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Trend and Time Series Analysis of Daily New Case Report on COVID - 19 in Ethiopia: A Two-Year Daily Report Analysis

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ABSTRACT

The outbreak of coronavirus disease was first reported in December 2019 and spreading rapidly across the world, the severity of this pandemic is rising in Ethiopia until January 2022, and it shows up and down fluctuation afterward. It remains a serious economic, political, and social challenge, with disastrous consequences for emerging countries like Ethiopia. Ethiopia has ordered the closure of schools and public gatherings, as well as the implementation of a variety of strict and preventative measures. The study's major purpose was to look at the overall trend of coronavirus disease cases and to build an adequate forecast model. Daily new cases reports of coronavirus disease between 13, March 2020 and 13 March 2022 at the Ethiopian Public Health Institute and the Minister of Health's official website were used for fitting the trend & time series ARIMA model. Trend analysis and Box Jenkins methodologies were employed. The automatic best differencing parameter was identified using R software, different candidate models were compared. A total of 469,184 newly confirmed coronavirus disease cases were reported from 13 March to 13 March 2022. A maximum number of new cases were reported on December 28, 2021, with 5185. A total of 172,576 number of a total number of cases with a minimum of 0 and a maximum of 1829 were reported in the first year. A total of 296,608 number of a total number of cases with a minimum of 14 and a maximum of 5185 were reported in the second year. Quadratic trend analysis and ARIMA (4, 1, 3) were finally confirmed as the optimal model that showed the pattern and modeled to the pandemic. The 60-day forecast showed that total coronavirus disease cases would reach between 469,498 and 483,349 at the end of May 2022. The up and down behavior of the pandemic in the study suggested that different prevention

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mechanisms should be implemented to control and handles the contagious behavior of the pandemic and its devastating effect on economic, social, and political issues of the nation.

Keywords: - ARIMA, COVID-19, Ethiopia, Forecast, Stationary, Trend

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1. INTRODUCTION

The first human cases of COVID-19, the disease caused by a novel coronavirus causing COVID-19, subsequently named SARS-CoV-2 were first reported by officials in Wuhan City, China, in December 2019 [1]. World Health Organization declared a global pandemic disease after one month of the outbreak pandemic [2]. The pandemic and its devastating impact of the infection were spreading at an alarming rate both domestically and internationally. Consequently, nations across the globe respond swiftly to different mitigation and measures of stringent were enforced such as travel and movement restrictions, gathering prohibitions, generalized or partial lockdown of different social and community activities, hand-washing, and good hygiene promotion [3].

The report of WHO on March 10, 2022, shows that coronavirus cases globally were over 453,833,910 million, causing nearly 6,052,190 million deaths, while approximately 388,054,455 million people recovered from their illness. As of 5 March 2022, a total of 10,704,043,684 vaccine doses have been administered [4]. The report of COVID – 19 cases in the African continent first came in contact with the coronavirus pandemic on February 14, 2020, in the northernmost part, particularly Egypt. Because of this, the different governments of the country in the continent took severe restrictive measures to try to curb the spread of the disease [3].

By the same date, the number of confirmed COVID-19 cases in Africa amounted to 11,257,474 which represented around 3% of the infections around the world and 249,000 cumulative deaths, 10,529,106 total recoveries, and 100,554,471 total tests [5]. South Africa, Morocco, Tunisia, Libya, Egypt, and Ethiopia are among the countries with the most cases in the continent, according to the agency. In the African continent, South Africa had the highest number of cases & deaths, 3,686,556 & 99,681 respectively. Morocco and Tunisia, the second and third most

affected in Africa, recorded new cases (death) reporting 1,161,776 (16,036) and 1,017,907 (28,031) deaths, respectively [5,6].

The overall number of coronavirus (COVID-19) cases in East Africa had surpassed 1.3 million as of March 1, 2022. Ethiopia and Kenya were the most heavily affected countries in the African continent's eastern region, with 469 thousand and 323 thousand cases, respectively [7].

As per the report of the Ethiopian Federal Ministry of Health, the first coronavirus disease (COVID- 19) was confirmed on March 13, 2020, in Addis Ababa, Ethiopia. Consequently, the government of Ethiopia suspended schools, and public transportation, and announces different stringent & prevention techniques [3,8,9]. The minister of health of Ethiopia admitted and promoted using media that OVID -19 pandemic is still a health risk and worry for the population. On 10 March 2022, the report of Ethiopia public health institute revealed the total confirmed cases increased to 469,134 the reported death rate of 7484, 421,411total recovery, with 4,555, 130 total laboratory tests and 26,178,996 total vaccinated since the first COVID – 19 report date [3,8,9].

Individuals infected with the pandemic may have little or no symptoms and the symptoms range from mild symptoms to severe illnesses, and the incubation period of this virus may last 2 weeks or longer. The disease may still be contagion and infectious during the latent & initial period of infection and the virus can spread through respiratory air droplets and close contact from person to person until the material previously held by an infected individual if the materials are not sanitized by sanitizers [10].

In curbing and fighting against the pandemic, it is crucial to be able to identify the rate at which it spreads. Awareness at the level of spread at any given time can help governments plan, and develop public health policies & interventions to deal with the consequences of the pandemic. Creating awareness of the magnitude of the spread, of the vaccine and thus the timing of its peakedness is to be able to accurately predict the number of active cases at any given time in the future [11].

According to research findings, no study with a significant amount of data and a long duration has been undertaken in Ethiopia on COVID-19 trend analysis and forecasting on the daily case reports [12]. The study's purpose was to use time series models to analyze two-year trends in

COVID-19 dissemination, determine the best predictive model, and apply it to the possible prediction occurrence of COVID-19 cases in Ethiopia.

The significance of this study can be to find the best empirical model that has been established for the prediction of newly reported cases of COVID-19, the precision of which helps governors in decision-making to handle the pandemic, vaccine administration, and health system strategies; it can also highlight the trend of reported new cases of COVID-19 in Ethiopia. Finally, this paper explores the forecasting values for 60 days. Therefore, this investigation and forecasting result will play its part to help the government, minister of health, health professionals, policymakers, and the public to adopt new strategies and strengthen existing preventive measures & vaccine administration against the pandemic and can help predict the intended health infrastructure wants in the future in tackling and curbing the devastating problem of the pandemic in the social, economic and political environment of Ethiopia.

2. MATERIALS AND METHODS

2.1. Description of Study Area and Data Source

COVID - 19 daily new confirmed cases were collected from the Ethiopian Public Health Institute (EPHI) and the Minister of Health's official website in Ethiopia. A total of 731 observations on daily numbers of newly confirmed cases for time series modeling of COVID-19 for two years were included in the study from 13 March 2020 to 13 March 2022.

2.2. Data Analysis

The statistical model used in this study is time series. Time series is broadly defined as any series of measurements taken sequentially at different times.

Data Analysis

Test of stationary

Before fitting a specific time series model for time series data, the series must be made stationary. Stationarity occurs in a time series when there is no systematic change in mean (no trend) and if there is no change in the variance of the series. To test the stationarity of the time series data graphical methods (time series plot, autocorrelation function, and partial

autocorrelation function) and hypothesis testing methods like unit root test (Augmented Dickey-Fuller (ADF) and Phillips - Perron (PP) stationary test) were used.

The unit root test was subsequently used to test the stationarity of the series.

H_o: The time series data are not stationary or the data needs to be differenced to make it stationary or the series has a unit root

H_1: The time series data are stationary or the data is stationary and does not need to be differenced [13, 14, 15].

Transformation is the process of changing non-stationary time-series observations into a stationary time-series data set. Non-stationary series can be transformed into stationary series using differencing the data that, given the series Y_t, we create the new series

$$\Delta Y_t = Y_t - Y_{t-1} \quad \text{..... [1]}$$

2.3 Time Series Model

Trend Analysis

Linear and quadratic trend analysis can be used to fit and assess the trend of the new COVID -19 daily reports.

Linear trend equation

$$y_t = \beta_o + \beta_1 t + \varepsilon_t \quad \text{..... [2]}$$

Quadratic trend equation

$$y_t = \beta_o + \beta_1 t + \beta_2 t^2 + \varepsilon_t \quad \text{..... [3]}$$

Accuracy measurements such as mean absolute percentage error (MAPE), mean absolute deviation (MAD) and mean squared deviation (MSD) are used to determine the trend line's fitness [13, 14, 15].

Autoregressive Process of Order p, AR (p)

Assume the error term is purely random with mean zero and variance σ^2, then the process y_t is said to be an autoregressive process of order p if:

$$y_t = \alpha_1 y_{t-1} + \alpha_2 y_{t-2} + \cdots + \alpha_p y_{t-p} + \varepsilon_t \quad \text{..... [4]}$$

Where, y_t is series, $\alpha_1, \alpha_2, \ldots, \alpha_p$ are parameters of AR($\alpha_p \neq 0$) [13, 14, 15]

Moving Average Model of Order q, MA (q)

Suppose that ε_t is a purely random process with mean zero and variance σ^2, then a process $y_t$defined by [13, 14, 15]

$$y_t = \varepsilon_t + \beta_1\varepsilon_{t-1} + \beta_2\varepsilon_{t-2} + \cdots + \beta_q\varepsilon_{t-q} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [5]$$

Where, $\beta_1, \beta_2, \ldots, \beta_p$ are parameters of MA.

Autoregressive Moving Average, ARMA (p, q)

The order of an ARMA model is expressed in terms of both p for Autoregressive and q for moving average. The model parameters relate what happens in period t to both the past values and the random errors that occurred in past periods [13, 14, 15].

It is given by the following general model:

$$y_t = \alpha_1 y_{t-1} + \cdots + \alpha_p y_{t-p} + \varepsilon_t + \beta_1\varepsilon_{t-1} + \cdots + \beta_q\varepsilon_{t-q} \quad \ldots\ldots\ldots\ldots [6]$$

Autoregressive Integrated Moving Average ARIMA (p, d, q)

Autoregressive integrated moving average (ARIMA) models are a specific subset of univariate modeling, in which a time series is expressed in terms of past values of itself (the autoregressive component) plus current and lagged values of a "white noise" error term (the moving average component) that consist of an autoregressive polynomial, an order of integration (d), and a moving average polynomial [13, 14, 15].

A process (y_t) is said to be an autoregressive integrated moving average process, denoted by ARIMA (p, d, q) if it can be written as:

$$\alpha(B)\nabla^{\mathrm{d}} y_t = \beta(B)\varepsilon_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [7]$$

Where $\nabla^{\mathrm{d}} = (1 - \mathrm{B})^{\mathrm{d}}$

To identify a perfect ARIMA model for a particular time-series data, Box and Jenkins (1976) proposed a methodology that consists of the following four phases: model identification, estimation of model parameters, diagnostic checking for the identified model, and application of the model (i.e., forecasting) [14].

2.4 Ljung-Box Q (LBQ) Statistic: The Ljung-Box Q statistic can be employed to check the independence of the residual instead of visual inspection of the sample autocorrelations. A test of the hypothesis can be done for the model adequacy by choosing a level of significance and then comparing the value of calculated x^2 with x^2 critical value. This uses the entire residual sample with the null hypothesis that Ho: $\rho_1 = \rho_2 = \cdots = \rho_k = 0$

The test statistic is calculated using the following equation [8]

$$Q_{(r)} = n(n+2)\sum \frac{\gamma_k{}^2}{n-k} \sim \mathrm{x}^2\ \alpha(k-q) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [8]$$

Where n is the number of observations in the original time series,γ_k^2 is the sample autocorrelation of the residuals at *lag k, q is the number of parameters* and *k is the number of lags.*

Under the null hypothesis of model adequacy, Ljung and Box (1978) show that the Q - statistic approximately follows the x^2(k-m) distribution, where m is the number of parameters estimated. If a model is correctly specified, residuals should be uncorrelated and $Q_{(r)}$should be small (p-value should be large) [16]**.**

2.5 Forecasting

The last step of the ARIMA modeling process is forecasting. In forecasting, the goal is to predict future values of a time series variable, x_{t+k}, k =1, 2 . . . based on the data collected to the present, y= {y_t, y_{t-1}. . . y_1}. Throughout this section, we assume that $\boldsymbol{y_i}$is stationary and that the model parameters are known [13, 14, 16].

Once forecasts are made, some measurements of the accuracy of forecasts are the AIC, root mean square error (RMSE), mean absolute error (MAE), mean absolute percentage error (MAPE), and so on.

3. RESULTS AND DISCUSSION

3.1. Descriptive Results

Among 4,567,310 total number tests, 469,184 positive cases were confirmed, 421,472 recovered, and 7,486 were dead. Until the study period, 23,960,213 people took the vaccine. The number of daily COVID -19 cases during the two years ranged from 0 to 5185.

Table 1: Summary report on the total number of tests, positive cases, recovery, death, and total vaccinated administered from 13 March 2020 to 13 March 13, 2022, in Ethiopia

Study year	Number of tests	Number of positive cases	Number of recoveries	Number of deaths	Vaccinated people
Year 1	4,567,310	172,576	140,396	2,517	23,960,213
Year 2		296,608	281,076	4,969	
Total		469,184	421,472	7,486	

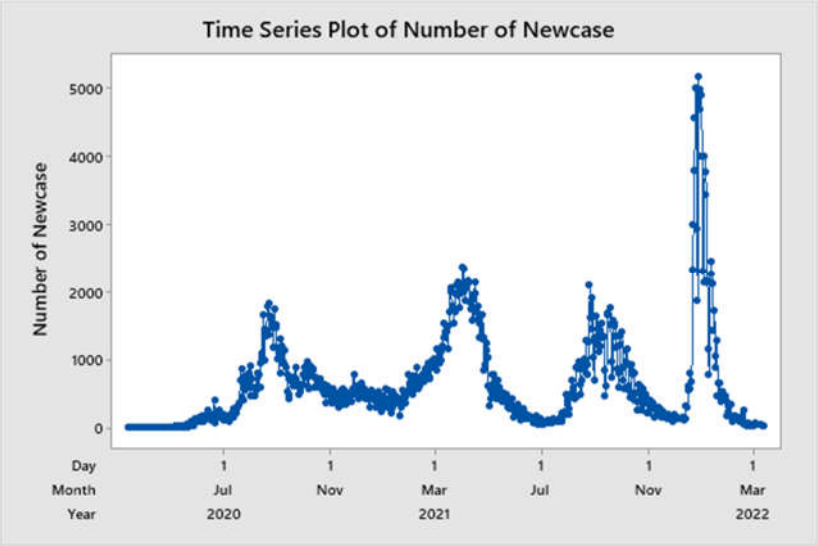


Figure 1: Time series plot for daily covid-19 new cases reported from 13 March 2020 to 13 March 2022 in Ethiopia

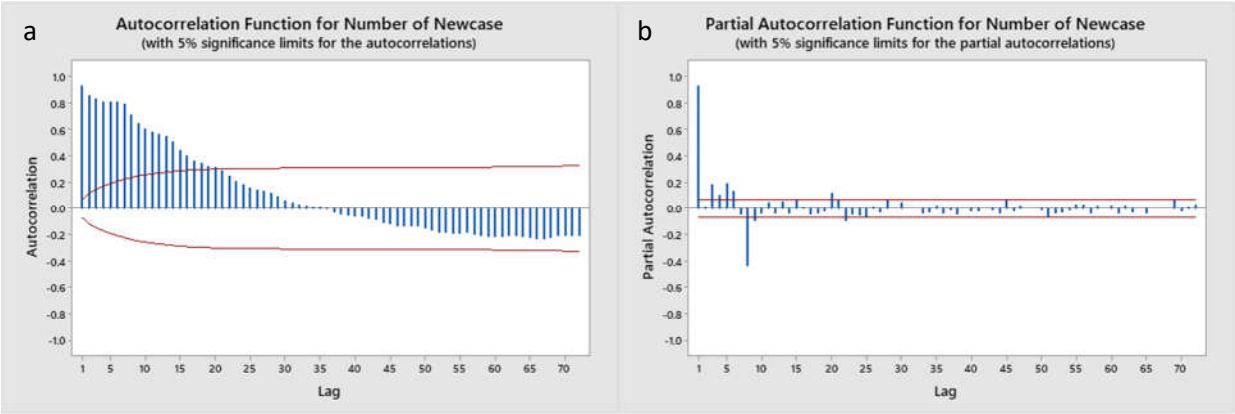


Figure 2: Autocorrelation (a) and Partial Autocorrelation (b) plot for daily covid-19 new cases report with 95% confidence interval in Ethiopia

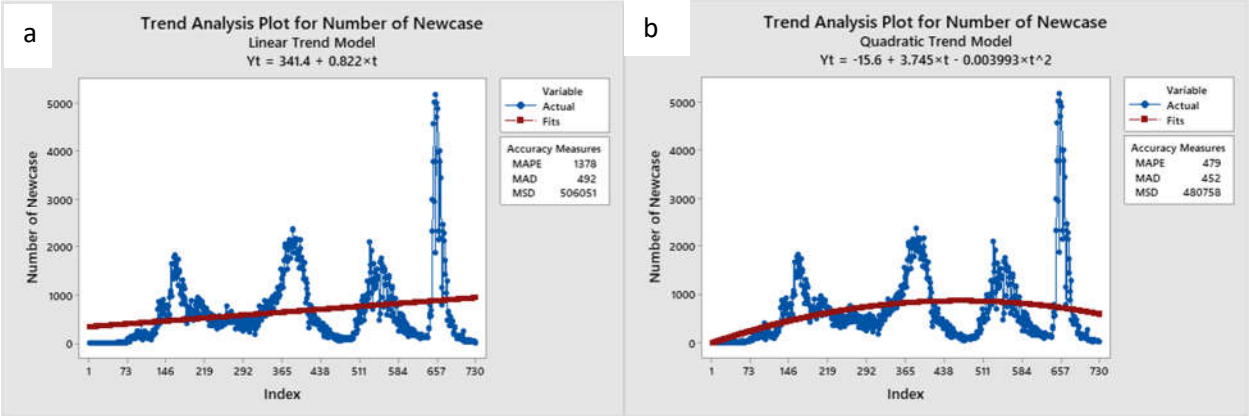


Figure 3: Linear (a) and Quadratic (b) trend plot for the daily covid-19 report from 13 March 2020 to 13 March 2022 in Ethiopia

3.2 Trend Analysis

In this article, the researchers employed linear and quadratic trend analysis. Based on measures of accuracy shown in Table 2 and Fig 3 (a) and (b), the quadratic trend is found to be best with the minimum value of MAPE, MAD, and MSD. From Fig.3b the quadratic trend model is the best-fitted overall trend for a daily case report of COVID-19 distribution in Ethiopia from 13 March 2020 to 13 March 2022.

Table 2: Measures of accuracy for trend analysis and Equation for daily COVID -19 cases reported from 13 March 2020 to 13 March 2022 in Ethiopia

Model Type	Measures of Accuracy			Equation
	MAPE	MAD	MSD	
Linear	1378	492	506051	$y_t = 341.4 + 0.822t$
Quadratic	479	452	480758	$y_t = -15.6 + 3.745t - 0.003993t^2$

3.3 Stationary Test

The pattern of the time series plot in Figure 1 shows a systematic upward and downward change in the mean. This indicates that the series is non-stationary. However, by critical observations day by day, it is clear that there existed a sharp rise and fall in daily confirmed cases of COVID-19. Besides, from the autocorrelation function plot in Figure- 2 (a) and (b), the series is not stationary & the behavior of the series is clear. Therefore, from the time series plot (Figure-1), autocorrelation, and partial autocorrelation plot (Figure- 2), it can be observed that our series has an upward & downward fluctuation then, differencing is needed to make it stationary.

Table 3: Summary statistic for different stationary tests on the original daily new cases reported from 13 March 2020 to 13 March 2022 in Ethiopia

Series	Types of test	P-value	Decision	Decision
Original	Augmented Dickey-Fuller Test	0.5179	Do not reject Ho	Non-stationary
	Phillips-Perron Unit Root Test	0.3885	Do not reject Ho	Non-stationary

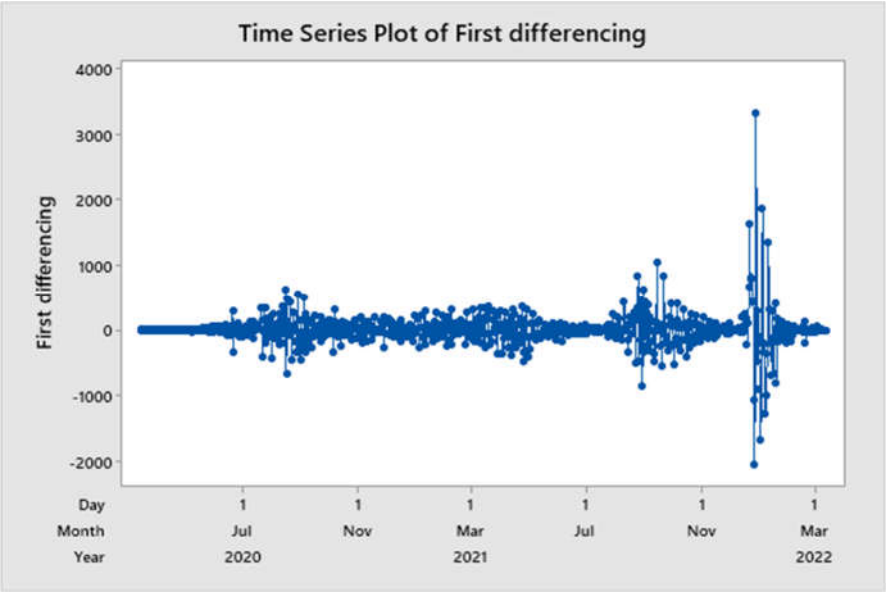


Figure 4: Time series plot after the first non-seasonal differencing of new covid-19 cases reported from 13 March 2020 to 13 March 2022 in Ethiopia

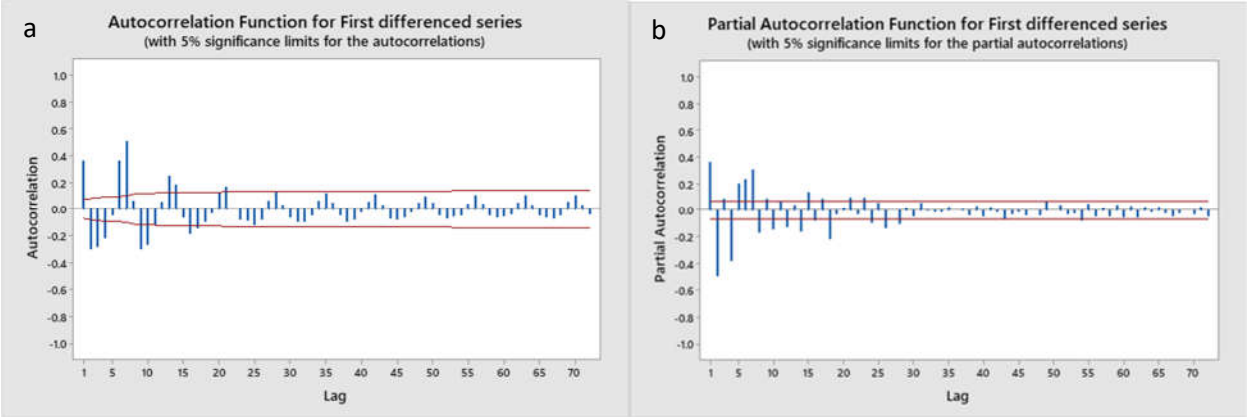


Figure 5: Autocorrelation (a) and Partial Autocorrelation (b) for the first differenced series with a 5 % significance limit for daily new cases from 13 march 2020 to 13 March 2022 in Ethiopia

Table 4: Summary statistic for different stationary tests after the first non-seasonal differencing of new daily Covid-19 cases from 13 March 2020 to 13 March 2022 in Ethiopia

Series type	Test type	P-value	Decision	Non-stationary/stationary
First non-seasonal differencing series	Augmented Dickey-Fuller Test	0.013	Reject Ho	Stationary
	Phillips-Perron Unit Root Test	0.021	Reject Ho	Stationary

Functions to estimate the number of differences required to make a given time series stationary was employed using the urca package in kpss unit root test, ndiffs (for non-seasonal differences), and nsdiffs (for seasonal differences). It suggested that the first differencing is enough for non-seasonal differencing & no need for seasonal differencing. The researchers also employed auto.arima function in forecast package in R software to get the best order of differencing to convert non-stationary data to stationary. The first differencing is enough to achieve stationarity and it gives us an initial model of ARIMA (4, 1, 3). After the first differencing of the original series, the data became stationary from Fig. 4 and Table 4

3.4 Box-Jenkins Models

ACF and PACF showed in Fig 5 (a) and (b) indicate a graph of sine function patterns, which would reveal some combination of AR(p) and MA(q) processes. From this, the researchers employed a comparison of different autoregressive integrated moving average models (ARIMA (p, q, q)) in the estimation stage. The auto.arima function in the forecast package of R software suggested that first differencing is enough to achieve stationarity and it gives us an initial model of ARIMA (4, 1, 3).

3.4.1 ARIMA (p, d, q) Model Comparison

Visual inspection of ACF, and PACF plots above shows; that there are no clear properties of autoregressive and moving average models that indicate the mixture of autoregressive and moving average models (ARMA) was better. So, based on different model selection criteria the best time series model after applying techniques of first differencing was selected. As can be seen from Table 5 ARIMA (4, 1, 3) model with the smallest value of ME, MAPE, RMSE, MAE, MASE, and AIC and the largest value of log-likelihood was the best.

Table 5: Different ARIMA models with different values of p and q with d=1 on daily new cases reported from 13 March 2020 to 13 March 2022 in Ethiopia

ARIMA Types	ME	MAPE	RMSE	MAE	MASE	AIC	Log-likelihood
ARIMA(4,1,3)	0.0275	30.860	242.8989	127.7192	0.1822	10109.36	-5046.68
ARIMA(4,1,2)	0.0409	32.219	245.5861	129.6082	0.9457	10123.04	-5054.52
ARIMA(4,1,1)	0.0544	33.044	259.0882	131.9598	0.9628	10198.48	-5093.24
ARIMA(3,1,3)	0.0057	33.689	245.7657	130.3098	0.9508	10124.43	-5055.21
ARIMA(2,1,3)	0.0251	38.175	247.0686	125.9882	0.9193	10130.03	-5059.01
ARIMA(1,1,3)	0.0442	35.353	264.2849	134.8127	0.9837	10225.29	-5107.64
ARIMA(2,1,2)	0.0107	34.307	248.0218	128.765	0.9395	10133.65	-5061.83
ARIMA(1,1,1)	0.0442	38.167	268.6893	133.078	0.9710	10245.34	-5119.67
ARIMA(2,1,1)	0.0454	33.014	263.4958	134.6445	0.9824	10218.95	-5105.48
ARIMA(4,1,4)	0.0284	35.006	242.8803	127.6378	0.9313	10111.24	-5046.62
ARIMA(5,1,3)	0.0434	33.519	244.5772	129.7554	0.9468	10121.05	-5051.53
ARIMA(5,1,4)	0.0128	35.005	242.2946	127.269	0.9286	10109.75	-5044.88

3.4.2 Test of the Significance for the ARIMA (4, 1, 3) Coefficients

In Table 6, the ARIMA (4, 1, 3) shows AR (1), AR (3), AR (4), MA (1), MA (2), and MA (3) coefficient was found to be statistically significant. Thus, the corresponding parameters are significantly different from zero. Therefore, we incorporate these parameters in the final model to forecast daily COVID – 19 reports in Ethiopia. In the reverse AR (2) coefficient was found to be insignificant. Hence, there is not enough evidence that the parameters of AR (2) are significantly different from zero.

Table 6: ARIMA (4, 1, 3) model for new daily COVID – 19 cases reported from 13 March 2020 to 13 March 2022 in Ethiopia

Type	Coef	SE of	T	P-value
AR (1)	0.2147	0.0608	3.531	0.000
AR (2)	0.0738	0.0589	1.253	0.289
AR (3)	-0.6687	0.0503	13.294	0.000
AR (4)	- 0.1879	0.0447	4.204	0.000
MA (1)	-0.4004	0.0523	7.656	0.000
MA (2)	-0.2997	0.0560	5.352	0.000
MA (3)	0.7407	0.0438	16.911	0.000
MSE	59653			

P-value< 0.05 significant

3.4.3 Diagnostic Checking

The box-pierce statistics gives an insignificant p-value = 0.1965 (p-value greater than significant level of alpha =0.05, Chi-squared value = 1.6681) which revealed that the residuals are uncorrelated. Because the first difference that applies before shows the constant mean, constant variance, and the residuals are white noise. Visual inspection in the top left corner of the normal probability plot in Figure 6 shows it is approximately a straight line this revealed that the residuals are normally distributed. The graph in the top right corner of residual versus fitted values has no obvious pattern this indicated that the residuals have constant variance.

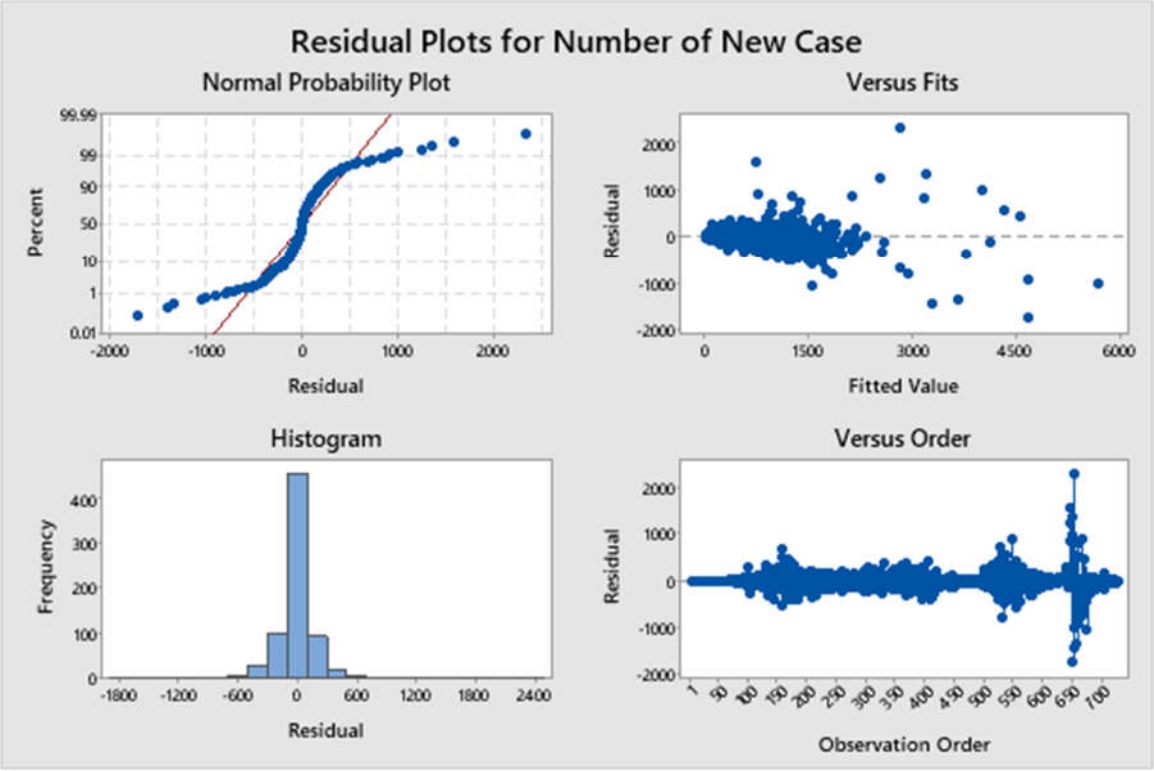


Figure 6: Normal probability (top left corner), residual vs fitted value (top right corner), histogram of residuals (lower-left corner), and residual vs order (lower right corner) plots of residual of coronavirus in Ethiopia between March 13, 2020, and march 13, 2022 in Ethiopia

3.4.4 Forecasting of New Daily COVID -19 Report

Using the selected model forecast was made for the coming 60 days. As shown in Figure 7 the number of daily COVID -19 incidences is forecasted in Ethiopia. If special emphasis is not

given, the 95 % forecasting values for the next 60 days shows there will be an increment of new report between 314 and 14,165.

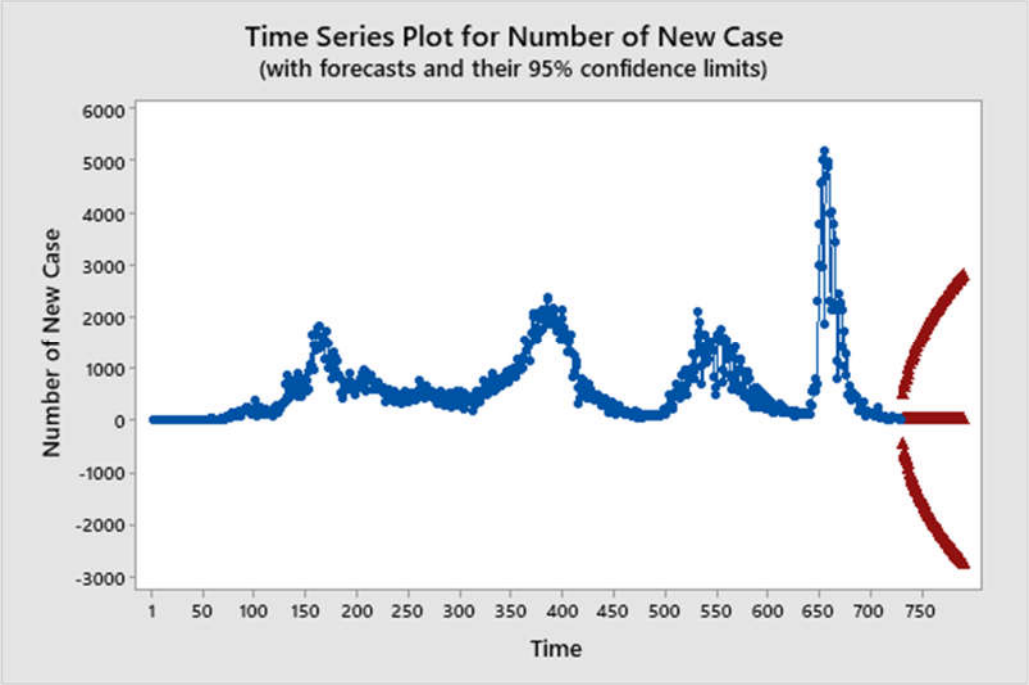


Figure 7: Forecasting graph for the coming 60 days in Ethiopia

4. CONCLUSION

The study data in the indicated period shows the highest records were recorded in December 2021 and January 2022 but the daily report of new cases decreases in February and March 2022. The maximum number of new cases was reported on December 28, 2021, with 5185. A total of 469,184 newly confirmed COVID-19 cases were reported from 13 March to 13 March 2022. Trend analysis and different ARIMA models were employed and Quadratic trend analysis and ARIMA (4, 1, 3) were finally confirmed as the optimal model. The ARIMA model was also used to identify the COVID-19 trend and showed an up-and-down pattern daily in the number of confirmed cases. Based on the next 60-day forecasted values of a 95% confidence interval between 314 and 14,165 new confirmed cases of COVID-19 will expect. This up-and-down behavior in the number of cases in Ethiopia needs more attention must have been paid to the control of COVID-19. Although the Minister of Health of Ethiopia and other concerned bodies of the government implements a mechanism to control the pandemic, it may affect the health, economic, political, and social activities of the country. The study suggested that different

stringency and control mechanisms should be implemented to control the contagious behavior in the seasons that indicate increment of the pandemic to curb its negative effect on economic, educational, social, and political issues of the nation.

ABBREVIATIONS

ACF, autocorrelation function; ADF, augmented Dickey-Fuller test; AIC, Ackakie information criteria; AR, autoregressive; ARIMA, autoregressive integrated moving average; CDC, communicable disease control; COVID-19, coronavirus disease 2019; EPHI, Ethiopia Public Health Institute; **MA,** Moving Average; **MAD, Mean Absolute Difference;** MAE, mean absolute error; MAPE, Mean Absolute Percentage Error; ME, Mean Error; MASE, Mean Absolute Squared Error; MoH, Minister of Health; **MSD,** Mean Squared Deviation**;** MSE, mean squared error; PACF, partial autocorrelation function; PP, Phillips-Perron; RMSE, root mean squared error; SPSS, statistical package for Social Science; WHO, World Health Organization.

Declarations

Ethics approval and consent to participate
Not applicable
Consent for publication
Not applicable
Availability of data and materials
The data used in this study are available from Ethiopia public health institute, https://www.ephi.gov.et/ and Ministry of Health, https://www.moh.gov.et/ facebook pages upon reasonable request.
Competing interests
The authors declared that there was no competing interest.
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