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Predictive Models for Forecasting Coronavirus Disease 2019 Cases: Relevance to Public Health Services

Alvin O. Cayogyog,[1]* Reynaldo O. Cuizon,[2] Felix C. Chavez Jr,[3] Randy A. Tudy[4]

[1]Agusan del Sur State College of Agriculture and Technology, Bunawan, Agusan del Sur, Philippines.
[2]Holy Cross of Davao College, Sta. Ana Avenue, Davao City, 8000 Davao del Sur, Philippines.
[3]Jose Maria College Foundation, Inc., Philippine-Japan Friendship Highway, Davao City, 8000 Davao del Sur, Philippines.
[4]University of Southeastern Philippines, Bo. Obrero, Davao City.

**Correspondence: acayogyog@asscat.edu.ph*

ABSTRACT

Introduction	The global impact of the coronavirus disease 2019 (COVID-19) pandemic has continually jeopardized vulnerable populations encompassing children, youth, elders, and individuals with immunodeficiency and comorbidities.
Methods	In recognizing the crucial role of predictive analytics in shaping public health decisions, this study utilizes a predictive design, drawing on official data from the Department of Health (DOH) in the Davao Region, Philippines, spanning 57 days from March 15 to May 10, 2020. By comparing the Susceptible, Infected, Recovered (SIR) model and the Autoregressive Integrated Moving Average (ARIMA) model, the research aims to provide a scientific foundation for informed decision-making by public health authorities.
Results	Analysis revealed that the SIR model emerged as the most effective in identifying trends and forecasting future cases. Despite both models indicating a substantial reduction in infection rates, caution is advised against discontinuing control and preventive measures due to the latent potential for another surge. The findings underscore the necessity for scientifically forecasted data to guide decision-makers in enhancing the responsiveness of public health services during similar and potentially worsening conditions.
Conclusions	Hence, this study contributes to the ongoing pandemic preparedness and responsiveness discourse. Its emphasis on predictive analytics, particularly the SIR model, offers valuable insights for authorities tasked with safeguarding public health. The significance lies in addressing the current situation in the Davao region and providing a template for future scenarios. As the world grapples with the unpredictable nature of infectious diseases, informed decision-making based on scientific forecasts becomes imperative for effective public health management.
Keywords	COVID-19; SIR; ARIMA; Enhanced Community Quarantine; Philippines

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INTRODUCTION

In the history of humankind, nothing has killed more people than the virulent disease.[1-3] Similarly, the entry of pneumonia with a strange cause, originally detected in Wuhan, China, on December 31, 2019[4-5] has unceasingly brought chaos to many countries, including the Philippines.[6] One month after the first case in China was reported, the World Health Organization declared the outbreak.[7] Subsequently, two months later, the virus was named Coronavirus Disease 2019 (COVID-19).[8]

The spread of COVID-19 has pushed the world to undertake handwashing, social distancing, and community quarantine, among others, as disease control measures.[9-10] The Philippines, particularly Davao City, adopted such interventions, which were raised to an enhanced level in one month and 15 days after the first case was reported on January 30, 2020. It was then extended up to 15 May 2020.[11] Before these dates, Davao City had no SARS-CovV-2 reported infection cases or incidence rate; hence, there was no report on doubling time or growth rate either on hospitalization or death. As soon as the pandemic struck, the *Ro* was 2.4 while the doubling time was 3 days.

The community quarantine issue received various responses, from affirmative to raging negative, not only in Davao City but even around the world.[12-13] Apart from front liners apprehension concerning critical health care preparedness[14-15] and government economic managers' dilemma on financial equilibrium,[16] the community's conditions, which revolved around sustenance from hunger, human suffering, and anxiety, were aggravating day after day.[17] Amidst the stressful feelings of fear and uncertainty pressures, governments, more than anybody else, have to decide the right time to shift into a new intervention system. Such a decision demanded an appropriate basis derived from scientific forecasting rather than just a hit-and-miss method. Hence, this study aimed to determine the trends and projections of the COVID-19 cases in Davao City in terms of growth rate, infection rate, doubling time, and basic reproduction number using the ARIMA and SIR models, hoping to further determine the most appropriate forecasting model both for this case and for similar cases in the future. In the absence of a similar study that focuses on Davao City, this study proves its importance and relevance as one of the bases of the city in making appropriate and scientific-based decisions to address the current problems. This study further aimed to document the relevance of forecasting COVID-19 cases for the enhancement of current and future public health services.

The study utilizes the official data provided by the Department of Health (DOH) in Davao Region, Philippines. The data were derived from March 15 to May 10, 2020 (57 days) and within the enhanced community quarantine intervention span. Such intervention strategies include, among others, specific rules such as social distancing, the use of face masks, district or barangay lockdown where checkpoints are strongly positioned, the provision of critical health care in a designated hospital, sanitation activities in populated places like markets and communities, and the use of food and medicine passes.

METHODS

This study used SIR and ARIMA predictive modeling techniques to analyze the current trend and to forecast the future values of COVID-19 cases in Davao City. Such techniques have undertaken the process that utilized data and statistics to calculate outcomes with data models. The ARIMA is a forecasting algorithm based on the idea that the information in the past values of the time series can alone be used to predict future values.[18] It is one of the most popular linear models in shorter time series forecasting.[19] The SIR Model is used in epidemiology to compute the amount of susceptible, infected, and recovered people in a population.[20] It is a promising approach for forecasting seasonal influenza while simultaneously accounting for multiple sources of uncertainty.[21] In this study, these models were used to foresee the values worthwhile as the basis for making decisions in terms of estimating possible shifts or extensions of interventions and actions that may be undertaken to address the COVID-19 cases in Davao City.

In the analysis utilizing the ARIMA model derived from IBM SPSS version 25 released in 2017, the dataset (t) encompasses a span of 57 consecutive days, starting from March 15 to May 10, 2020. The dataset comprises only the daily reported newly infected or diagnosed cases as officially documented by the Department of Health (DOH) of the Davao region. This investigation employed census sampling, wherein each day's recorded cases were meticulously considered to be included in the dataset.

To facilitate analysis, a uniform time interval was maintained across observations. The time axis was appropriately rescaled to a set of days $\{1, 2, \ldots, 57\}$. To assess the model's appropriateness, a stationary process was implemented by applying a first-order differencing sequence at d=1. This procedure involved calculating the differences between pairs of observations at lag intervals, effectively transforming the nonstationary series into a stationary one. After performing the stationary process, it was obtained that the model is good for forecasting future values through the parameters of ARIMA (0,1,0) using the general form of ARIMA (p, d, q) that is expressed as:

$$Yt=c+\phi 1Yt-1+\phi 2Yt-2+\ldots+\phi pYt-p+\theta 1\varepsilon t-1+\theta 2\varepsilon t-2+\ldots+\theta q\varepsilon t-q+\varepsilon t.$$

Where:
Yt is the observed time series at time t
c is a constant term
$\phi 1,\phi 2,\ldots,\phi p$ are the autoregressive coefficients
εt is the white noise error term at time t
$\theta 1,\theta 2,\ldots,\theta q$ are the moving average coefficients

The fit of the model is clearly illustrated by the respective relevant lines for the observed, fit, and the lower and upper limits of the model.

Finally, the Department of Health took a conscientious approach during the pandemic by refraining from disclosing or providing the demographic profile of COVID-19 cases. Given the sensitivity of being infected with the Coronavirus disease, all details regarding the background of the cases, except for the actual numbers of infections, were carefully concealed. This ethical stance by the department was accorded utmost consideration and respect in the course of this study. To ensure adherence to ethical concerns, this study sought and obtained approval for exemption from ethical board review from the accredited ethics review board of the University of the Immaculate Conception with the decision hereunder:

After a preliminary review on December 28, 2023, of the above documents stating the utilization of secondary data for modeling purposes, the UIC-Research Ethics committee deemed it appropriate that the above proposal be exempted from review.

RESULTS

The succeeding presentations are focused on the findings on the trends of the COVID-19 cases in Davao City. The first part is on the findings with the use of the SIR model. It is followed by the findings with the use of the ARIMA model.

The use of the SIR Model

Table 1 shows a decrease in the Basic Reproduction Number from 3 April (2.423) to 10 May (1.010). It suggests a potential reduction in the transmission rate and the risk of a widespread outbreak. A Basic Reproduction Number below 1 would typically indicate that, on average, each infected person is transmitting the infection to less than one other individual. This is a critical threshold for controlling the spread of the disease, as it suggests a decline in the outbreak.

Figure 1 displays an erratic behavior of new cases from May 5 to May 9. Hence, it can be observed that the growth rate goes beyond five percent on May 5 and May 8, suggesting a potential spread of infection which may grow exponentially at any given time. It can be explained by the computed Basic Reproduction Number (Ro) estimate on May 10 which is still above 1 (See Table 1). The Ro indicates the transmissibility of the virus. For Ro > 1, the transmission is likely to increase, and for Ro < 1, it is likely to die out.[22]

Nevertheless, the Ro values have drastically dropped from April 3 (Ro=2.423) before the start of Enhanced Community Quarantine (ECQ) to almost nearly 1 on May 10. The decline in the Basic Reproduction Number would represent the effectiveness of ECQ implementation and other preventive measures in lowering the infection rate in the city. Indeed, it can be noticed that the daily cases growth factor is mostly below 5 percent during the ECQ period (see Figure 2).

On the other hand, an epidemic doubling time was computed as another test to capture the trajectory of the outbreak (see Table 2). This metric determines the sequence of intervals at which the cumulative incidence doubles.[23] The results show an increase in the doubling time from 3 days (before ECQ) to 11 days (during ECQ), which indicates a slowdown in transmission.

The use of the ARIMA Model

As a result, (Figure 3), it appears that the newly infected cases of COVID-19 in Davao City had a gradual erratic trend in the initial phase, then rapidly rose to a peak and went down subsequently before it went to an erratic upward trend and then dropping tremendously in the final phase.

Table 3 presents the model statistics of ARIMA (0,1,0). The generated model is good in forecasting the new cases of COVID-19 in Davao City as substantiated by the R-squared of -0.710, which is closer to /1/. Moreover, the Table 3 shows a Root Mean Squared Error (RMSE) value of 4.136 which is considered a lesser value. The lesser the RMSE value, the better the model. The result appears to be not normally distributed as shown in the Ljung-Box, which informs that the generated model has a *p*-value of 0.333 which is greater than 0.05 degree of confidence.

Figure 4 traces the fitting prediction of the ARIMA (0,1,0) model. It depicts the forecasting model in a blue line graph, and the upper control line (UCL) and lower control line (LCL) in dotted lines on the sides of the observed trend in red line graphs.

Table 1 Basic Reproduction number (Ro) estimates

Date	Basic Reproduction Number
3-Apr	2.423
10-May	1.010

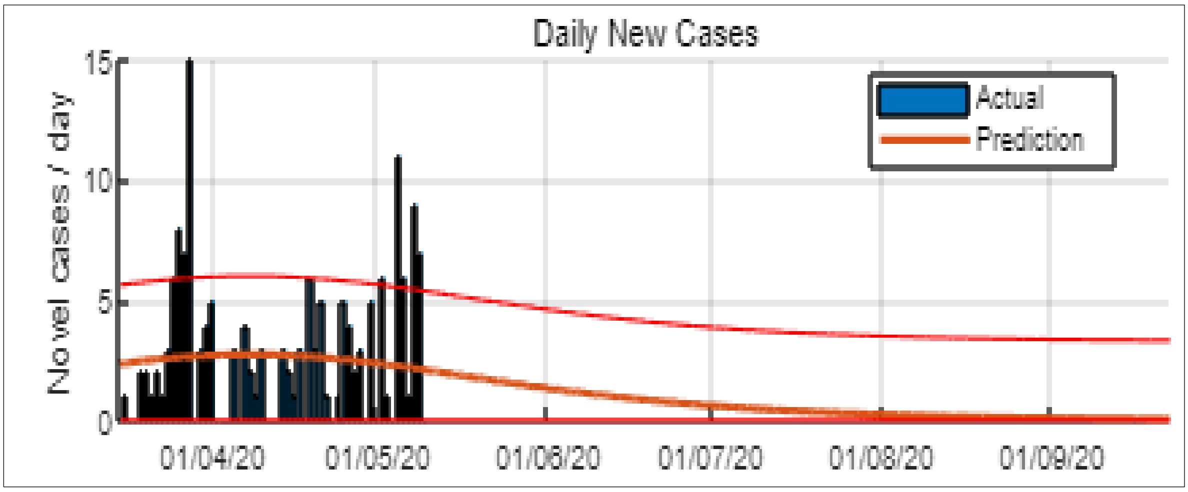


Figure 1 Infection Rate Status in Davao City

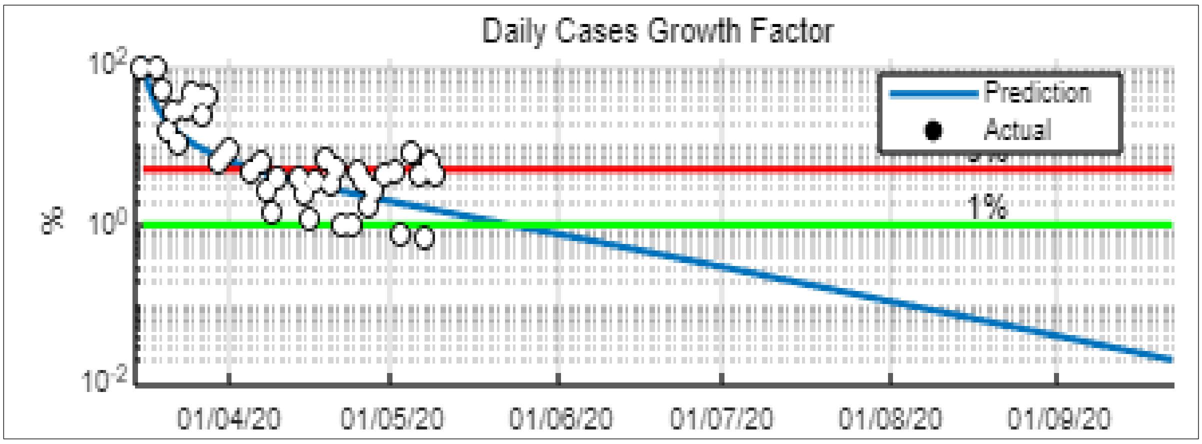


Figure 2 Growth Rate of COVID-19 in Davao City

Table 2 Epidemic Doubling Time

Date	Doubling Time
Before ECQ (till April 4)	3 days
During ECQ (till May 9)	11 days

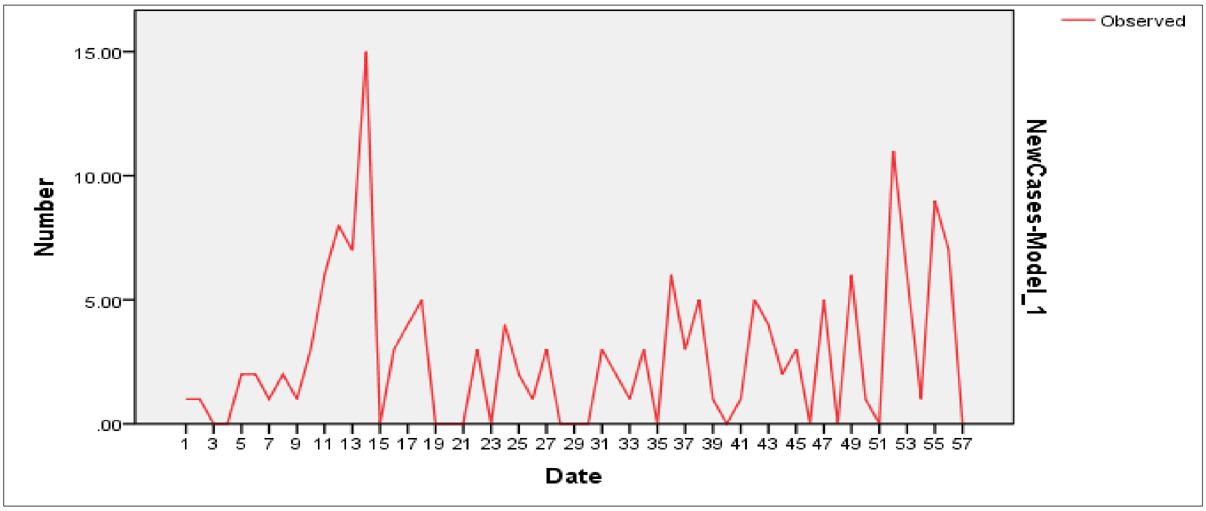


Figure 3 New Infected Cases of COVID-19 in Davao City

Table 3 Model Statistics

Model	Number f Predictors	Model Fit statistics			Ljung-Box Q(18)			Number of Outliers
		Stationary R-squared	R-squared	RMSE	Statistics	DF	Sig.	
New Cases-Model_1	1	.001	-.710	4.136	19.997	18	.333	0

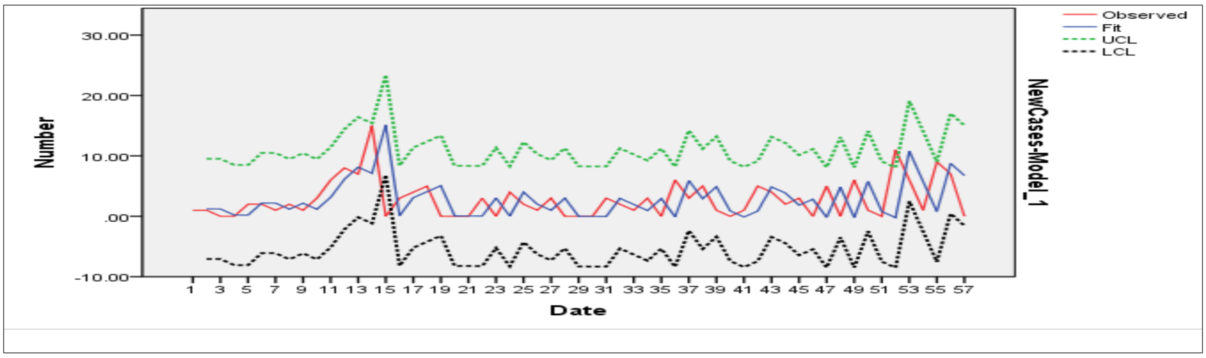


Figure 4 The fitting prediction based on ARIMA (0,1,0) Model

Table 4 ARIMA Model Parameters

					Estimate	SE	t	Sig.
New Cases-Model_1	New Cases	No Transformation	Constant		.245	1.150	.213	.832
			Difference		1			
	Days	No Transformation	Numerator	Lag 0	-.009	.034	-.261	.795

Based on the information appearing in Table 4, it can be explained that a positive estimate (0.245) for new Coronavirus cases suggests a positive relationship between this variable and the predicted outcome (number of cases). The t-value being 2.13 indicates that the estimate is statistically significant at a certain confidence level. The p-value (Sig. = 0.832) is relatively high, suggesting that there might not be strong evidence to reject the null hypothesis that the coefficient is equal to zero. For the numerator estimate, the values and significance level are lower, suggesting that this variable may not have a statistically significant impact.

Furthermore, Figure 5.0 shows the active infected cases (current cases) with COVID-19 in Davao City. In this study, the set of days (t) consists of 57 series of days from March 15 up to May 10, and corresponding day-to-day recorded active infected cases are considered and measured. Given a set of observations made at uniformly spaced in time intervals, the time axis is conveniently rescaled, that is, time is the set {1, 2, …, 57). The result shows that the active infected cases of COVID-19 in Davao City are fluctuating but in a constantly rising trend as illustrated in the red color line graph (Figure 1).

Table 5 presents the model statistics of ARIMA (0,1,0). The generated model is good in forecasting the current infected cases of COVID-19 in Davao City as substantiated by the R-squared of 0.943, which is closer to /1/. Moreover, the table shows a Root Mean Squared Error (RMSE) value of 3.472 which is considered a lesser value. The lesser the RMSE value, the better the model. The figures presented in the Ljung-Box inform that the generated model has a *p*-value of 0.480, which is greater than 0.05 degree of confidence. It indicates that the data are not normally distributed and non-linear.

Figure 6 traces the fitting prediction of the model. It depicts the forecasting model in a blue line graph, and the upper control line (UCL) and lower control line (LCL) in dotted lines on sides with the observed trend in red line graphs.

The ARIMA Model Parameters shown in table 6 explain that the estimate of 0.790 for current Coronavirus cases suggests a positive relationship between this variable and the predicted outcome (number of cases). The t-value being 0.818 indicates that the estimate is not statistically significant at a conventional level of 0.05. This means there may not be strong evidence against the null hypothesis that the coefficient is equal to zero. The p-value (Sig. = 0.417) is relatively high, further supporting the notion that the estimate might not be statistically significant.

For the Lag 0 variable, the values and significance level are again not statistically significant, indicating that this variable may not have a significant impact on the prediction.

Results on Projections

The succeeding presentations are the findings on the projections of the COVID-19 cases in Davao City. The first part is on the findings with the use of the SIR model. It is followed by the findings with the use of the ARIMA model.

The use of the SIR Model

Using the SIR Model Analysis (See Figure 7) as of May 10, the epidemic stage of the city is still in the fast-growth phase (RED). Subsequently, if the government intervention does not change (ECQ) and the situation remains stable, then by the SIR Model, the predicted final size of an epidemic is about 230 cases. However, it should be noted that there are 6,516 total susceptible individuals, who can likely be infected in the entire epidemic duration. The total epidemic duration in the ECQ model will be about 200 days, which is expected to end on October 02, 2020.

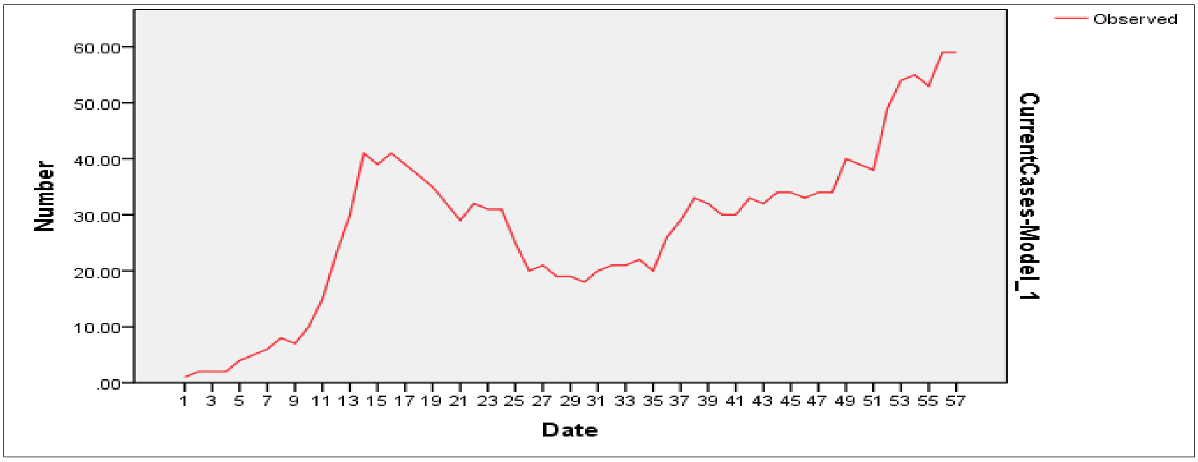


Figure 5 Active Infected Cases of COVID-19

Table 5 Model Statistics

Model	Number of Predictors	Model Fit statistics			Ljung-Box Q(18)			Number of Outliers
		Stationary R-squared	R-squared	RMSE	Statistics	DF	Sig.	
Current Cases-model_1	1	.002	.943	3.472	17.637	18	.480	0

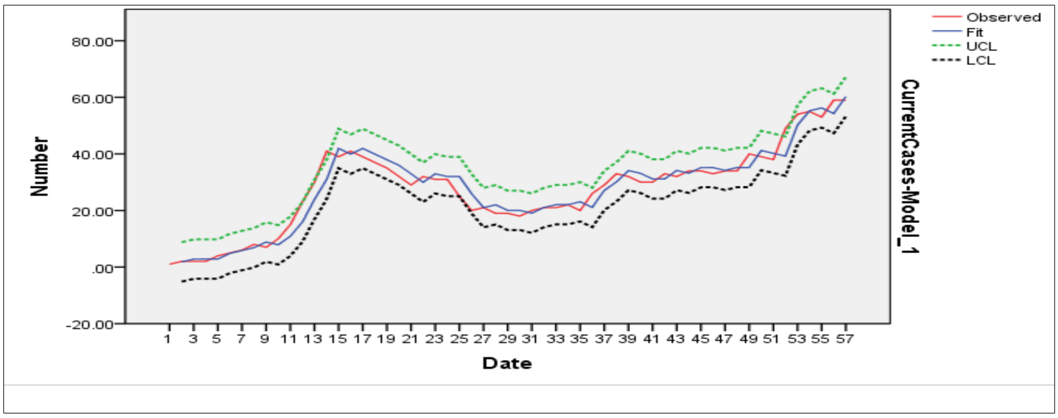
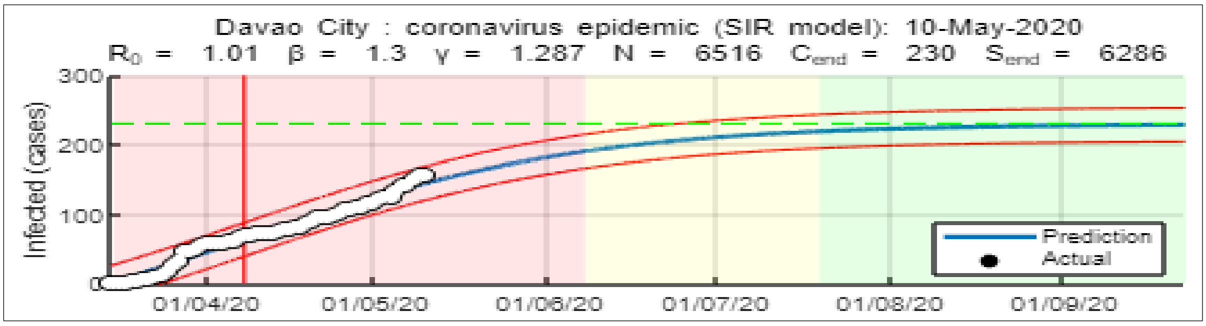


Figure 6 The fitting prediction based on the ARIMA (0,1,0) Model

Table 6 ARIMA Model Parameters

					Estimate	SE	t	Sig.
Current Cases-Model_1	Current Cases	No Transformation	Constant		.790	.966	.818	.417
			Difference		1			
	Days	No Transformation	Numerator	Lag 0	.008	.029	.291	.773



*Color coding representing epidemic phases:**Red** - fast growth phase; **Yellow** - transition to steady-state phase; **Green** - ending phase (plateau stage)*

Figure 7 Forecast of COVID-19 Epidemic in Davao City using SIR Model

The use of the ARIMA Model

Figure 8 traces the fitting prediction for newly infected cases of COVID-19 in Davao City with corresponding forecast data for the next 60 days. It is divided into two parts, namely, the actual and forecasted new infected cases. It revealed that the forecasted new infected cases go from an erratic trend in the actual phase into a downward trend in the forecast phase. It further suggests that as time (days) increases, the trend of forecasted new infected cases as indicated in the thick blue line graph goes in a downward direction until it approaches zero level apparently in the 60th day.

Table 7 presents the computation results to forecast the new infected cases of COVID-19 in Davao City using the actual data. Specifically, it shows both the actual new infected cases in 56 days and the forecasted values in 4 days. As shown, the forecasted values of specific new infected cases of COVID-19 become zero (0) on the 60th day. It appears that from day 57 to 60, the forecasted lower limit with 0 values has a corresponding upper control limit ranging from 9 to 14 values. It simply explains that newly infected cases within a straight 4-day span are constantly in zero levels with a lower limit of 0 and an upper limit with values not more than 14. Nevertheless, this situation presumes that the intervention since day one has been undertaken continuously. Furthermore, it explains that there is a forecast of three (3) new infected cases in around three days before the date set for the supposed end of the enhanced community quarantine period was assessed and before the extension of ECQ, especially for Luzon and other selected areas was announced.

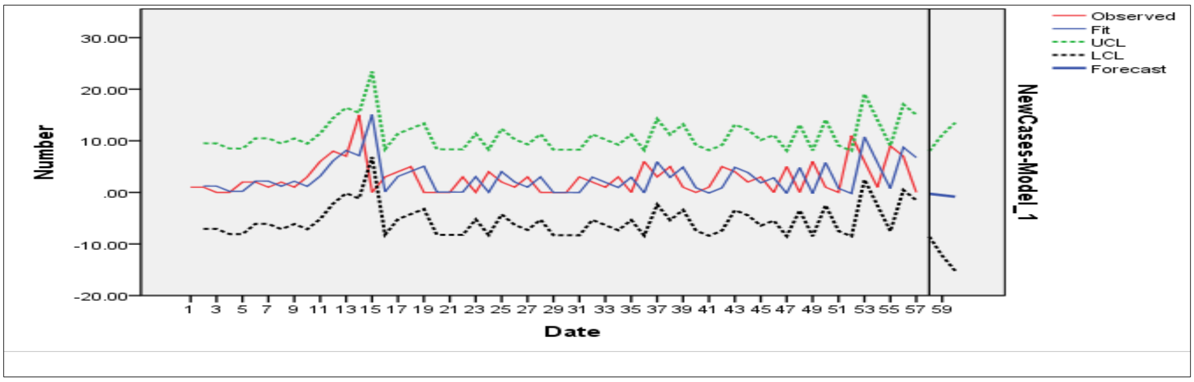


Figure 8 The fitting prediction based on New Infected Cases of COVID-19 in Davao City using ARIMA (0,1,0) Model

Table 7 Computation results on forecasting of new cases of COVID-19

	Days	New Cases of COVID-19		
Actual	1	1		
	2	1		
	54	1		
	55	9		
	56	7		
	57	0		
Forecast			Lower Control Line	Upper Control Line
	58	0	0	9
	59	0	0	12
	60	0	0	14

DISCUSSION

Results derived from interviews with key informants revealed several lessons learned from their experiences of the COVID-19 pandemic. First, the lack of competent personnel in concerned healthcare offices to spearhead the analysis of the trends and to forecast future cases caused their difficulty in coming up with decisions anchored on scientific data. Second, the healthcare services cannot depend on "hit and miss" strategies in initiating intervention to protect public health and safety because aside from being dangerous, it usually causes delayed actions from concerned authorities. Third, without the scientifically forecasted data, the preparedness of healthcare facilities cannot be ensured and the danger of being overwhelmed with soaring cases remains a constant threat. Fourth, the absence of scientifically forecasted data contributed to the increasing numbers of the anxious public because of an uncertain duration of life-threatening infection. Fifth, without well-defined forecasted information, the health departments, facilities, programs, and healthcare personnel are unable to craft and implement appropriate action as an intervention. In other words, forecasted data helps in promoting prevention rather than cure.

Using the data from the DOH Davao City, trends and projections were analyzed using the SIR and the ARIMA models. It was only the SIR model that showed a predictive power. The ARIMA model did not provide significant findings precisely because the data were not normally distributed and were non-linear. On the trends and forecasting, the results of the SIR model showed that the implementation of ECQ significantly slowed down the reported number of cases in Davao City. Hence, this study proved the effectiveness of the use SIR model and the implementation of ECQ. First, based on the findings, the SIR model was effective in measuring the trends and projections. The use of this model and its findings are consistent with previous studies. For example, in their review of literature involving 29 studies (10 modeling studies on COVID-19, four observational studies, and 15 modeling studies on Severe Acute Respiratory Syndrome (SARS) and the Middle East Respiratory Syndrome (MERS), Nussbaumer-Streit[24] found that the findings of studies on SARS and MERs were consistent with the findings of COVID-19 studies. Other studies using SIR revealed the effectiveness of this model in identifying the trends and projecting the rise and fall of the number of cases.[25-26]

Second, the strict implementation of ECQ, as revealed in the findings using the SIR model, proved that there was a significant slowdown in the number of reported cases. When the people of Davao City followed the government's policy, testing done by DOH, specifically the Southern Philippines Medical Center (SPMC), showed a decrease in the number of positive cases. The same findings were reported in different countries where the strict implementation of community quarantine was imposed. For instance, using the SIR model,[26] found that the mitigation strategies of the Chinese government in targeting vulnerable places such as Hubei province and in managing people's behavior were seen as effective in stopping the epidemic. In Brazil[27] a study applied the SIR model to predict the spread of COVID-19 and found out that the imposition of the social distancing measures by the government helped flatten the curve of the contamination. It was also true in the case of Davao City. People stayed at home especially the most vulnerable children, youth, elders, and persons with immunodeficiency and comorbidities. If there was a dire need to go out like buying food and medicines, such a task was undertaken by less vulnerable individuals in the family but they needed to wear a protective mask and strictly observe social distancing. Consequently, the infection rate had slowed down.

The aforementioned results are relevant to current and future implementations of public health services. As shown, scientific data are vital for the decision-making process of public health providers in safeguarding public health and safety. Hence, generated, monitored, and analyzed scientific data through predictive models help the providers of public health services in forecasting the future scenarios of the case and in implementing appropriate preventive measures in cases when similar or even worse conditions are forecasted.[28] The global experiences from the COVID-19 pandemic serve as great challenges to public health providers to strengthen their health services[29] ranging from the professional competence of health providers and practitioners to advanced and sufficient technologies in healthcare facilities. Further, legislators are likewise challenged to prioritize the legislation for the protection of public health and safety.[30]

Limitation of the Study

This study focused exclusively on new and active cases of COVID-19 within Davao City, with a sample size limited to 57 cases. It is essential to exercise caution when interpreting and applying the findings to decision-making. Firstly, the forecasted absence of cases does not signify the complete eradication of the virus; individuals remain susceptible, and preventive measures should persist. Secondly, the results should not be extrapolated to predict cases in areas under different types of quarantine, as the Modified Community Quarantine (MCQ) or General Community Quarantine (GCQ) generates distinct datasets requiring specific forecasting models. Finally, there is a risk of misinterpretation of forecasted values, potentially leading to inappropriate responses from the Department of Health (DOH), local government units (LGUs), and other sectors. Careful consideration of these limitations is crucial to ensure the responsible and informed use of the study's outcomes.

Summary Findings

On Trends Analysis: The examination of COVID-19 trends in Davao City using the Susceptible, Infected, and Recovered (SIR) model and Autoregressive Integrated Moving Average (ARIMA) model revealed valuable insights. The SIR model illustrated an erratic pattern in new cases from May 5 to May 9, 2020, indicating a potential exponential spread. The Basic Reproduction Number (Ro) remained above 1 until May 10, suggesting sustained transmissibility. Nevertheless, the Ro values significantly dropped from April 3, reflecting the effectiveness of Enhanced Community Quarantine (ECQ) measures in reducing infection rates. The epidemic doubling time increased from 3 to 11 days during ECQ, signaling a slowdown in transmission. The ARIMA model, despite presenting an initially erratic trend, effectively forecasted new cases, showcasing its utility in predictive analytics.

On Projections: The projections for COVID-19 cases using the SIR model indicated a fast-growth phase, projecting a final size of around 230 cases by October 2, 2020, if current interventions persist. The ARIMA model forecasted a downward trend in newly infected cases over the next 60 days, demonstrating the potential impact of sustained interventions. Despite variations between the models, both highlighted the importance of ongoing preventive measures to mitigate the spread.

On Relevance to Public Health Services: The scientifically forecasted data has a critical role in guiding public health decisions. The findings underscored the need for competent personnel, data-driven decision-making, and timely interventions. The study's relevance extends to promoting prevention over cure, addressing healthcare facility preparedness, and mitigating public anxiety. Lessons learned stress the importance of leveraging forecasted data for effective public health service planning and response.

CONCLUSION

Based on the findings, it is concluded that the combination of SIR and ARIMA models provided comprehensive insights into the trends, projections, and potential future scenarios of COVID-19. The study highlights the effectiveness of ECQ measures in slowing transmission and emphasizes the crucial role of scientifically forecasted data in informed decision-making for public health services. It is worth mentioning that the SIR model excelled over the ARIMA model in identifying trends and predicting future COVID-19 cases. While both models showed a substantial decrease in infection rates, it is crucial to exercise caution and maintain control measures to prevent a potential resurgence. Emphasizing the importance of scientifically forecasted data and which model is more worthwhile, this research accentuates the vital role of scientifically forecasted data in facilitating informed decision-making and bolstering the adaptability of public health services. This significance extends to its crucial relevance in effectively tackling future health crises.

RECOMMENDATION

Building upon the aforementioned conclusions, it is advised that the findings of this study be leveraged as a foundational element in formulating city plans and actions, particularly in safeguarding vulnerable groups such as children, youth, elders, and individuals with immunodeficiency and comorbidities. Before making any decisions, careful consideration should be given to the following key concerns:

Firstly, a comprehensive evaluation of the Critical Health Care capabilities of the city is essential. This assessment should encompass personnel, facilities (including beds, ventilators, and testing kits), and the availability of essential resources such as food and medicines. The readiness level of these capacities should align with forecasted growth rates, RO values, and doubling time values of new and active cases to effectively address potential rebounds in contamination growth rates.

Secondly, there is a need for extensive research to ascertain the equilibrium between public health, the socio-psychological conditions of the population, and the economic sustainability of the city. This research is integral for informing Local Government Unit decisions in handling similar situations in the future.

Thirdly, consideration should be given to re-appropriating, reallocating, or redirecting government funding towards critical healthcare capacity building, mass distribution of Personal Protective Equipment (PPE), and the procurement of test kits for comprehensive health examinations.

Moreover, the global experiences from the COVID-19 pandemic present a significant challenge for healthcare providers, practitioners, and legislators. It emphasizes the need to ensure that healthcare services are adequately prepared for similar and potentially more severe conditions that may arise in the future.

ACKNOWLEDGMENT

We would like to express our sincere gratitude to the Department of Health of the Davao region for their invaluable support in facilitating our COVID-19 research. We extend our deepest appreciation for generously allowing us access to their secondary data, which played a pivotal role in the success of our study. Their unwavering trust and confidence in our capabilities as the research team were instrumental in carrying out this vital investigation. Their collaborative spirit and commitment to advancing scientific knowledge in the fight against the pandemic have been truly commendable. This acknowledgment is a testament to the collaborative efforts that contribute to the betterment of public health, and we are immensely thankful for the Department of Health's crucial role in our research endeavors.

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