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Enhanced Machine Learning Decision Support Systems for COVID-19 Management in Saudi Arabia: A Comparative Study of Advanced Predictive Models

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ABSTRACT

This study analyzes the usefulness of several machine learning (ML) models in predicting COVID-19 cases in Saudi Arabia, with the goal of improving healthcare decision-support systems. The comparative analysis includes five major models: Decision Tree Regressor, Random Forest Regressor, Seasonal Autoregressive Integrated Moving Average with Exogenous Inputs (SARIMAX), Long Short-Term Memory (LSTM), and Convolutional Neural Network (CNN). The Random Forest model had the highest predictive accuracy (MAE: 0.214106, RMSE: 0.809336, R^2: 0.999997), followed by the Decision Tree Regressor. In contrast, classic statistical approaches such as ARIMA and SARIMAX performed significantly worse, suggesting their inadequacies in the setting of COVID-19. The study emphasizes the importance of specialized modeling approaches that take into account local epidemiological characteristics and encourages continued interactions between data scientists and healthcare practitioners. Furthermore, the findings call for greater data integration, model validation, and training for healthcare workers in order to maximize the use of sophisticated prediction models. Overall, this study provides significant information for healthcare officials, allowing them to make more educated decisions and allocate resources strategically when dealing with public health problems.

INTRODUCTION

Coronavirus disease 2019 (COVID-19) is caused by severe respiratory syndrome coronavirus 2 (SARS-CoV-2), It was originally found in Wuhan City in late 2019 (Zhu et al., 2020). The World Health Organization (WHO) declared the disease to be pandemic on March 11, 2020 (Cucinotta & Vanelli, 2020). Since then, significant publications on the epidemiology, features, and effects of the disease from diverse areas and people have yielded variable results (Heesakkers et al., 2022).

Due to the challenges of this unusual condition, healthcare providers, patients, and their families have been forced to make critical and difficult decisions with little information (Debnath et al., 2020). There is a significant need for early prediction of COVID-19 for better future forecasting and efficient pandemic-tackling policy measures, decreasing load on the healthcare system (Tariq & Ismail, 2024). Clinical decision support systems assist healthcare providers in making informed decisions and screening patients early on (Ameri et al., 2024).

They offer personalized recommendations based on patient characteristics, radiological imaging, clinical examinations, and guidelines (Ameri et al., 2024). The COVID Patient and Facility

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Management Information System enables end-to-end pandemic-oriented facilities in districts. District Supply Offices (DSOs), Chief District Medical Offices (CDMOs), State Health Authorities, Delhi Disaster Management Authority (DDMA), and the revenue department have been the primary customers of the system (Hasan et al., 2023).

Indeed, innovations and spread of numerous technologies have culminated in unprecedented production of mobile, digital gadgets and a massive amount of organized and unstructured data that enterprises and governments can mine for good and timely decision-making (Sheng et al., 2021). In today's world, advancements in information and communication technology (ICT) lead to the growth of diverse data from various sources in the healthcare system (Awotunde et al., 2021). The COVID-19 pandemic has resulted in significant human casualties and disruptions to global economic, social, sociocultural, and health systems. Controlling such a pandemic necessitates an understanding of its traits and behavior, which can be determined by gathering and analyzing relevant big data (Alsunaidi et al., 2021). Big data analytics technologies are critical in generating the knowledge needed for decision-making and preventative measures (Alsunaidi et al., 2021).

One study indicated that, data science, together with statistical analysis, computer science, and computational biology, is useful in a wide range of applications, including epidemiology, drug development, and molecular design for diagnostics and therapy (Saxena et al., 2020). A variety of data-driven models, mathematical models, correlations, and predictive models have been created for the new coronavirus (Saxena et al., 2020). This ability to process massive amounts of data using advanced algorithms and intelligent analysis and processing tools is a very promising solution to the effective detection and tracing of active cases, while also laying the groundwork for the development of spatiotemporal solutions tailored to real-world needs, as well as methods of timely forecasting of potential threats to public health (Demertzis et al., 2021).

In fact, four Saudi systems have recently been introduced to assist with the diagnosis and management of COVID-19: To begin, the Health Electronics Surveillance Network (HESN) is a web-based e-health solution that is integrated and flexible enough to accommodate all Saudi public health programs, and the Public Health Information System (PHIS) is designed to better support public health professionals across the Kingdom (Bangar et al., 2020). During the COVID-19 outbreak, few articles used machine learning to forecast mortality and identify risk factors (Elhazmi et al., 2023). Traditional statistical analysis methods used to uncover such risk variables are limited in their ability to stress the effect on outcome caused by potential interactions among these factors (Elhazmi et al., 2023).

One study indicated that COVID-19 pandemic has underlined the significance of sound healthcare decision-making and resource allocation, posing substantial problems for healthcare systems around the world, including Saudi Arabia. In response, a machine learning-based decision support system was created to improve COVID-19 outcomes management, specifically in terms of hospitalization, recovery, and mortality rates. The study analyzed large-scale datasets of daily confirmed cases, recoveries, and fatalities using a variety of machine learning approaches, including decision trees, linear regression, random forests, and SARIMAX. The results show that the random forest model surpasses both linear regression and SARIMAX in predicting accuracy, as evidenced by higher mean absolute error (MAE) and root mean square error (RMSE) metrics, successfully capturing the complexity of COVID-19 transmission. Furthermore, the study stressed the importance of large datasets, rigorous feature selection, and complete model validation in improving prediction accuracy. These findings have significant significance for healthcare practitioners and policymakers, allowing for more informed decisions and effective resource management throughout the continuing pandemic. To maximize the benefits of machine learning applications in healthcare, the study recommends ongoing predictive model improvement, enhanced multidisciplinary collaboration, and real-time data integration, ultimately contributing to improved patient outcomes and response during

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public health emergencies (Budor et al., 2024).

Despite the acceptance of the crucial role that machine learning and big data analytics may play in managing the COVID-19 pandemic, there is still a lack of understanding of their specific uses and effectiveness in Saudi Arabia's unique setting. Many studies have investigated predictive modeling and decision support systems in various regions; however, the findings are not always directly applicable to different healthcare environments, particularly in Gulf countries where cultural, social, and infrastructural factors can significantly influence healthcare responses.

Furthermore, the available literature frequently relies on generalized models that ignore the subtleties of local epidemiology data, healthcare facilities, and socioeconomic conditions in Saudi Arabia. There are also few comparison studies that assess the efficacy of various machine learning models for COVID-19 predictions in the Saudi setting. As a result, healthcare leaders lack personalized, evidence-based insights that may guide successful patient management, resource allocation, and public health policy. This work aimed to fill this gap by undertaking a comparative review of advanced prediction models for COVID-19 management in Saudi Arabia, drawing on worldwide data and making actionable recommendations for improving healthcare decision support systems.

Contributions to the Study

This study contributes significantly to healthcare management and predictive modeling in the context of COVID-19 in Saudi Arabia by conducting a thorough comparative analysis of various machine learning models such as Decision Tree Regressor, Random Forest Regressor, Long Short-Term Memory, Autoregressive Integrated Moving Average, Convolutional Neural Network and SARIMAX. The study evaluates performance using established metrics such as Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and Coefficient of Determination (R^2), providing evidence-based insights for healthcare policymakers to inform resource allocation and patient management. Furthermore, it addresses specific healthcare needs by contextualizing model applications within the Saudi context, finally providing recommendations for effective model selection and encouraging multidisciplinary collaboration between data scientists and healthcare practitioners. These contributions advance our understanding of machine learning's function in public health and provide an instructional resource for future healthcare analytics research and training.

METHODOLOGY

This section presents the structured approach adopted for the comparative analysis conducted in the study titled "Enhanced Machine Learning Decision Support Systems for COVID-19 Management in Saudi Arabia: A Comparative Study of Advanced Predictive Models." This methodology strictly involves evaluating existing machine learning models applied in prior research and analyzing their outcomes based on established datasets.

1. Selected Models for Comparison

The comparative analysis focuses on comparing many well-known machine learning models that have previously been used in the area of COVID-19 management. The chosen models are as follows:

- ✓ Decision Tree Regressor: This model is distinguished by its clear structure, with splits based on feature values at each node. The interpretability of decision trees is a significant advantage, as it allows stakeholders to understand the reasoning behind forecasts. However, decision trees are prone to overfitting, especially with complicated datasets.
- ✓ Random Forest Regressor: Random Forest is an ensemble method that uses several decision trees. It improves prediction accuracy by averaging the outputs of multiple trees trained on random subsets of data. This method eliminates overfitting and increases robustness, making it appropriate for a variety of COVID-19 data patterns.

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- ✓ SARIMAX (Seasonal Autoregressive Integrated Moving Average with eXogenous Inputs): SARIMAX is ideal for time series forecasting because it successfully incorporates seasonality and exogenous variables. This model is critical for studying how external factors influence the course of COVID-19 patients.

2. Data Sources

The study is based primarily on current, publically available datasets that document COVID-19 cases in Saudi Arabia. These figures have been compiled from credible sources, such as government health statistics and scholarly publications, to ensure their reliability and usefulness. The data includes critical parameters such daily reported infections, recoveries, and fatalities, as well as demographics and public health measures.

Validation of Data Quality: To provide robust comparison analysis, each source was thoroughly checked for quality, completeness, and credibility. This care ensures that future evaluations are based on high-quality, validated data.

3. Performance Evaluation Criteria

To evaluate the selected machine learning models, a set of established performance indicators were derived from previously published studies. The criteria for performance comparison are:

- ✓ Mean Absolute Error (MAE): MAE calculates the average of the absolute deviations between anticipated and actual values, providing an intuitive measure of predictive accuracy. Lower MAE indicates higher performance, giving it an easy tool for comparing results.
- ✓ Root Mean Squared Error (RMSE): RMSE calculates the square root of the average of squared differences, with a focus on larger errors. This is especially important in pandemic management since considerable discrepancies from real case numbers might have major consequences.
- ✓ The Coefficient of Determination (R^2) measures the proportion of variation explained by independent variables in a model. Values closer to one indicate a better fit, demonstrating how effectively the model reflects the underlying trends in the data.
- ✓ Long Short-Term Memory (LSTM): is a recurrent neural network (RNN) architecture created primarily for modeling data sequences and capturing long-range dependencies. It was created to address the constraints of traditional RNNs, which have difficulty with the vanishing gradient problem while learning from extended sequences.
- ✓ ARIMA (Autoregressive Integrated Moving Average): ARIMA is a widely used statistical method for evaluating and forecasting time series data. It uses several important components to capture various features of a time series, such as trend, seasonality, and noise.
- ✓ CNN (Convolutional Neural Network): CNN is a type of deep neural network that processes structured grid data, such as photographs. They are intended to automatically and adaptively learn spatial hierarchies of features over several layers.

4. Comparative Analysis Workflow

The comparative workflow included systematic stages to ensure an objective evaluation of model performance based on current research.

- ✓ Literature Review: The procedure began with a thorough examination of existing studies that used the chosen machine learning models for COVID-19. Relevant publications were found based on the reported performance data.
- ✓ Metrics: We extracted relevant performance metrics (MAE, RMSE, R^2) from recognized studies to create a comparative matrix of model performance.
- ✓ Side-by-Side Analysis: The comparative matrix enables immediate evaluation of model performance. This systematic comparison identifies commonalities and differences in how

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each model fared across multiple datasets while focusing primarily on previously published results.

5. Synthesis of findings

The comparative analysis results were compiled to provide insights into the efficacy of each machine learning model. The synthesis was containing:

- ✓ Performance Ranking: The models was ranked according to their evaluated performance indicators. This ranking was helped determine which models are most effective for COVID-19 management based on previous studies.
- ✓ Interpretation of Results: The performance of each model was discussed in terms of its implications for Saudi public health management, taking into account practical applications and potential problems.
- ✓ Recommendations for Future Use: Based on the findings, actionable recommendations were made on the best machine learning models for certain circumstances in managing COVID-19 instances, informed by comparative performance outcomes.

RESULTS

The findings of this study provide a comparative examination of several machine learning models used in COVID-19 management in Saudi Arabia. This section discusses each model's performance measures, as well as its rating and implications for public health management.

1. Performance Metrics

For each selected machine learning model — Decision Tree Regressor, Random Forest Regressor, SARIMAX, LSTM, ARIMA and CNN — performance metrics were calculated based on the established criteria: Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and Coefficient of Determination (R^2). The following table summarizes the findings:

Model	MAE	RMSE	R^2	Source
Decision Tree Regressor	0.229167	1.125771	0.999994	(Budor et al., 2024)
Random Forest Regressor	0.214106	0.809336	0.999997	
SARIMAX	458.398876	623.598559	-	
Model	**MAE**	**RMSE**	**R^2**	**Source**
LSTM	104.78	196.58	0.96	(Al-Rashedi & Al-Hagery, 2023).
ARIMA	258.6	578.1	0.15	
CNN	97.58	200.62	0.95	
Model	**MAE**	**RMSE**	**R^2**	**Source**
LSTM	0.0058633	0.007901	-	(Khan et al., 2023)

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This study's findings give a comparison of multiple machine learning models used to predict confirmed COVID-19 cases in Saudi Arabia. This section explains each model's performance measures and how they relate to public health management.

- The performance measures for each machine learning model—Decision Tree Regressor, Random Forest Regressor, SARIMAX, LSTM, ARIMA, and CNN—included Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and Coefficient of Determination (R^2). The Random Forest Regressor performed better than its counterparts, with the lowest MAE of 0.214106, RMSE of 0.809336, and R^2 of 0.999997. This level of accuracy shows that the Random Forest model is quite good at predicting confirmed COVID-19 cases, which can greatly benefit public health decision-making.
- The Decision Tree Regressor had good performance metrics, with an MAE of 0.229167 and RMSE of 1.125771, yielding a R^2 value of 0.999994. Its results demonstrate its potential utility in public health analytics centered on case prediction. The LSTM model from Khan et al. (2023) provided excellent precision, with an MAE of 0.0058633 and an RMSE of 0.007901, although no Coefficient of Determination was provided. The very low MAE and RMSE demonstrate its capacity to handle time-series data successfully, making it a promising choice for accurate forecasting in healthcare applications.
- The CNN model had an MAE of 97.58, RMSE of 200.62, and R^2 of 0.95. While this suggests a fair level of prediction, it falls short of the Random Forest and Decision Tree models' higher performance. Al-Rashedi & Al-Hagery's (2023) LSTM model performed well with an MAE of 104.78, RMSE of 196.58, and R^2 of 0.96, but had lower case prediction efficacy compared to Random Forest and Decision Tree models.
- In contrast, standard statistical approaches such as ARIMA and SARIMAX have shown substantial limits in predicting confirmed COVID-19 cases. ARIMA's high MAE of 258.6 and RMSE of 578.1 led to a low R^2 value of 0.15, showing inability in effectively modeling COVID-19 data. The SARIMAX model had the weakest performance, with an MAE of 458.398876 and RMSE of 623.598559, and no relevant R^2 value. These findings highlight the lower efficacy of traditional statistical models in comparison to machine learning methods in the context of COVID-19.

In conclusion, the performance rankings show that machine learning models, notably the Random Forest and Decision Tree Regressors, are more predictive of confirmed COVID-19 cases than standard statistical frameworks like ARIMA and SARIMAX. These findings underscore the importance of incorporating advanced modeling tools into public health management to guarantee accurate predictions and prompt reactions during health crises, ultimately improving the potential to effectively manage the COVID-19 pandemic.

Comparative Analysis Workflow

The comparison process was composed of systematic stages intended to ensure an objective evaluation of model performance based on current research. The literature research began with a detailed analysis of previous studies that used the selected machine learning models for COVID-19. Relevant publications were discovered using the reported performance data. The performance measures MAE, RMSE, and R^2 were gathered from reputable studies to provide a comparative matrix of model performance. Finally, a side-by-side study of this matrix enabled an immediate evaluation of model performance, assisting in identifying commonalities and differences across several datasets while focusing primarily on previously published results.

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Synthesis of Findings

The comparative study results were combined to provide insight into the efficacy of each machine learning model used in COVID-19 management. This synthesis consists of three main components: performance ranking, result interpretation, and recommendations for future use.

Interpretation of Results

Each model's performance has important implications for public health management in Saudi Arabia. The Random Forest and Decision Tree models' excellent accuracy suggests that they are suitable for real-time forecasting and resource allocation during COVID-19 outbreaks. These models can alert decision-makers to potential case surges, allowing for prompt interventions such as expanding hospital capacity, mobilizing healthcare resources, and implementing community health measures. The LSTM model performs well with time-series data, making it useful for tracking pandemic patterns over time. However, the lack of a stated R^2 value should be considered when applying it. In contrast, the poor performance of ARIMA and SARIMAX suggests that classical statistical methods should be replaced with more advanced machine learning algorithms in public health analytics.

Recommendations for Future Use

Based on the findings, numerous actionable recommendations emerge regarding the optimal machine learning models for controlling COVID-19 instances:

- Random Forest and Decision Tree Models should be favored in COVID-19 management efforts due to their greater prediction capabilities. Public health officials can use these tools to improve forecasting accuracy and guide strategic planning.
- Integration of LSTM for Time-Series Analysis: The LSTM model is useful for time-series forecasting, notably for tracking the progression of COVID-19 instances over time. This should be supplemented with methods for tracking model performance and making improvements to assure continued accuracy.
- Continuous Evaluation of Performance Metrics: Public health professionals should evaluate the success of machine learning models in practice on a frequent basis, modifying their techniques in response to real-world outcomes and new data. This iterative procedure can help to enhance model utilization and forecast accuracy.
- Capacity Building and Training: Healthcare practitioners and data analysts should be trained to use advanced machine learning models designed specifically for COVID-19 management. This training will help them better interpret model outputs and make data-driven decisions.
- Research and Development Funding: To progress the discipline, funds should be focused toward research efforts that investigate novel modeling techniques while resolving inadequacies in traditional statistical methods.

DISCUSION AND CONCLOSION

The COVID-19 pandemic has raised awareness about the importance of robust predictive models for public health decision-making. This debate compares the findings of studies undertaken in Saudi Arabia to those from other international contexts, offering a full comparative overview that aims to bridge knowledge gaps and inform practical recommendations for healthcare decision support systems.

Performance Metrics and Model Comparisons

Budor et al. (2024) in Saudi Arabia emphasized the Random Forest model's excellent performance, which outperformed other machine learning techniques such as Linear Regression and SARIMAX in terms of Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE). This finding is consistent with studies from other nations, such as Devaraj et al. (2021), in which deep

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learning approaches, notably Stacked Long Short-Term Memory (SLSTM), produced similarly high levels of predicting accuracy with errors of less than 2%. The similarity among these research demonstrates a growing preference for machine learning and deep learning approaches as credible tools for anticipating COVID-19 case incidence.

In contrast, Al-Rashedi and Al-Hagery (2023) found that while LSTM and Convolutional Neural Networks (CNN) performed well in certain cases, they struggled in others, showing flaws in long-term forecasting ability. This difference in performance indicators teaches us an important lesson: model selection must be context-specific, taking into consideration regional epidemiological characteristics and data availability. This conclusion is consistent with the findings of Tariq et al. (2024), who demonstrated that model efficacy might vary dramatically across different geographical and demographic conditions. These findings highlight the importance of personalized techniques when deploying prediction models in public health, which is especially important given the diverse regional reactions to the epidemic.

Impact on Healthcare Decision Support Systems

Khan et al.'s (2023) findings, which showed an extraordinarily low Mean Absolute Percentage Error (MAPE) of 5.0553, show that machine learning may give exact real-time data, allowing for agile policy responses. Karthikeyan et al. (2021) confirm the potential for real-time data integration, which was highlighted in Saudi Arabian studies. They focused on using routine blood test data to predict mortality risk. This method represents a move from broad predictive modeling to more specific, data-driven insights that can guide clinical treatments, which is a critical component of an effective healthcare decision support system. The capacity to foresee with such precision has the potential to significantly improve resource allocation, not only in Saudi Arabia but also abroad, emphasizing the global importance of decision-makers having access to credible forecasting tools.

International studies, such as those conducted in India, have shown that incorporating extensive demographic and environmental data into predictive models improves forecasting accuracy. Devaraj et al. (2021) incorporated parameters such as temperature, rainfall, and population density, resulting in a more sophisticated understanding of COVID-19 transmission patterns. This method contrasts with the more streamlined models commonly employed in Saudi Arabia, which are based mostly on case counts, recoveries, and mortality. Integrating larger contextual elements may increase model robustness and accuracy in the Saudi context, hence informing public health initiatives more effectively.

Future Recommendations for Global Practices

Several proposals emerge for improving the predictive potential of machine learning models in COVID-19 management in Saudi Arabia and other comparable scenarios. To begin, Budor et al. (2024) propose emphasizing ongoing model refining through multidisciplinary collaboration. Collaboration between the healthcare, data science, and public health sectors can lead to a better understanding of local disease dynamics and increased model validity.

Furthermore, drawing on ideas from international research might provide useful lessons. The strong performance metrics produced by models that incorporate large datasets emphasize the need for Saudi public health sectors to take a more integrative approach. By merging real-time epidemiological data with environmental and demographic factors, Saudi Arabia can improve predicted accuracy, allowing health officials to make timely and informed decisions.

Finally, investing in capacity building through healthcare professional training on the use and interpretation of complex prediction models is critical. As demonstrated by the divergence in accuracy across multiple algorithms in the studies by Al-Rashedi & Al-Hagery (2023) and Karthikeyan et al. (2021), a thorough understanding of model strengths and limitations enables better implementation in practice.

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Conclusion

This comparative analysis of machine-learning applications in COVID-19 management shows that, while significant progress has been made in Saudi Arabia, lessons from international studies emphasize the importance of taking a flexible, context-aware approach to model development and implementation. Saudi Arabia may strengthen its healthcare decision support systems by incorporating worldwide research findings, increasing data diversity, and encouraging cross-sector collaboration, resulting in better public health outcomes.

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