the forecast depends on the precision of the applied data, this means that there is no other additional evidence that can estimate the exact number of patients with COVID-19 since only the number of official cases reported by the National Institute of Health and the National Center for Epidemiology, Prevention and Control of Diseases of the Ministry of Health was considered.

CONCLUSION

Compared with the observed data, the results obtained with the ARIMA model show an adequate adjustment of the values. This model is easy to apply and interpret, but does not simulate the exact behavior over time. It can be considered a simple and immediate tool to approximate the number of cases.

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