Modeling Earth Systems and Environment (2022) 8:947–959
https://doi.org/10.1007/s40808-021-01138-z

ORIGINAL ARTICLE

Modeling and forecasting of milk production in the SAARC countries and China

Pradeep Mishra[1] · Adelajda Matuka[2] · Mostafa Salaheldin Abdelsalam Abotaleb[3] · W. P. M. C. N. Weerasinghe[4] · Kadir Karakaya[5] · S. S. Das[6]

Received: 16 November 2020 / Accepted: 11 February 2021 / Published online: 26 February 2021

Abstract
This study uses yearly data from 1961 to 2018 to forecast milk production in South Asian countries (including China) using ARIMA/GARCH models and Holt's Linear approach. It is revealed that not all the methods are equally effective in forecasting. Comparison of mean absolute percentage errors between ARIMA and Holt's Linear model shows that Holt's approach reveals higher errors.ARIMA forecasting results show that India will be the country with the highest milk production, followed by Pakistan and China while GARCH model fits better to Bangladesh. This paper has policy implications as it can be used for the proper planning of dairy products in the South-Asian counties to safeguard nutritional security.

Keywords ARIMA · GARCH · Holt's model · Modeling · Time series

Introduction

Dairy products are part of daily life, and perception about them have evolved through time from a luxurious product accessible from the "elite" into a common product consumed by millions of people. One glass of milk can tremendously improve the nutritional levels of the children in the region of Asia (Siddiky 2015). One of the core dairy products is milk, which has grabbed the attention of governments trying to implement policies which could forecast its subproducts whilst enterprises are becoming dairy driven as the best way to make profitable margins as consumer's preference are rising for high-quality milk. Hence, the manufactured dairy product output is estimated to grow 10% to INR 283,000 crore ($37.58 billion) during the current financial year (April 2020-March 2021, www.fao.org.) Currently, South Asian countries including China are leading milk producer (China sustain milk output growth in Asia and FAO 2020). India ranked first position in the world for milk production, which is accounted for 196.18 million tones (2019) and China ranked 5th position (FAO 2019).

In the European Union countries have the highest second level of milk production whilst Africa and Oceania have the lowest level of milk production in the world (Fig. 1).

European Union countries have the highest second level of milk production whilst Africa and Oceania have the lowest level of milk production in the world.

We show cow's milk production as share per region indicating that in comparison to other countries, Asia counts the highest share. European Union countries have the highest second level of milk production whilst Africa and Oceania have the lowest level of milk production in the world.

In Table 1 we show total milk production in recent years revealing that world total milk production has increased. As the level of milk production has increased, trade has raised to 77.9 million tones in November 2020.

There is vast existing literature on milk production, which focuses on a particular country or firm while the studies in SAARC region including China seem scant so

✉ Pradeep Mishra
pradeepjnkvv@gmail.com

[1] J.N.K.V.V., College of Agriculture, Powarkheda, M.P., India

[2] Department of Economics and Law, University of Macerata, Macerata, Italy

[3] Department of Electrical Engineering and Computer Science, South Ural State University, Chelyabinsk, Russia

[4] Department of Statistics and Computer Science, University of Kelaniya, Kelaniya 11600, Sri Lanka

[5] Faculty of Science, Department of Statistics, Selçuk University, Konya, Turkey

[6] Ranchi Agriculture College, Birsa Agricultural University, Ranchi, India

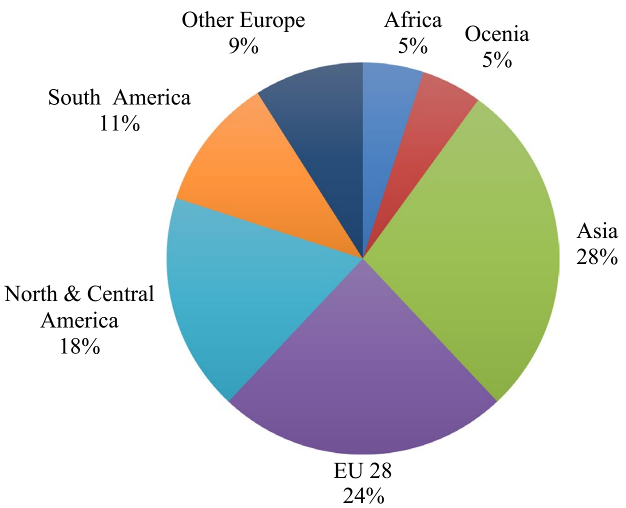

Fig. 1 Cow's milk production (Share per region)

Table 1 World milk production[1] *(million tonnes)*

	2018	2019	2020 (forecast)		Change: 2020 over 2019 (tonnes)
			June	November	
Total milk production	840.3	848	858.9	860.1	1.4
Total Trade	76	76.8	73.6	77.9	1.5

Food and agriculture organization of the united nations (FAO)

far. Mainly, the SAARC region, most households rear livestock either as a mainstay and/or complementary to crop production (Ahuja and Staal 2012). Therefore, due to the importance of dairying, we try to estimate and forecast milk production to promote the commercialization of dairying in SAARC member countries (SAARC 2015). Forecasting of milk production is required so that necessary policy formations can be done (Mishra et al. 2020a, b; Deshmukh and Paramasivam2016). Lohano and Soomro (2006) have used a random walk model with a drift autoregressive model to forecast milk production in Pakistan. Schmit and Kaiser (2006) indicate that decline in retail per capita demand would persist but at a reduced rate from years past. In a similar approach to ours, (Akter and Rahman 2010) forecasts milk supply up to 3 years for a dairy cooperative in Murphy et al. (2014), Zhang et al. (2020) have conducted a study to identify the different modeling techniques for the prediction of total daily herd milk yield in Ireland and non-linear model especially for short-term milk-yield predictions. Li (2020) also studied the genome-wide association study of milk production using statistical models. Taye et al. (2020) have considered the trends of actual yield of cow milk production. They have forecasted the volume of milk in Andassa dairy farm in Ethiopia using ARIMA (1, 2, 1). Mishra et al. (2020a, b) used time series models in milk production and forecasted for 2020. Uddin et al. (2020) determine that Bangladesh will be self -sufficient in milk production 2029.

(Wood 1967; Ali and Schaeffer 1987; Wilmink 1987; Guo 1995) tried to fit a lactation curve to the data while (Ptak and Schaeffer 1993 and (Shallo et al. 2004) proved the nutrition of milk through genetic analysis and bio-economic modeling. Milk production is highly influenced from certain factors such as nutritional interventions (Kolver and Muller 1998), disease (Collard et al. 2000), seasonality of pasture production (Adediran et al. 2012), grazing conditions (Baudracco et al. 2012) or other factors such as (Olori et al. 1999a, b; Tekerli et al. 2000; Brun-Lafleur et al. 2010). Macciottaet al. (2002) and Vasconcelos et al. (2004) have used auto-regressive models to forecast lactation while (Sharma et al. 2006; and Sharma et al. 2007) have used large models such as multiple regression and artificial neural networks. Other studies have revealed the set of variables which could influence milk production such as season of calving (Wood 1967), climatic conditions (Smith 1968), number of DIM (Grzesiak et al. 2003) and stocking rate (McCarthy et al. 2011).

In general, there is much success in the production of dairy products in the developed countries than in developing countries such as South-Asian countries. Even though the government has implemented policies, the growth process has been low. Smallholders constitute a large portion of the dairy industry while privately owned and state-owned farms constitute the other portion. Lack of dairy animals with good generic merit, lack of good quality feed, limited knowledge of and skills of farmers, high cost of inputs and lack of good marketing are the main challenges that South-Asian countries are facing now. The ability to forecast milk production is important as it will affect energy consumption and farmer's income. Predicting milk production is the best tool to adjust its supply. Hence, due to the importance of milk as dairy production and as South-Asian countries are leading the production we try to forecast milk production using ARIMA/GARCH models and Holt's Linear Model (Oliveros 2019).

The results show ARIMA approach indicates that India would be the leading state in milk production with 91 MMT in the year 2024–2025 among South Asian countries. The second country ranked is Pakistan which milk production would reach 26 MMT in 2024–2025, China is the third country with 3MMT, while Bangladesh and Sri Lanka seem to be the countries with the lowest production of milk. Since the residuals of the fitted ARIMA models for China, India, Nepal, Pakistan, and Sri Lanka are having an absence of ARCH effects, we cannot estimate an

ARCH/GARCH model. Hence, we proceed by fitting a GARCH model only for Bangladesh and Myanmar and the findings suggest that Bangladesh forecasts an abundance of milk production. In comparison to the ARIMA model, Holt's linear model forecasts higher levels of milk production for the region. It indicates that India's forecasted level will reach 105 MMT, Pakistan 58 MMT and China 4 MMT in the year 2024–2025. We compare the mean absolute percentage error (MAPE) between ARIMA and Holt's models and the findings suggest that ARIMA model shows higher errors. The only exception is China, Nepal and Pakistan which errors are higher using Holt's model (Fig. 2).

Material and methods

The main approaches to the research problem with their methodologies are discussed here.

Data collection

Milk production data of SAARC countries and China were collated separately. The milk production data are in tons. The data set contains annual data from 1961 to 2018 (www.fao.org.in). The data sets were divided into two parts as 80% and 20% for the model building and model validation, respectively. The statistical packages used for model building are R and E-views software.

ARIMA model

ARMA (p,q) model where p is the order of the autoregressive part and q is the order of the moving average part (as defined below).

Autoregressive model

The notation AR (p) refers to the autoregressive model of order p. The AR(p) model is written Eq. 1

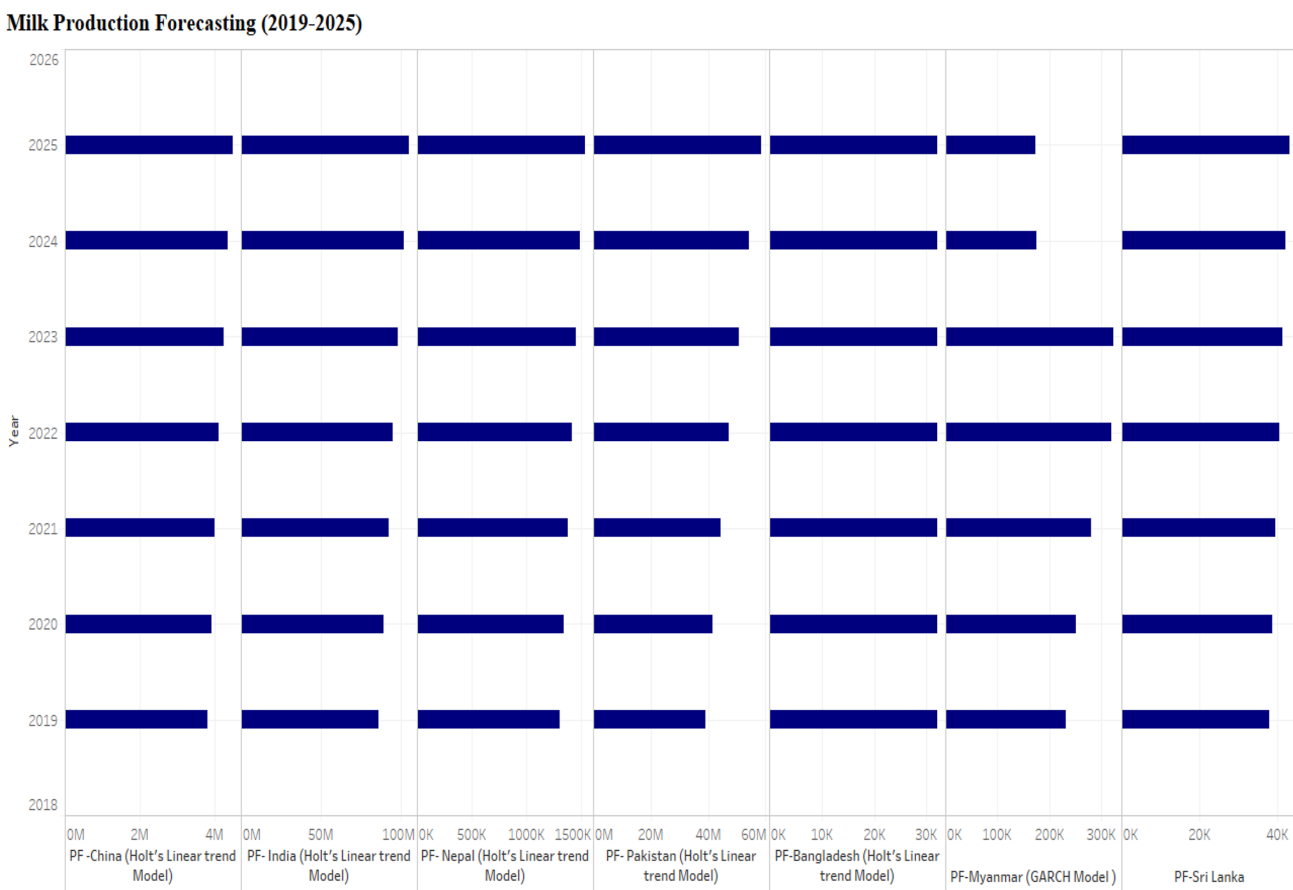

Fig. 2 Milk production forecasting

$$X_t = c + \sum_{i=1}^{P} \rho_i X_t + \varepsilon_t \tag{1}$$

where $\rho_1, \rho_2 \ldots . \rho_p$ are the parameters of the model, c is a constant and ε_t is white noise. Sometimes the constant term is avoided.

Moving average model

The notation MA (q) refers to the moving average series of order q:

$$X_t = \mu + \varepsilon_t + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i} \tag{2}$$

where the $\theta_1, \ldots, \theta_q$ are the parameters of the model, μ is the expectation of X_t (often assumed to equal 0), and the $\varepsilon_t, \varepsilon_{t-1} \ldots$

Stationary time series can be modelled with ARIMA models. The non-seasonal ARIMA model can be written as in Eq. 3.

$$z\}_t = c + \emptyset_1 z\}_{t-1} + \emptyset_2 z\}_{t-2} + \ldots + \emptyset_p z\}_{t-p} + e_t + \theta_1 \varepsilon_{t-1} + \theta_2 e_{t-2} + \ldots + \theta_p e_{t-p} \tag{3}$$

where $z\}_t$ is the differenced series. The "predictors" on the right-hand side include both lagged values of z_t and lagged errors. This is defined as the ARIMA (p, d, q) model where p, d and q, respectively, represent the order of the autoregressive part, the degree of the differencing involved and the order of the moving average part. ARIMA has four major steps as model building and identification, estimation, model diagnostics and forecast. Firstly, tentative model parameters are identified through ACF (Auto Correlation Function) and PACF (Partial Auto Correlation Function), then the best coefficients for the model are determined through MSE, MAPE etc. next steps involve is to forecast and finally validate and check the model performance by observing the residuals through Ljung Box test and ACF plot of residuals.

Holt's linear trend method

Holt's Linear Trend Method is an extension of the simple exponential smoothing and allows forecasting data with a trend. This method involves a forecast equation and two smoothing equations: one for the level and one for the trend given by Eq. 4, Eq. 5 and Eq. 6, respectively (Holt 1957).

$$\text{Forecast Equation}\hat{z}_{t+h|t} = k_t + hd_t \tag{4}$$

$$\text{Level Equation } k_t = \rho z_t + (1-\rho)\left(k_{t-1} + d_{t-1}\right) \tag{5}$$

$$\text{Trend Equation}d_t = \sigma^*\left(k_t - k_{t-1}\right) + (1-\sigma^*)d_{t-1} \tag{6}$$

where k_t denotes an estimate of the level of the series at time t, d_t denotes an estimate of the trend (slope) of the series at time t, ρ is the smoothing parameter for the level, $0 \le \rho \le 1$, and σ^* is the smoothing parameter for the trend, $0 \le \sigma^* \le 1$.

Generalized autoregressive conditionally heteroscedastic (GARCH) process

The generalized autoregressive conditional heteroscedasticity (GARCH) model describes the error variance of a model Bollerslev (1986).

$$h_t = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \ldots + \alpha_q \varepsilon_{t-q}^2 + \beta_1 h_{t-1} + \ldots + \beta_p h_{t-p}$$

$$h_t = a_0 + \sum_{i=1}^{q} a_i \rho_{t-1}^2 + \sum_{j=1}^{p} b_j h_{t-j} \tag{8}$$

A sufficient condition for the conditional variance to be positive is

$$a_0 > 0, a_i \ge o, i = 1, 2, \ldots, q; b_j \ge 0, j = 1, 2, \ldots, p$$

The GARCH model is equivalent to an infinite ARCH model. In that case, the GARCH (p, q) model, where p is the order of the GARCH terms ρ^2 and q is the order of the ARCH terms e^2 is shown in Equation 0.9

$$\rho_t^2 = \theta_0 + \alpha_1 e_{t-1}^2 + \cdots + \theta_q e_{t-q}^2 + \omega_1 \rho_{t-1}^2 + \cdots + \omega_p \rho_{t-p}^2 \tag{9}$$

Results and discussion

Some descriptive statistics such as mean, maximum, minimum, standard deviation, skewness, and kurtosis are given in Table 2. When Table 2 is examined, India's produced approximately three times the milk of Pakistan, the closest competitor, between 1961 and 2018. Bangladesh had the lowest mean milk production among the studied seven countries. From Table 2 anyone can see this; during the period study under investigation, India has a tremendous growth of 422.33%. Myanmar reached 193,841 tonnes in 2018, with 560.41 percent. In all counties taken in the study is positive skewness, which indicates that milk production increased from 1961 to 2018. Except the Myanmar, other counties found negative kurtosis in milk production indicating steadiness in production.

After seeing the nature through descriptive statistics next steps is validated and forecast the milk production

Table2 Descriptive statistics of milk production data (Tonnes)

	Mean	Minimum	Maximum	Standard deviation	Skewness	Kurtosis
China, mainland	1,957,335	917,000	3,100,000	791,574	0.09699714	– 1.599469
India	34,725,088	10,929,000	91,817,140	22,691,830	0.7834235	– 0.5095129
Nepal	678,285	340,000	1,338,277	279,431.2	0.7466306	– 0.6696471
Pakistan	12,627,086	4,209,000	28,109,000	7,540,331	0.51971	– 1.183356
Sri Lanka	45,636	18,320	85,914	17,528.07	0.3599365	– 1.181533
Bangladesh	23,377	13,090	39,000	6580.095	0.6333173	– 0.6418137
Myanmar	103,086	18,180	305,631	74,419.61	0.9259912	0.09181194

Population of seven countries (SAARC) milk production (China, mainland, India, Nepal, Pakistan, Sri Lanka, Bangladesh, and Myanmar), milk production data for SAARC cover the period of 1961 to 2018

time series. For projection purpose different time series models used ARIMA,GARCH and Holt's winter model and compared. ARIMA model selections for seven c ountries obtained by making use of some goodness of fit criteria such as Akaike information criterion (AIC), Bayesian information criterion (BIC), and bias-corrected Akaike information criterion (AIC), and the results are given in Table 3. In Table 2, it is also shown Holt's model results.

The best models of India, China, and Myanmar are selected ARIMA (1,2,1) for milk production data over the period of 1961 to 2018. ARIMA (0,1,0) model is also specified for Sri Lanka and Bangladesh. ARIMA (1,2,2) and ARIMA(1,2,0) models are determined, respectively, by Nepal and Pakistan.

Milk production from different counties in time series of the ARIMA model equation is given except for Bangladesh and Sri Lanka:

$$\mathbf{Z_t} = 2 * \mathbf{Z_{t-1}} - \mathbf{Z_{t-2}} + \boldsymbol{\varepsilon}_\mathbf{t}, \mathbb{E}(\boldsymbol{\varepsilon}_\mathbf{t}) = 0$$

For Sri Lanka and Bangladesh only first differencing is required for making data stationary. For Bangladesh and Sri Lanka milk production ARIMA model is equation.

$$\mathbf{Z_t} = 1 * \mathbf{Z_{t-1}} + \boldsymbol{\varepsilon}_\mathbf{t}, \mathbb{E}(\boldsymbol{\varepsilon}_\mathbf{t}) = 0$$

ARIMA-GARCH models fitting for milk production data are given in Table 4. Because the residuals of the ARIMA models of China, India, Nepal, Pakistan, and Sri Lanka do not indicate the ARCH effect, these countries' residuals cannot be modeled by the GARCH models. These results were obtained using the ARCH test given in the third column of Table 3. GARCH (1,1) model is also specified for Bangladesh and Myanmar. Milk production data is using fitted models between 1961 and 2007.

While the part of milk production data between 1961 and 2007 was used for modeling, the part between 2008 and 2018 was used to test the model validity. Model validation results for the ARIMA-GARCH models given in Table 5 between 2008 and 2018 for the milk production data. From Table 5 it is observed that the actual values of the milk productions are very close to the point forecasted milk productions in both Bangladesh and Myanmar. The comparison of ARIMA and ARIMA-GARCH models is given in Table 6. The lowest values of the RMSE, MAE, and MAPE are shown the best model. The model with the lowest values of RMSE, MAE, and MAPE shows the best model. From Table 6, because ARIMA(0,1,0)-GARCH(1,1) and ARIMA(1,2,1)-GARCH(1,1) has the lowest value for the RMSE, MAE, and MAPE, these models selected in the best models for Bangladesh and Myanmar, respectively.

The best models for modeling and forecasting milk production for seven countries are also given in Table 7. For Sri Lanka and Myanmar GARCH (1,1) is betted in milk production and equation is

$$\varepsilon_t^2 = a_0 + \sum_{i=1}^{Max(p,q)} \left(a_i + b_j\right)\varepsilon_{t-i}^2 + \eta_t + \sum_{j=1}^{p} b_j\eta_{t-j}$$

Thus a GARCH model can be regarded as an extension of the ARMA approach to squared series $\{\varepsilon_t^2\}$.Parameter estimates for the exponential growth model using Holt's methods are given in Table 8. The point forecasting (PF), the lower bound (Lo), and higher bound (Hi) for α = 0.2 and α = 0.2 are presented in Table 9 for the milk production using Holt's linear models trend from 2019 to 2025. From Table 9, it is concluded that the upward milk production trend in India and Pakistan will continue. It is expected to exceed 100 million metric tons (MTT) milk productions in 2025 in India. It is also expected to exceed 55 million tone milk productions in 2025 in Pakistan. While milk productions in China, India, and Pakistan will be expected to increase significantly, in Nepal, Sri Lanka, and Myanmar will be expected to increase more slowly over the years. It will also be expected to decrease milk productions in Bangladesh over the years.

From Tables 10, 11, and 12, we find that a model in Holt's Linear model achieves the lowest MAPE in China, India, Nepal, Pakistan, Sri Lanka, and Bangladesh, and thus a Holt's Linear Model is the best in Forecasting production

Table 3 ARIMAModels fitted and Holt's linear model for milk production time series over the period (1961–2018)

	Model	Drift	AR	MA	LL	AIC	BIC	AICc	ME	RMSE	MAE	MPE	MAPE	MASE	ACF1	LB[a]
China, mainland	ARIMA (1,2,1)	–	− 0.16	− 0.77	− 542.17	1090.35	1095.77	1090.93	177,943.5	245,563.4	178,239.4	5.33	5.34	–	0.76	0.08
India	ARIMA (1,2,1)	–	0.14	− 0.79	− 620.29	1346.57	1351.99	1347.16	− 3,912,409	6,015,012	4,207,575	− 5.22	5.71	–	0.65	0.07
Nepal	ARIMA (1,2,2)	–	− 0.49	− 0.05	− 484.53	977.06	984.29	978.06	− 35,288.29	45,132.93	35,552.66	− 3.12	3.14	–	0.25	0.54
Pakistan	ARIMA (1,2,0)	–	− 0.63	–	− 603.39	1210.77	1214.39	1211.06	− 2,198,966	2,511,836	2,198,966	− 9.67	9.67	–	0.72	0.54
Sri Lanka	ARIMA (0,1,0)	–	–	–	− 485.23	972.46	974.29	972.55	− 25,776.36	30,083.48	25,776.36	− 94.56	94.56	–	0.35	0.97
Bangladesh	ARIMA (0,1,0)	–	–	–	− 405.99	813.99	815.82	814.08	− 4032.82	4265.16	4032.82	− 12.60	12.60	–	0.43	0.80
Myanmar	ARIMA (1,2,1)	–	− 0.27	− 0.76	− 481.61	969.21	974.63	969.8	95,303.58	130,655	109,765.8	26.87	32.32	–	0.74	0.92
Holt's linear model																
China, mainland	Holt's model	–	–	–	–	− 1279.844	− 1270.593	− 1278.381	− 3844.146	44,415.05	24,190.94	− 0.1955345	1.202316	0.5032381	− 0.2975724	–
India	Holt's model	–	–	–	–	275.4604	284.7111	276.9238	90,158.63	684,422.9	474,951.9	0.430057	2.210809	0.4377875	0.1083532	–
Nepal	Holt's model	–	–	–	–	− 407.2761	− 398.0254	− 405.8127	502.267	11,073.18	7838.862	− 0.02164949	1.40627	0.5221118	0.1572573	–
Pakistan	Holt's model	–	–	–	–	− 816.1363	− 806.8855	− 814.6729	− 44,082.97	252,917.5	165,840.1	− 0.1034639	1.377794	0.4659282	0.6672319	–
Sri Lanka	Holt's model	–	–	–	–	1086.306	1095.556	1087.769	− 1370.963	9204.253	4867.231	− 6.332225	13.80561	0.9811848	− 0.02080074	–
Bangladesh	Holt's model	–	–	–	–	813.99	814.08	815.82	− 4032.82	4265.16	4032.82	− 12.60	12.60	0.80	0.43	–
Myanmar	Holt's model	–	–	–	–	437.0612	446.3120	438.5246	784.4944	10,200.05	5720.191	− 1.374684	6.90126	0.9976296	0.07656917	–

Population of seven countries (SAARC) milk production (China, mainland, India, Nepal, Pakistan, Sri Lanka, Bangladesh, and Myanmar), Milk Production data for SAARC

[a]It corresponds to the *p* value of Ljung-Box test

Table 4 ARIMA-GARCH models fitting for milk production time series over the period (1961–2018)

	ARIMA model (Mean equation)	ARCH Test (*)	GARCH Model (Variance equation)	AIC	RMSE	MAE	MAPE
China, mainland	ARIMA (1,2,1)	0.23	[redacted]				
India	ARIMA (1,2,1)	0.41					
Nepal	ARIMA (1,2,2)	0.79					
Pakistan	ARIMA (1,2,0)	0.59					
Sri Lanka	ARIMA(0,1,0)	0.80					
Bangladesh	ARIMA(0,1,0)	0.04	GARCH(1,1)	17.17	1503.719	864.94	2.45
Myanmar	ARIMA(1,2,1)	0.03	GARCH(1,1)	21.29	113250.5	98114.64	51.58

GARCH models: GARCH models were fitted using EViews software. 80% of data was used in fitting the models (i.e., from 1961 to 2007). The remaining 20% was used in model validation (i.e., 2008–2018). Since the residuals of the fitted ARIMA models in the countries China, India, Nepal, Pakistan, and Sri Lanka do not show the ARCH effect, the residuals cannot be models using ARCH/GARCH models

Table 5 Milk production forecasting and model validation using ARIMA-GARCH models (PF: point forecast)

Years	Bangladesh		Myanmar	
	Actual	Forecasted	Actual	Forecasted
2008	34,000	32,794.63	238,704	232,357.1
2009	35,000	34,794.63	265,117	251,728.6
2010	36,000	35,794.63	302,974	279,622.2
2011	37,200	36,794.63	305,631	320,096.4
2012	38,000	37,994.63	171,184	322,595.5
2013	39,000	38,794.63	175,526	174,928.1
2014	35,173	39,794.63	179,751	173,228.3
2015	35,303	35,967.63	184,142	178,422
2016	35,432	36.97.63	188,490	183,665.5
2017	35,562	36,226.63	192,134	188,760.1
2018	35,691	36,356.63	193,841	192,993.4

in these countries as well. Anyone can find that a model in Myanma that GARCH model is better than ARIMA and when we compare MAPE Myanmain Holt's Linear model and GARCH model, we find that GARCH model more accurate than Holt's Linear model and achieve low MAPE in GARCH model.

The dairy sector is an important activity in the agriculture sector. Milk production plays a crucial role in development. The dairy sector: data were analyzed in the following seven countries, China, India, Nepal, Pakistan, Sri Lanka,

Table 7 Best time series models selected for modeling and forecasting milk production

Country	Best model
China, mainland	ARIMA (1,2,1)
India	ARIMA (1,2,1)
Nepal	ARIMA (1,2,2)
Pakistan	ARIMA (1,2,0)
Sri Lanka	ARIMA(0,1,0)
Bangladesh	**ARIMA(0,1,0)-GARCH(1,1)**
Myanmar	**ARIMA(1,2,1)-GARCH(1,1)**

Bold letter indicates ARIMA and GARCH both performed for Bangladesh and Myanmar

and Bangladesh during the study period. For all the milk production data, we expect China there will be an increase in milk production during the coming period, while India we expect an increase in milk production in the coming period, and by 2024, dairy production in India will exceed 100 million tons annually and will have a good impact on the rest of the sectors in India. Of the dairy production in India during the coming period, and we expect Nepal, there will be an increase in milk production. The annual increase in milk production in Nepal will be a slight increase in the annual production rate.

For Pakistan, we also expect more annual production for the amount of milk production. Also, there will be a slight increase

Table 6 Comparison of ARIMA and ARIMA-GARCH models

Country	Model	RMSE	MAE	MAPE
Bangladesh	ARIMA(0,1,0)	4265.16	4032.82	12.60
	ARIMA(0,1,0)-GARCH(1,1)	**1503.719**	**864.94**	**2.45**
Myanmar	ARIMA(1,2,1)	130,655	109,765.8	32.32
	ARIMA(1,2,1)-GARCH(1,1)	**113,250.5**	**98,114.64**	51.58

Bold letter indicates ARIMA and GARCH both performed for Bangladesh and Myanmar

Table 8 Holt's linear trend models fitted for milk production time series over the period (1961–2018)

Country	Box-cox transformation	Smoothing parameters		Initial states		Sigma
	Lambda	Alpha	Beta	L	B	
China, mainland	− 0.8014	0.9365	0.5325	1.2478	0	0
India	0.2582	0.9999	0.1536	250.1244	1.1341	2.5688
Nepal	− 0.1848	0.9999	1e-04	4.8944	0.002	0.0018
Pakistan	− 0.4138	0.9999	0.0327	2.4125	0	0
Sri Lanka	1.0369	0.9265	0.0086	36,086.5029	2113.4565	14,320.69
Bangladesh	0.0809	0.1845	0.0116	− 14.586	0.4601	4.6949
Myanmar	0.4266	0.7669	1e-04	148.0494	6.224	14.3336

Parameter estimates for exponential growth model using Holt's method

Population of seven country (SAARC) milk production (China, mainland, India, Nepal, Pakistan, Sri Lanka, Bangladesh, and Myanmar), Milk Production data for SAARC

Holt's linear model: Holt's linear models were fitted using R software. 80% of data was used in fitting the models (i.e., from 1961 to 2007). The remaining 20% was used in model validation (i.e., 2008–2018). Using Holt's Linear Trend Method, this is the average of smoothing variability as a random process, and also called a moving average of exponentially weighted

in the rate of production. Annual for Albanians in Pakistan. We expect Sri Lanka that there will also be an increase in the amount of dairy production during the coming period, but there will be a decrease in the annual production rate of milk, thus it will have a negative impact in Sri Lanka in the sectors related to dairy production. Therefore, attention must be paid to the dairy production sector in Sri Lanka to prevent further losses in The period is the leader in the sectors related to dairy. In Bangladesh, we expect that there will be stability in the amount of dairy products in the coming period. We expect in Myanmar increases in dairy production, but there will be a difference in growth rates. It will witness a decrease and increase and an increase in the growth rates of milk production.

However, lower growth rates are expected in 2025 compared to the previous period. To increase milk production, you need to provide the animals with good fodder and proper health care. This projection helps strategize to meet our future milk demand. To increase the need for milk production to educate dairy owners and farmers about the animal breeding program and health care practices.

Conclusions

This paper uses annual data from 1961 to 2018 to forecast milk production in South-Asian countries using an Auto-Regressive Integrated Moving average model (ARIMA) model, a Generalized Autoregressive Heteroskedastic (ARCH-GARCH) model and then Holt's Linear Trend. The findings employing the ARIMA approach show that India would be the leading state in milk production with 91 MMT in the year 2024–2025 among South Asian countries. The second country ranked is Pakistan which milk production would reach 26 MMT in 2024–2025, China is the third country with 3MMT, while Bangladesh and Sri Lanka seem to be the countries with the lowest production of milk. Since the residuals of the fitted ARIMA models for China, India, Nepal, Pakistan, and Sri Lanka are having absence of ARCH effects, we proceed by fitting a GARCH model only for Bangladesh and Myanmar. GARCH model for Bangladesh forecasts an abundance of milk production. In comparison to the ARIMA model, Holt's linear model forecasts higher levels of milk production for the region. It indicates that India's forecasted level will reach 105 MMT, Pakistan 58 MMT and China 4 MMT in the year 2024–2025. We compare the mean absolute percentage error (MAPE) between ARIMA and Holt's models and the findings suggest that ARIMA model shows higher errors. The only exception is China, Nepal and Pakistan which errors are higher using Holt's model. This study has policy implications, as it can be used by policymakers in the national agriculture sector to forecast milk production and other dairy productions.

The limit of the study

In this paper, we use annual data to forecast milk production in South Asian countries using autoregressive models. As a matter of fact, autoregressive models are used with high-frequency data, and the usage of annual data instead of quarterly or monthly data can reduce the robustness of our results. Another limitation is related to the models' properties; we use ARIMA models with different lags, while the autoregressive models are sensitive to the number of lags. Instead, GARCH models are the benchmark among the autoregressive models; the coefficients are restricted to be positive, and by imposing artificial restrictions, it makes the model less reliable and far from reality. Hence, the researcher should be careful while using autoregressive

Table 9 Milk production forecasting using Holt's linear trend (PF: point forecast)

	Milk production—China					Milk production—India				
Year	PF	Lo 80	Hi 80	Lo 95	Hi 95	PF	Lo 80	Hi 80	Lo 95	Hi 95
2019	3,803,153	2,334,634	8,570,512	1,916,533	19,654,561	86,427,539	70,712,785	104,595,440	63,309,095	115,286,482
2020	3,901,199	2,267,432	10,414,588	1,831,379	36,433,249	89,348,068	71,930,530	109,714,449	63,803,187	121,793,926
2021	4,003,894	2,200,145	13,209,086	1,749,273	139,105,924	92,341,178	73,132,357	115,060,949	64,256,495	128,642,974
2022	4,111,564	2,133,179	17,867,331	1,670,424	NA	95,408,035	74,317,617	120,643,307	64,668,870	135,848,776
2023	4,224,564	2,066,875	26,932,789	1,594,951	NA	98,549,815	75,485,734	126,470,048	65,040,292	143,426,887
2024	4,343,285	2,001,518	50,733,409	1,522,905	NA	101,767,701	76,636,186	132,549,877	65,370,842	151,393,293
2025	4,468,154	1,937,337	206,213,189	1,454,276	NA	105,062,884	77,768,495	138,891,691	65,660,682	159,764,448

	Milk production—Nepal					Milk production—Pakistan				
Year	PF	Lo 80	Hi 80	Lo 95	Hi 95	PF	Lo 80	Hi 80	Lo 95	Hi 95
2019	1,305,156.9	1,172,820.3	1,455,560	1,109,222.7	1,543,465	38,981,232	33,101,611	46,453,264	30,487,296	51,249,271
2020	1,340,245.3	1,198,502.9	1,502,290	1,130,683.8	1,597,437	41,509,487	34,786,079	50,227,985	31,837,846	55,920,638
2021	1,376,457.1	1,225,055.8	1,550,542	1,152,925.0	1,653,221	44,275,938	36,596,478	54,447,602	33,277,424	61,210,659
2022	1,413,833.9	1,252,493.1	1,600,394	1,175,948.4	1,710,919	47,310,414	38,544,632	59,183,362	34,812,931	67,231,377
2023	1,452,419.2	1,280,832.6	1,651,926	1,199,760.6	1,770,634	50,647,458	40,643,847	64,520,886	36,452,060	74,120,538
2024	1,492,258.6	1,310,094.2	1,705,218	1,224,371.2	1,832,473	54,327,238	42,909,114	70,563,778	38,203,378	82,048,951
2025	1,533,399.4	1,340,300.8	1,760,353	1,249,792.4	1,896,542	58,396,660	45,357,355	77,438,304	40,076,417	91,230,389

	Milk production—Sri Lanka					Milk production—Bangladesh				
Year	PF	Lo 80	Hi 80	Lo 95	Hi 95	PF	Lo 80	Hi 80	Lo 95	Hi 95
2019	37,869.64	− 6350.0160	79,482.82	− 29,412.583	101,149.19	32,000	24,685.89	39,314.11	20,814.03	43,185.97
2020	38,746.03	− 7439.7363	82,183.18	− 31,458.244	104,795.02	32,000	24,387.23	39,612.77	20,357.27	43,642.73
2021	39,621.69	− 8472.3410	84,833.20	− 33,424.503	108,364.83	32,000	24,099.86	39,900.14	19,917.77	44,082.23
2022	40,496.64	− 9455.4610	87,438.84	− 35,321.155	111,867.68	32,000	23,822.57	40,177.43	19,493.71	44,506.29
2023	41,370.89	− 10,395.2561	90,005.08	− 37,156.323	115,311.11	32,000	23,554.39	40,445.61	19,083.56	44,916.44
2024	42,244.46	− 11,296.7990	92,536.12	− 38,936.827	118,701.50	32,000	23,294.47	40,705.53	18,686.03	45,313.97
2025	43,117.36	− 12,164.3326	95,035.54	− 40,668.455	122,044.26	32,000	23,042.08	40,957.92	18,300.04	45,699.96

	Milk production—Myanmar				
Year	PF	Lo 80	Hi 80	Lo 95	Hi 95
2019	310,747.5	244,454.7	386,308.2	213,004.2	430,162.7
2020	319,599.4	249,749.4	399,489.4	216,716.3	445,959.9
2021	328,594.2	255,196.8	412,809.8	220,588.2	461,896.8
2022	337,732.4	260,791.2	426,275.7	224,611.1	477,983.1
2023	347,014.6	266,528.3	439,892.8	228,778.1	494,226.9
2024	356,441.4	272,404.4	453,665.7	233,083.2	510,635.0
2025	366,013.4	278,416.6	467,598.5	237,521.7	527,213.3

(PF: point forecast); Lo 80 and Hi80 are (respectively) the lower and higher bounds of predictive interval for an error term alpha = 0.2; Lo 95 and Hi95 are (respectively) the lower and higher bounds of predictive interval for an error term alpha = 0.05.)

Table 10 MAPE ARIMA Model

	Milk Production—China			Milk Production -India			Milk Production -Nepal			Milk Production -Pakistan		
Years	Actual	Forecasted	Error	Actual	Forecasted	Error	Actual	Forecasted	Error	Actual	Forecasted	Error
2008	2,950,000	2,949,706	0.009966%	57,895,000	58,606,485	1.228923%	987,780	990,496.7	0.275031%	20,971,000	20,528,277	2.11112%
2009	3,000,000	2,999,460	0.018%	59,758,000	60,544,002	1.315308%	1,031,500	1,022,351.3	0.886932%	21,622,000	20,957,802	3.071862%
2010	3,050,000	3,049,207	0.026%	62,350,000	62,475,926	0.201966%	1,066,867	1,054,216.7	1.185743%	22,279,000	21,216,361	4.769689%
2011	3,050,000	3,098,955	1.605082%	65,352,000	64,407,047	1.445944%	1,109,325	1,086,079.1	2.0955%	22,955,000	21,581,890	5.981747%
2012	3,080,000	3,148,702	2.230584%	67,675,432	66,338,053	1.976166%	1,153,838	1,117,942.4	3.110974%	23,652,000	21,880,490	7.489895%
2013	3,050,000	3,198,450	4.867213%	70,442,617	68,269,043	3.085595%	1,188,433	1,149,805.4	3.250297%	24,370,000	22,220,966	8.818359%
2014	3,100,000	3,248,197	4.780548%	74,709,900	70,200,030	6.036509%	1,167,773	1,181,668.5	1.189914%	25,001,000	22,535,242	9.862637%
2015	2,990,666	3,297,945	10.2746%	76,459,000	72,131,017	5.660528%	1,167,154	1,213,531.6	3.973563%	25,744,000	22,865,910	11.17965%
2016	3,005,201	3,347,693	11.39664%	81,266,300	74,062,003	8.865049%	1,210,441	1,245,394.7	2.887683%	26,510,000	23,186,322	12.53745%
2017	2,946,374	3,397,440	15.30919%	86,261,680	75,992,990	11.90412%	1,245,954	1,277,257.8	2.512436%	27,298,000	23,513,151	13.86493%
2018	3,003,323	3,447,188	14.77913%	91,817,140	77,923,977	15.13134%	1,338,277	1,309,120.9	2.17863%	28,109,000	23,835,965	15.20166%
MAPE			5.936087%			5.168313%			2.140609%			8.626273%

Years	Milk production—Sri Lanka			Milk production—Bangladesh			Milk production—Myanmar		
	Actual	Forecasted	Error	Actual	Forecasted	Error	Actual	Forecasted	Error
2008	30,105	27,260	9.450257%	34,000	32,000	5.882353%	238,704	234,338.3	1.828918%
2009	41,600	27,260	34.47115%	35,000	32,000	8.571429%	265,117	250,549.5	5.494744%
2010	46,990	27,260	41.98766%	36,000	32,000	11.11111%	302,974	266,123.9	12.16279%
2011	46,330	27,260	41.16123%	37,200	32,000	13.97849%	305,631	281,872.0	7.773753%
2012	61,710	27,260	55.82564%	38,000	32,000	15.78947%	171,184	297,572.6	73.83202%
2013	54,060	27,260	49.57455%	39,000	32,000	17.94872%	175,526	313,286.3	78.48427%
2014	45,854	27,260	40.55044%	35,173	32,000	9.021124%	179,751	328,996.3	83.02891%
2015	36,118	27,260	24.52517%	35,303	32,000	9.356145%	184,142	344,707.4	87.19651%
2016	66,128	27,260	58.77692%	35,432	32,000	9.686159%	188,490	360,418.2	91.21343%
2017	68,591	27,260	60.25718%	35,562	32,000	10.01631%	192,134	376,129.0	95.76389%
2018	85,914	27,260	68.2706%	35,691	32,000	10.34154%	193,841	391,839.9	102.145%
MAPE			44.07734%			11.0639%			58.08402%

The accuracy: MAPE ARIMA model in milk production (China mainland, India, Nepal, Pakistan, Sri Lanka, Bangladesh, and Myanmar)

Table 11 MAPE Holt's Linear Trend Model

Years	Milk production—China			Milk production—India			Milk production—Nepal			Milk production—Pakistan		
	Actual	Forecasted	Error	Actual	Forecasted	Error	Actual	Forecasted	Error	Actual	Forecasted	Error
2008	2,950,000	2,961,053	0.374678%	57,895,000	58,767,312	1.506714%	987,780	982,923.3	0.491678%	20,971,000	21,371,536	1.909952%
2009	3,000,000	3,023,254	0.775133%	59,758,000	60,963,917	2.018001%	1,031,500	1,007,979.1	2.280262%	21,622,000	22,441,794	3.791481%
2010	3,050,000	3,087,849	1.240951%	62,350,000	63,220,851	1.396714%	1,066,867	1,033,795.3	3.09989%	22,279,000	23,589,424	5.88188%
2011	3,050,000	3,154,973	3.441738%	65,352,000	65,539,185	0.286426%	1,109,325	1,060,398.6	4.410466%	22,955,000	24,821,814	8.132494%
2012	3,080,000	3,224,773	4.700422%	67,675,432	67,919,997	0.361379%	1,153,838	1,087,816.9	5.721869%	23,652,000	26,147,232	10.54977%
2013	3,050,000	3,297,405	8.111639%	70,442,617	70,364,375	0.111072%	1,188,433	1,116,079.2	6.088168%	24,370,000	27,574,962	13.15126%
2014	3,100,000	3,373,037	8.807645%	74,709,900	72,873,415	2.458155%	1,167,773	1,145,215.7	1.931651%	25,001,000	29,115,447	16.45713%
2015	2,990,666	3,451,853	15.42088%	76,459,000	75,448,223	1.321986%	1,167,154	1,175,257.9	0.69433%	25,744,000	30,780,470	19.56367%
2016	3,005,201	3,534,050	17.59779%	81,266,300	78,089,913	3.908615%	1,210,441	1,206,238.3	0.347204%	26,510,000	32,583,360	22.90969%
2017	2,946,374	3,619,841	22.85749%	86,261,680	80,799,606	6.331982%	1,245,954	1,238,191.1	0.623049%	27,298,000	34,539,239	26.52663%
2018	3,003,323	3,709,458	0.374678%	91,817,140	83,578,435	8.972949%	1,338,277	1,271,151.6	5.015808%	28,109,000	36,665,316	30.43977%
MAPE			8.332836%			2.606727%			2.791307%			14.48307%

Years	Milk production—Sri Lanka			Milk production—Bangladesh			Milk production—Myanmar		
	Actual	Forecasted	Error	Actual	Forecasted	Error	Actual	Forecasted	Error
2008	30,105	28,175.23	6.410131%	34,000	32,268.47	5.092735%	238,704	222,633.8	6.732271%
2009	41,600	29,061.09	30.14161%	35,000	32,534.80	7.043429%	265,117	229,954.1	13.26316%
2010	46,990	29,945.95	36.27165%	36,000	32,798.96	8.891778%	302,974	237,410.5	21.63998%
2011	46,330	30,829.86	33.45595%	37,200	33,061.02	11.12629%	305,631	245,003.7	19.83676%
2012	61,710	31,712.83	48.6099%	38,000	33,321.01	12.31313%	171,184	252,734.3	47.63897%
2013	54,060	32,594.89	39.70609%	39,000	33,578.99	13.90003%	175,526	260,602.9	48.46969%
2014	45,854	33,476.08	26.9942%	35,173	33,835.00	3.804054%	179,751	268,610.2	49.43461%
2015	36,118	34,356.41	4.877319%	35,303	34,089.10	3.438518%	184,142	276,756.7	50.29526%
2016	66,128	35,235.91	46.7156%	35,432	34,341.31	3.078263%	188,490	285,043.1	51.22452%
2017	68,591	36,114.60	47.3479%	35,562	34,591.68	2.72853%	192,134	293,470.0	52.74236%
2018	85,914	36,992.51	56.9424%	35,691	34,840.25	2.383654%	193,841	302,037.9	55.81735%
MAPE			34.3157%			6.709128%			37.91772%

The accuracy: MAPE Holt's linear trend model in milk production (China mainland, India, Nepal, Pakistan, Sri Lanka, Bangladesh, and Myanmar)

Table 12 MAPE milk production forecasting and model validation using ARIMA-GARCH models (PF: point forecast)

Years	Bangladesh			Myanmar		
	Actual	Forecasted	Error	Actual	Forecasted	Error
2008	34,000	32,794.63	3.545205882%	238,704	232,357.1	2.6589%
2009	35,000	34,794.63	0.586771429%	265,117	251,728.6	5.049997%
2010	36,000	35,794.63	0.570472222%	302,974	279,622.2	7.707526%
2011	37,200	36,794.63	1.089704301%	305,631	320,096.4	4.732962%
2012	38,000	37,994.63	0.014131579%	171,184	322,595.5	88.44956%
2013	39,000	38,794.63	0.526589744%	175,526	174,928.1	0.340633%
2014	35,173	39,794.63	13.13970944%	179,751	173,228.3	3.628742%
2015	35,303	35,967.63	1.882644534%	184,142	178,422	3.106298%
2016	35,432	36.97.63	89.56415105%	188,490	183,665.5	2.559552%
2017	35,562	36,226.63	1.868933131%	192,134	188,760.1	1.756014%
2018	35,691	36,356.63	1.864979967%	193,841	192,993.4	0.437266%
MAPE			10.42302666%			10.94795%

The accuracy: MAPE GARCH model in milk production (Bangladesh, and Myanmar)

models as fitting an ARIMA or GARCH models is more an “art than of science”.

Acknowledgement The work was supported by the Ministry of Science and Higher Education of the Russian Federation (government order FENU-2020-0022).

References

Adediran SA, Ratkowsky DA, Donaghy DJ, Malau-Aduli AEO (2012) Comparative evaluation of a new lactation curve model for pasture-based Holstein- Friesian dairy cows. J Dairy Sci 95:5344–5356

Ahuja V, Staal S (2012) Poverty, food security, livestock and smallholders: issues and options for the Asia and the Pacific region. Asian livestock 16:97

Akter, Sh., and Rahman,S.(2010) Milk supply forecasting for a dairy cooperative in the UK using univariate time series modelling techniques, In book: Agricultural Economics: New Research (pp.227–242), Chapter:11, Publisher: Nova Science Publishers, New York, Editors: Thomas H. Lee

Ali TE, Schaeffer LR (1987) Accounting for covariances among test day milk yields in dairy cows. Can J Anim Sci 67:637–644

Baudracco J, Lopez-Villalobos N, Holmes CW, Comeron EA, Macdonald KA, Barry TN, Friggens NC (2012) e-cow: an animal model that predicts herbage intake, milk yield and live weight change in dairy cows grazing temperate pastures, with and without supplementary feeding. Animal 6:980–993

Bollerslev T (1986) Generalized autoregressive conditional heteroskedasticity. J econom 31(3):307–327

Brun-Lafleur L, Delaby L, Husson F, Faverdin P (2010) Predicting energy × protein interaction on milk yield and milk composition in dairy cows. J Dairy Sci 93:4128–4143

Collard BL, Boettcher PJ, Dekkers JCM, Petitclerc D, Schaeffer LR (2000) Relationships between energy balance and health traits of dairy cattle in early lactation. J Dairy Sci 83:2683–2690

Deshmukh SS, Paramasivam R (2016) Forecasting of milk production in India with ARIMA and VAR time series models. Asian J Dairy Food Res 35(1):17–22

FAO (2019) Food outlook, dairy market review report. Rome, Italy

FAO (2020) Food outlook, biannual report on global food markets. Italy, Rome

Grzesiak W, Lacroix R, Wójcik J, Blaszczyk P (2003) A comparison of neural network and multiple regression predictions for 305-day lactation yield using partial lactation records. Can J Anim Sci 83:307–310

Guo ZSH (1995) Modelling of the lactation curve as a sub-model in the evaluation of test day records. Prague, SverigesLantbruksuniv, Uppsala, Sweden, INTERBULL

Holt CC (1957) Forecasting seasonals and trends by exponentially weighted moving averages. ONR Memorandum, Vol 52, Carnegie Institute of Technology, Pittsburgh. Available from the Engineering Library, University of Texas, Austin

Kolver ES, Muller LD (1998) Performance and nutrient intake of high producing Holstein cows consuming pasture or a total mixed ration. J Dairy Sci 81:1403–1411

Li H (2020) Genome-wide association study of milk production traits in acrossbred dairy sheep population using three statistical models. Anim Genet 51:624–628

Lohano DH, Soomro MF (2006) Unit root test and forecast of milk production in Pakistan. Int J Dairy Sci 1(1):63–69

Macciotta NPP, Vicario D, Pulina G, Cappio-Borlino A (2002) Test day and lactation yield predictions in Italian Simmental cows by ARMA methods. J Dairy Sci 85:3107–3114

McCarthy B, Delaby L, Pierce KM, Journot F, Horan B (2011) Meta-analysis of the impact of stocking rate on the productivity of pasture-based milk production systems. Animal 5:784–794

Mishra P, Fatih C, Niranjan HK, Tiwari S, Devi M, Dubey A (2020a) Modelling and forecasting of milk production in Chhattisgarh and India. Indian J Anim Res 54(7):912–917

Mishra P, Fatih C, Vani GK, Tiwari S, Ramesh D, Dubey A (2020b) Time series investigation of milk production in major states of india using ARIMA modeling. J Anim Res 10(1):77–84

Murphy DM, Zhang F, Upton J, Shine P (2014) A review of milk production forecasting models, in book: dairy farming operations management, animal welfare and milk production, 1st edn, Nova Science Publishers, pp 14–61

Oliveros RM (2019) The Dairy industry in Southeast Asia: perspective, challenges and opportunities, earth and environmental. Science 372:1–9

Olori VE, Brotherstone S, Hill WG, McGuirk BJ (1999a) Fit of standard models ofthe lactation curve to weekly records of

milk production of cows in a single herd. Livestock Prod Sci 58:55–63
Olori VE, Brotherstone S, Hill WG, McGuirk BJ (1999b) Fit of standard models of the lactation curve to weekly records of milk production of cows in a single herd. Livestock Prod Sci 58:55–63
Ptak E, Schaeffer LR (1993) Use of test day yields for genetic evaluation of dairy sires and cows. Livestock Prod Sci 34:23–34
SAARC (2015) SAARC diary outlook, March 2015
Schmit TM, Kaiser HM (2006) Forecasting fluid milk and cheese demands for the next decade. J dairy sci 89(12):4924–4936
Shalloo L, Dillon P, Rath M, Wallace M (2004) Description and validation of the Moorepark dairy system model. J Dairy Sci 87:1945–1959
Sharma AK, Sharma RK, Kasana HS (2006) Empirical comparisons of feed-forward connectionist and conventional regression models for prediction of first lactation 305-day milk yield in Karan Fries dairy cows. Neural Comput Appl 15:359–365
Sharma RK, Sharma AK, Kasana HS (2007) Prediction of first lactation 305-day milk yield in Karan Fries dairy cattle using ANN modeling. Appl Soft Comput J 7:1112–1120
Siddiky MNA (ed) (2015) SAARC dairy outlook. SAARC Agriculture Centre, Dhaka, Bangladesh
Smith LP (1968) Forecasting annual milk yields. Agricult Meteorol 5:209–214
Taye BA, Alene AA, Nega KA, Yirsaw GB (2020) Time series analysis of cow milk production at Andassa dairy farm. West Gojam Zone, Amhara Region, Ethiopia, Modeling Earth Systems and Environment, p 364
Tekerli M, Akinci Z, Dogan I, Akcan A (2000) Factors affecting the shape of lactation curves of Holstein cows from the Balikesir province of Turkey. J Dairy Sci 83:1381–1386
Uddin MM, Khaleduzzaman ABM, Akter A (2020) Sustainable dairying and self-sufficiency in quality milk production in Bangladesh: the role of policy and a way forward. Bangladesh J Acad Sci (Submitted)
Vasconcelos J, Martins A, Petim-Batista MF, Colaço J, Blake RW, Carvalheira J (2004) Prediction of daily and lactation yields of milk, fat, and protein using an autoregressive repeatability test day model. J Dairy Sci 87:2591–2598
Wilmink JBM (1987) Adjustment of test-day milk, fat and protein yield for age, season and stage of lactation. Livestock Prod Sci 16:335–348
Wood PDP (1967) Algebraic model of the lactation curve in cattle. Nature 216(5111):164–165
Zhang F, Shine P, Upton J, Shaloo L, Murphy MD (2020) A Review of Milk Production Forecasting Models: Past & Future Methods.