Research Article

Indian Journal of Extension Education
Vol. 61, No. 2 (April–June), 2025, (14-18)

ISSN 0537-1996 (Print)
ISSN 2454-552X (Online)

Forecasting Milk Production in India: Strategic Insights for Policymakers and Farmers

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HIGHLIGHTS

- India's milk production is forecasted to increase from 239.1 million tons in 2024 to 321.4 million tons by 2033, indicating strong sector growth potential.
- Consistency between ARIMA and Holt's models ensures accurate and dependable forecasts.
- The application of FAO's Sustainable Food and Agriculture Framework can guide the dairy sector toward climate-resilient and environmentally sustainable practices.

ARTICLE INFO

Keywords: Indian dairy industry, ARIMA, Holt's exponential smoothing, Sustainable development.

https://doi.org/10.48165/IJEE.2025.61203

Conflict of Interest: None

Research ethics statement(s): Informed consent of the participants

ABSTRACT

India's dairy sector plays a critical role in rural income, employment, and food security, contributing significantly to the nation's GDP. This study forecasts India's milk production for the period 2024–2033, using historical data from 1981–2023 obtained from the Department of Animal Husbandry and Dairying, Government of India. The study adopts ARIMA and Holt's Exponential Smoothing models for the forecasting of milk production in India, both the models reflected strong fits, with ARIMA excelling in capturing temporal structures and Holt's model focusing on linear trends. Performance metrics highlighted the high accuracy of both models, with R-squared values exceeding 0.99 and minimal error margins. The research provides actionable insights for farmers, policymakers, and other stakeholders. The results project milk production to increase steadily, reaching 315.6–321.4 million tons by 2033. The study highlights the potential of leveraging these forecasts for strategic planning, including synchronizing production with demand, improving market stability, and addressing infrastructural and environmental challenges.

INTRODUCTION

Milk production occupies a strategic position in India's economy as it is one of the important inputs in agriculture, rural income and nutrition. Indian dairy industry is very important on the global level as well as for the internal economy because India is the largest producer of milk in the world (Department of Animal Husbandry & Dairying, 2023). The sector supports more than 70 million rural, offers stable income and employment opportunities, especially small and marginal farmers (Shumway and Stoffer, 2017; TAAS, 2023) Besides, milk provides another protein-based food security for a predominantly vegetarian population (Lyngkhoi et al., 2022). The dairy industry of India makes up more than 4 per cent of the country's GDP, and the liquid milk segment is growing at annual rates ranging from 6-7 per cent (Suganthi, 2023). Apart from the economic roles the dairy industry also plays a significant

Received 02-01-2025; Accepted 04-02-2025

social role by employing 70 per cent of the women (Fos, 2023). They are involved in animal husbandry, milking, and farm work, which has improved their financial and economic status as well as the welfare of the community (Kaur & Toor, 2024). The greatest impact on dairy farming was perceived as changes in the feeding behaviour of cattle (Singh et al., 2016; Phebe et al., 2024). Various government schemes such as Operation Flood, the Rashtriya Gokul Mission and the National Programme for Dairy Development have played major roles in changing the Indian dairy sector. Such programs increased milk production to 230.58 million tonnes in 2022-23 with a growth of 3.83 per cent per annum (Chand, 2023).

It is argued that appropriate forecasting is essential for the planning processes of the dairy industry. For farmers, it can be used to predict demand, balance resources, and match production cycles with demand. Likewise, the forecasts can be used by stakeholders such as government officials and business executives to counter market changes, enhance the supply chain, and develop effective strategies for all. Some well-known models to model agricultural data and to give precise forecasts are time series models such as ARIMA and Holt's Exponential Smoothing. These models will be used to predict India's milk production in the period 2024 to 2033 in this study. Thus, the opportunities that have been outlined in the analysis are aimed at providing decision-making support, solving the problems of the sector, and achieving sustainable development of the Indian dairy industry.

METHODOLOGY

This study forecasts India's milk production for the period 2024–2033 using ARIMA and Holt's Exponential Smoothing models, leveraging historical data. These models are particularly well-suited for univariate non-stationary data and effectively capture trends essential for agricultural forecasting. In contrast, the VAR (Vector Autoregression) model is ideal for the multivariate forecasting analysis, as pointed out by Hyndman & Athanasopoulos (2018). The data on the milk production (in million tonnes) utilised in the present study was collected from the Department of Animal Husbandry and Dairying from 1981 to 2023. The data was cleaned and prepared by removing the outliers and filling the missing values in the data in a statistical way (Chatfield, 2016). The data set was partitioned into the training set (1981–2018) for model training and into the validation set (2019–2023). The descriptive analysis was done using exploratory data analysis (EDA), and this included a time series and autocorrelation function (ACF) plot (Makridakis et al., 2018). ARIMA was derived from the Box and Jenkins approach, where the stationarity of data was tested using the Augmented Dickey-Fuller test while parameters in the model were selected from the Auto Correlation Function (ACF) and Partial Auto Correlation Function (PACF) diagrams (Box, 2013; Dickey & Fuller, 1979). As mentioned by Hyndman & Khandakar (2008), using AIC and BIC values to identify the best-fit ARIMA model, the selected model is (0,2,0) as shown in equation 1.

$$y''_t = y_t - 2y_{t-1} + y_{t-2} \qquad ...(1)$$

Where, y_t is the value of milk production at time *t,* y_{t-1} is the value of milk production at the time *t-1,* y_{t-2} is the value of milk production at the time *t-2*.

Level and trend components were used to model linear trends in Holt's Exponential Smoothing with the optimal smoothing parameters ($\alpha = 0.9999$, $\beta = 0.8335$) for minimum errors as shown below in equations 2-4 (Holt, 2004; Box et al., 2015).

Level equation: $l_t = \alpha y_t + (1 - \alpha)(l_{t-1} + b_{t-1})$ ...(2)

Where, y_t is value at time *t,* l_{t-1} is a smoothed level at time *t-1,* b_{t-1} is a smoothed trend at time *t-1.* α is the smoothing parameter for the level ($0 \leq \alpha \leq 1$).

Trend equation: $b_t = \beta(l_t - l_{t-1}) + (1 - \beta)b_{t-1}$ ...(3)

Where, β is the smoothing parameter for the trend ($0 \leq \beta \leq 1$).

Forecast equation: $\widehat{y_{t+h}} = l_t + hb_t$ ...(4)

Where, $\widehat{y_{t+h}}$ is Forecast for *h* periods ahead, *h* is forecast horizon

Both models also passed the residual diagnostic checks that included the Shapiro-Wilk test for normality of the residuals and the Ljung Box test for independence of the residuals. The performance of the forecast was evaluated by the root mean square error (RMSE), the mean absolute error (MAE), and the mean absolute percentage error (MAPE) according to Makridakis et al., (2018). Due to these strong fits and reliable performance, both models were used to predict trends in milk production for the years 2024-2033. These forecasts serve as a valuable tool for understanding future demand, helping policymakers plan more effectively to address upcoming challenges. The data analysis was conducted using the Python programming language within the Google Collab platform.

RESULTS

The application of ARIMA (0,2,0) and Holt's Exponential Smoothing models provided key insights into the forecasting of milk production in India from 2024 to 2033. The results indicate that both models are effective in capturing the underlying patterns in milk production, although each offers unique advantages depending on the specific requirements of forecasting.

Model performance and error metrics

Table 1 highlights the performance metrics of the ARIMA (0,2,0) and Holt's Exponential Smoothing models. Both models demonstrate high accuracy in forecasting milk production, with minimal error values and strong explanatory power. The ARIMA model achieved an R-squared value of 0.9995, reflecting a high degree of explained variance, while the Root Mean Square Error (RMSE) was 1.1726, indicating a close alignment between predicted and actual values. The Mean Absolute Error (MAE) of 0.8709 and Mean Absolute Percentage Error (MAPE) of 1.04 per cent further confirm its precision. The model also showed strong suitability for capturing temporal structures with an Akaike Information Criterion (AIC) of 133.36 and a Bayesian Information Criterion (BIC) of 135.07.

Holt's Exponential Smoothing model also delivered robust results, with an R-squared value slightly higher at 0.9996. It demonstrated comparable accuracy with an RMSE of 1.1667, an

Table 1. Error Metrics Comparison of ARIMA and Holt's Exponential Smoothing Models

Measure	ARIMA (0,2,0)	Holt's Exponential Smoothing
R-squared	0.9995	0.9996
RMSE (Root Mean Square Error)	1.1726	1.1667
MAE (Mean Absolute Error)	0.8709	0.8766
MAPE (Mean Absolute Percentage Error)	1.04%	1.01%
AIC	133.36	184.9898
BIC	135.07	193.7958

MAE of 0.8766, and a MAPE of 1.01%. However, its AIC (184.99) and BIC (193.80) were higher than those of ARIMA, indicating a slightly less optimal fit. Despite this, the model effectively captured linear trends within the dataset, making it a reliable option for trend-focused forecasting. Both models exhibited minimal errors and strong fits, highlighting their reliability for forecasting milk production. The choice between ARIMA and Holt's models ultimately depends on specific needs, with ARIMA being better suited for capturing temporal structures and Holt's model excelling in trend-focused analysis.

Table 2 presents the residual diagnostic results for the ARIMA (0,2,0) and Holt's Exponential Smoothing models, confirming the adequacy of both models in terms of residual behaviour. For the ARIMA model, the Shapiro-Wilk test yielded a p-value of 0.1943, indicating that the residuals are normally distributed. Additionally, the Ljung-Box test produced a p-value of 0.1254, confirming the independence of residuals, and further validating the model's reliability. Similarly, the residual diagnostics for Holt's Exponential Smoothing model showed a Shapiro-Wilk test p-value of 0.1737 and a Ljung-Box test p-value of 0.1859. These results also confirm that the residuals are normally distributed and independent, demonstrating the adequacy of this model for forecasting.

Table 2. Residual Diagnostic Tests for ARIMA and Holt's Exponential Smoothing Models

	ARIMA	Holt's Exponential Smoothing
Shapiro-Wilk Test p-value	0.1943	0.1737
Ljung-Box Test p-value	0.1254	0.1859

The results from both tables signify the strengths of each model. While the ARIMA model offers a slightly better fit based on AIC and BIC values, Holt's method provides a comparable level of accuracy with a marginally higher R-squared. The choice between these models ultimately depends on the specific forecasting needs– whether a more nuanced approach to temporal patterns is required (favouring ARIMA) or a simpler trend-focused analysis (favouring Holt's method).

Forecasting values and trends

Table 3 displays the forecasted milk production values for each year from 2024 to 2033 using both models. The table provides a detailed comparison of the point forecasts along with separate columns for the lower and upper bounds of the 95 per cent confidence intervals, offering insights into the range of possible outcomes. Both ARIMA and Holt's models provided consistent forecasts, indicating a steady upward trend in milk production from 2024 to 2033. The forecasts generated by the ARIMA model start at approximately 239.1 million tons in 2024 and gradually rise to about 315.6 million tons by 2033. In comparison, Holt's Exponential Smoothing forecasts begin slightly higher, at 239.7 million tons in 2024, reaching approximately 321.4 million tons by 2033. The similarity in the forecasted values between the two models indicates high consistency and reliability in the projections.

Figure 1 illustrates the forecasted milk production in India from 2024 to 2033, comparing ARIMA and Holt's Exponential Smoothing models. The chart shows a steady upward trend, with confidence intervals highlighting the reliability of the projections. Both models align closely, reinforcing the consistency and accuracy of the forecasts.

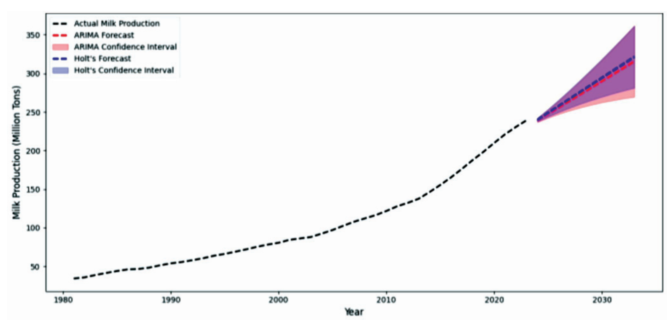

Figure 1. Milk Production Forecast in India (2024–2033): ARIMA vs. Holt's Models

Table 3. Forecasted Milk Production Values (2024-2033)

Year	ARIMA Forecast (Million Tons)	LW[1]	UB[2]	Holt's Forecast (Million Tons)	LW[1]	UB[2]
2024	239.1	236.7	241.5	239.7	237.3	242.1
2025	247.6	242.3	252.9	248.8	243.7	253.8
2026	256.1	247.3	264.9	257.8	249.7	266
2027	264.6	251.7	277.5	266.9	255.2	278.6
2028	273.1	255.6	290.6	276	260.4	291.7
2029	281.6	259.1	304.1	285.1	265.1	305.1
2030	290.1	262.3	317.9	294.2	269.5	318.8
2031	298.6	264.9	332.2	303.3	273.7	332.9
2032	307.1	267.4	346.8	312.3	277.5	347.2
2033	315.6	269.4	361.8	321.4	281	361.8

[1]Lower Bound Limit of the confidence interval; [2]Upper Bound Limit of the confidence interval

DISCUSSION

The projections of milk production in India for the period 2024 to 2033 offer valuable insights for strategic development and planning in the dairy sector. Based on historical data, forecasts utilizing ARIMA and Holt's Exponential Smoothing models indicate an upward trend in milk production. According to the ARIMA model, milk production is projected to increase from 239.1 million tons in 2024 to 315.6 million tons in 2033. Meanwhile, Holt's Exponential Smoothing method forecasts an increase from 239.7 million tons in 2024 to 321.4 million tons in 2033. While Holt's model estimates slightly higher production levels, the close alignment of the two models emphasizes their credibility and resilience. Both models highlight the sector's growth potential through data analysis. The projections signify the importance of synchronizing production with demand and leveraging cooperatives and value-added products to improve the resilience of rural communities. The study emphasizes that policymakers and societal stakeholders play a critical role in shaping the future of India's dairy sector. Addressing challenges such as inadequate infrastructure, demand volatility, and environmental issues is essential for sustained development.

The differences in projections between the models highlight the importance of selecting methodologies suited to specific conditions. ARIMA, with its small confidence intervals, is well-suited for risk-sensitive planning, whereas Holt's method is more appropriate for trend-focused planning. These findings are consistent with prior studies by Singh et al., (2014); Sharma et al., (2022) & Sowmya et al., (2023), which established the effectiveness of ARIMA in the Indian context. The study suggests strategies such as investments in supply chain management, technology, and sustainability to address the projected growth in milk production. These measures will prepare India to meet domestic demand and provide a competitive edge in the international dairy market, benefitting farmers, society, and policymakers alike.

CONCLUSION

India's dairy sector remains a vital segment of the rural economy and presents enormous potential for development and profitability. Market projections for milk production indicate that the sector may attain 315.6–321.4 million tons by 2033. These projections can help farmers, societies, and policymakers to better understand current challenges and opportunities, avoiding missed prospects. Guided by the principles of FAO's Sustainable Food and Agriculture Framework, farmers can improve production efficiency in response to market signals, adopt sustainable practices such as better resource management, and explore the value-added product market to enhance profitability. Communities should be empowered through knowledge sharing, affordable credit access, and robust cooperative networks to strengthen their economic resilience. Policymakers play a crucial role in creating a conducive environment by addressing infrastructure deficits, enhancing supply chains, and supporting climate-resilient practices, ensuring governance aligns with sustainable development goals. Societies can contribute by fostering rural livelihoods, supporting innovative practices in dairy operations, and promoting environmentally conscious strategies.

The adoption of advanced technologies such as artificial intelligence and data analytics aligns with FAO's principle of improving efficiency and minimizing environmental impacts. Cooperation among farmers, rural societies, and policymakers can drive sustainable development and elevate India's dairy sector's global competitiveness. By embedding FAO's framework into planning and decision-making, this work highlights the importance of coordinated efforts to unlock the sector's full potential for all stakeholders, ensuring its future viability and positive impacts.

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