ORIGINAL RESEARCH ARTICLES

Forecasting water buffalo milk production dynamics in major producing nations (2024–2028)

Pronóstico de la dinámica de producción de leche de búfala en los principales países productores (2024–2028)

Previsão da dinâmica da produção de leite de búfala nos principais países produtores (2024–2028)

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Abstract

Background: Water buffalo milk production increased from 17.86 million tons in 1961 to 150.34 million tons in 2023. India, Pakistan, China, Egypt, and Nepal accounted for 96% of global buffalo milk production in 1961 and 99% in 2023, respectively. Accurate forecasting of water buffalo milk production is crucial for planning, policy-making, and ensuring a sustainable supply to meet the growing demand for dairy products. **Objective:** to determine the current production levels of the top five leading nations in the world in terms of water buffalo milk production, as well as the total production of water buffalo milk worldwide, in the years 2024–2028. **Methods:** To do this, we used ARIMA models in the SAS statistical program to make the most appropriate estimates. We analyzed FAOSTAT data from 1961 to 2023 to identify appropriate models and generate projections. **Results:** From 2024 to 2028, we estimated the world water buffalo milk production as 153.05, 154.07, 158.24, 162.12, and 164.11 million tons, with the leading countries accounting for 99.20% of the average annual production of 158.32 million tons in 2028. **Conclusion:** Based on the findings of this study, the share of India, Pakistan, China, Egypt, and Nepal, which are the leading countries in the world's water buffalo milk production, is estimated to be 69.88%, 25.46%, 2.11%, 0.87%, and 0.87% respectively, between 2024 and 2028.

Keywords: *ARIMA; forecasting; leading countries; milk production; water buffalo.*

Resumen

Antecedentes: La producción de leche de búfala aumentó de 17,86 millones de toneladas en 1961 a 150,34 millones de toneladas en 2023. India, Pakistán, China, Egipto y Nepal representaron el 96 % de la producción mundial de leche de búfala en 1961 y el 99 % en 2023, respectivamente. La previsión precisa de la producción de leche de búfala es crucial para la planificación, la formulación de políticas y la garantía de un suministro sostenible que satisfaga la creciente demanda de productos lácteos. **Objetivo:** determinar los niveles actuales de

producción de las cinco principales naciones del mundo en términos de producción de leche de búfala, así como la producción total de leche de búfala a nivel mundial, en el período 2024-2028. **Métodos:** Para ello, se utilizaron modelos ARIMA en el programa estadístico SAS para realizar las estimaciones más adecuadas. Se analizaron los datos de FAOSTAT de 1961 a 2023 para identificar modelos adecuados y generar proyecciones. **Resultados:** De 2024 a 2028, estimamos la producción mundial de leche de búfala en 153,05, 154,07, 158,24, 162,12 y 164,11 millones de toneladas, y los países líderes representaron el 99,20 % de la producción anual promedio de 158,32 millones de toneladas en 2028. **Conclusión:** Según los hallazgos de este estudio, se estima que la participación de India, Pakistán, China, Egipto y Nepal, países líderes en la producción mundial de leche de búfala, será del 69,88 %, 25,46 %, 2,11 %, 0,87 % y 0,87 %, respectivamente, entre 2024 y 2028.

Palabras clave: *ARIMA; búfala; países líderes; producción de leche; pronóstico.*

Resumo

Antecedentes: A produção de leite de búfala aumentou de 17,86 milhões de toneladas em 1961 para 150,34 milhões de toneladas em 2023. Índia, Paquistão, China, Egito e Nepal foram responsáveis por 96% da produção mundial de leite de búfala em 1961 e 99% em 2023, respectivamente. A previsão precisa da produção de leite de búfala é crucial para o planejamento, a formulação de políticas e para garantir um fornecimento sustentável que atenda à crescente demanda por produtos lácteos. **Objetivo:** Determinar os níveis atuais de produção nos cinco maiores países produtores de leite de búfala do mundo, bem como a produção mundial total de leite de búfala, para o período de 2024 a 2028. **Métodos:** Modelos ARIMA foram utilizados no software estatístico SAS para obter as estimativas mais adequadas. Dados da FAOSTAT de 1961 a 2023 foram analisados para identificar modelos adequados e gerar projeções. **Resultados:** De 2024 a 2028, estimamos a produção global de leite de búfala em 153,05, 154,07, 158,24, 162,12 e 164,11 milhões de toneladas, com os principais países respondendo por 99,20% da produção média anual de 158,32 milhões de toneladas em 2028. **Conclusão:** Com base nas descobertas deste estudo, as participações estimadas da Índia, Paquistão, China, Egito e Nepal, os principais países na produção global de leite de búfala, serão de 69,88%, 25,46%, 2,11%, 0,87% e 0,87%, respectivamente, entre 2024 e 2028.

Palavras-chave: *ARIMA; búfala; principais países; produção de leite; prognóstico.*

Introduction

Water buffaloes significantly contribute to the economies of numerous developing countries, particularly in Asia, by providing milk, meat, draught power, and high-quality hides. Two subspecies are acknowledged: river buffaloes and swamp buffaloes. Swamp buffaloes, which constitute 20.5% of the global buffalo population, are predominantly located in Southeast Asia and are utilized for draft and meat due to their minimal milk production. Their population has diminished in recent decades owing to the rise in agricultural technology (Pineda et al., 2021). River buffaloes, found mainly in India, Pakistan, and parts of Europe, West Asia, and the Americas, are primarily bred for high milk productivity and are used as dual-purpose animals (Minervino et al., 2020). Water buffaloes are notable for their long productive lives, disease resistance (Deb et al., 2016), ability to utilize poor-quality feed efficiently (Ermetin, 2023), and suitability for ecological farming (Özdemir, 2024). Given these traits, zoologists have highlighted the future potential of these animals as a key livestock species, especially for smallholder farmers in low-income regions of the world (Minervino et al., 2020).

The increasing global attention given to water buffaloes is largely due to the superior nutritional composition of their milk, which is characterized by elevated levels of fat, protein, casein, lactose, and essential minerals. Additionally, water buffalo milk contains lower cholesterol and higher tocopherol concentrations than cow's milk, contributing to its enhanced health-promoting properties (Costa et al., 2020). Water buffalo milk and its cheeses are rich in essential amino acids (leucine, lysine, and valine) and non-essential ones (glutamic acid and aspartic acid), contributing to dietary quality (Becskei et al., 2020). It is also more efficient for dairy processing: 5 kg of water buffalo milk yields 1 kg of cheese, compared to 8 kg for cow's milk; for butter, 10 kg of water buffalo milk suffices versus 14 kg of cow's milk (Emakpor et al., 2024). Due to these benefits, the domesticated water buffalo (*Bubalus bubalis*), first domesticated in Asia 6,300 years ago, is now found across all continents (Zhang et al., 2020).

From 1961 to 2023, India, Pakistan, China, Egypt, and Nepal consistently ranked among the top five global producers of water buffalo milk, with slight changes in ranking after 2020. According to FAOSTAT (2025), average annual milk yield per buffalo in these countries is India (2.294 kg), Pakistan (2.175 kg), Egypt (1.686 kg), Nepal (869 kg), and China (504 kg). Globally, water buffalo milk accounts for approximately 15.4% of total milk production. In the last decade alone, production rose from 107 million to 143.6 million tons, a 34.2% increase compared to just 6.6% for cattle milk. Although Asia dominates buffalo husbandry, buffalo populations in Europe and the Americas have grown by 14.2% and 42.2%, respectively. India

leads global production with a 69.1% share, followed by Pakistan (26.1%), China (2.0%), Nepal (1.0%), and Egypt (0.9%) (FAOSTAT, 2025).

Although buffalo milk has gained growing global importance, very limited studies have provided systematic analyses or reliable forecasts to support future development. Forecasting production with ARIMA models can offer valuable insights for designing sustainable production policies and making informed decisions in international trade. This study therefore aims to predict future buffalo milk production in the world's leading producer countries using the ARIMA model and to assess possible production trends based on these forecasts.

Materials and Methods

Material

This study primarily utilized FAO data, focusing on major water buffalo milk-producing countries between 1961 and 2023.

Method

Global water buffalo milk production data were obtained from the FAO database. An ARIMA time-series model, implemented via SAS 9.4, was applied to production data from the top five producing countries (1961–2023) to forecast output for 2024–2028. Competitiveness was assessed using concentration ratios and the Herfindahl-Hirschman Index (HHI) calculated over 10-, 5-, and 3-year periods. Microsoft Excel was used for data processing and visualization.

Herfindahl-Hirschman Index (HHI) and Concentration Ratios (CR$_5$)

Market concentration can be measured in several ways, but the HHI and CRn are the most often used. While the HHI considers all enterprises and is sensitive to their size, concentration ratios demonstrate how a small number of major firms drive output or sales in a sector. These techniques aid in assessing the degree of market rivalry and directing the development of a competitive atmosphere that guarantees effective resource use (Ukav, 2017).

For each decade (1961–2020 periods), 2021–2023, and 2024–2028 periods, we calculated HHI and CR_5 in the context of production competition between countries. Drawing on the methodologies of Baye & Prince (2021), Krugman & Wells (2021), and Uzundumlu et al. (2021), market scenarios were delineated based on concentration levels calculated using the HHI and standard CR_n (Table 1).

Table 1. Current state of the market as measured by the HH index and concentration rates

Markets	HHI	HHI^{-1}	CR$_5$
Perfect Competition	0-0.0099	9.99-100.00	<1
Monopolistic Competition	0.0100-0.1799	5.56-10.00	%1.00-49.99
Oligopoly	0.1800-0.9999	1.01-5.55	%50.00-99.99
Monopoly	1.0000	1.00	%100.00

Source: Krugman and Wells, 2021.

The HHI value normally varies between 0 and 10,000 and is obtained by squaring the production shares of the first 5 countries. It takes values between 0 and 1, as given in Table 1, by dividing the results by 10,000 in terms of their severity. An HHI value equal to 10,000 means that the market share is 1 or that there is a country that controls the world water buffalo milk production market, while an HHI value close to 0 indicates that there are many countries that control the water buffalo milk industry. CR_1 shows the share of the first country in water buffalo milk production; CR_2 shows the proportional total share of the first and second countries in water buffalo milk production; and CR_5 shows the proportional total share of the first 5 countries in water buffalo milk production. When this ratio is 100%, it indicates that a single country dominates the market in terms of production, and as it approaches 0, it indicates that there are many producing countries.

The computation presents the results as follows: Historically and currently, seven nations primarily produce water buffalo milk: India, Pakistan, China, Egypt, and Nepal, the competitiveness indices (HHI, HHI^{-1}, and CR_5) for these countries are listed below.

$$\mathbf{HHI} = \mathrm{MS_1}^2 + \mathrm{MS_2}^2 + \mathrm{MS_3}^2 + \mathrm{MS_4}^2 + \mathrm{MS_5}^2 \tag{1}$$

$$\mathbf{HHI^{-1}} = 1/\,\mathrm{HHI} \tag{2}$$

$$\mathbf{CR_1} = MS_1 \tag{3}$$

$$\mathbf{CR_2} = MS_1 + MS_2 \tag{4}$$

$$\mathbf{CR_3} = MS_1 + MS_2 + MS_3 \tag{5}$$

$$\mathbf{CR_4} = MS_1 + MS_2 + MS_3 + MS_4 \tag{6}$$

$$\mathbf{CR_5} = MS_1 + MS_2 + MS_3 + MS_4 + MS_5 \tag{7}$$

ARIMA models

A time series is a sequence of data ordered by time, typically plotted on the vertical axis and the horizontal axis. It is important to display data in the order they arose; as successive observations are likely dependent. Time series modeling involves dealing with temporal factors and analyzing data in a specific order. Time series modeling creates and predicts data by simulating the variation in a time series. After simulating the data, the accuracy of each model was checked using various factors (Araghinejad, 2013). ARIMA models were used to analyze time-series properties and predict future trends. They break down the series into systematic and random parts, using the weighted sum of past values and random shocks. The "Box-Jenkins approach" is used for estimating these models. ARIMA models meticulously examine time-series properties and require significant effort to develop a vision formula. The observed trends guide the prediction process, select a suitable model, and ensure compatibility with the data. The best targets for this series were then investigated (Akgul, 2003). Various statistical techniques describe and predict time-series data, including AR, MA, ARMA, ARIMA, and ARMAX. These models connect dependent variables to indicators, which are factors that change over time, ensuring an accurate and reliable data analysis (Araghinejad, 2013). Most stationary data series that show a constant mean, variance, and autocorrelation function over time use it. This model uses autoregressive terms to show how variables are related to each other and moving average terms to show how variables are related to errors that have already happened (Alsuwaylimi, 2023).

The model is typically applied to stationary data series, but it can also be applied to non-stationarity data series after transformations like differencing and logging. The AR model consists of an autoregressive component, a difference, and moving average components, represented by p, d, and q, respectively. Historical data is decomposed into AR processes, I

process, and MA processes, with p representing linear relationships between dependent variables and their lags. An ARMA model is formed by combining AR (p) and MA (q) components (Montgomery et al,. 2015). The Markov chain, a time series that correlates each individual piece of data with its past and future data, serves as the foundation for AR models. The concept of an autoregressive model is derived from the concept of a linear regression model, expressed as $Y = \beta_1 X + \beta_0 + \varepsilon$, where Y represents the dependent variable, X represents the independent variable, and ε represents a random variable. Expressing the automatic regression AR(p) can be written as the following formula (Araghinejad, 2013).

$$X_t = \sum_{i=1}^{k} \varphi_i X_{t-i} + \varepsilon_t \tag{8}$$

In the above model, X represents the time series data, k represents the lag time between the current variable and the recorded prior data, and φ_i represents the parameters of the linear regression. The equation is commonly referred to as the autoregressive model.

The variable X may be converted to a standard normal variable using the following procedure:

$$Y_t = g(X_t) \tag{9}$$

Where g is a transformation function that converts data with a specified distribution to data with a normal distribution. The data is normalized and then standardized using Z_t.

$$Z_t = \frac{Y_t - \mu}{\sigma} \tag{10}$$

where μ and σ the average and standard deviation of Y_t time series, respectively. Z_t time series as AR(p) can be written as the following formula (Kontopoulou *et al*., 2023)

$$Z_t = C + \sum_{i=1}^{P} \varphi_i Z_{t-i} + \varepsilon_t \tag{11}$$

In this context, Z_t represents a static variable, C is a constant, φ_i refers to the autocorrelation coefficients at time delay steps 1, 2, ..., p, and ε_t represents the samples of a Gaussian white noise series. The Gaussian white noise series has a mean of zero and a variance of σ^2.

Unexpected external influences at intervals $t_1, t_2, t_3,....t_k$ affect the time period at t. Errors or residuals are the unforeseen consequences. The coefficient factor determines the impact of previous locations. The moving average (MA) model is a regression analysis that uses residuals or mistakes from previous time series to predict present or future values. MA(q) can be written as the following formula (Araghinejad, 2013; Kontopoulou et al., 2023).

$$\text{MA} = \varepsilon_t = \mu + \sum_{j=1}^{q} \varphi_j \varepsilon_{t-j} + \zeta_t \qquad (12)$$

The expected value of ε_t is μ, and it's usually 0. The weights for the current and past values of the stochastic term of the time series are φ_j, and $\varphi_0 = 1$. ε_t, Gaussian white noise series, which means it has zero mean and variance (σ^2_ε). ζ_t random variable or the error of the model.

The ARMA model of class (p,q) is made by putting these two models together: Autoregression and Moving Average. The equation to be applied for the ARMA model is given below (Araghinejad, 2013; Kontopoulou *et al*., 2023).

$$Z_t = C + \sum_{i=1}^{P} \varphi_i Z_{t-i} + \sum_{j=1}^{q} \varphi_j \varepsilon_{t-j} + \zeta_t \qquad (13)$$

Where φ_i and $\varphi_j \neq 0$ also $\sigma^2_\varepsilon > 0$. The order of the AR and MA models is dictated by the corresponding parameters p and q. The equation to be applied for the ARIMA model is given below.

$$V_t = \nabla^d Z_t = C + \sum_{i=1}^{P} \varphi_i \nabla^d Z_{t-i} + \sum_{j=1}^{q} \varphi_j \nabla^d \varepsilon_{t-j} + \zeta_t \qquad (14)$$

V_t is the output of the preprocessing procedure, which involves subtracting the original Z_t data by d^{th}.

In order for the ARIMA model to make more consistent predictions, it is desired that the data include at least 30 periods, be stationary, not contain missing data, and show a normal distribution. If the data from at least 30 periods lacks stability, we can stabilize it by calculating the 1st, 2nd, or 3rd degree difference using difference operations. If normality tests reveal no normal distribution in the data, we fix the series' variance by taking the square root or logarithm of the data. Excluding data outside the ranges formed by the standard deviation values is necessary, as these values only indicate excessive deviation in cases that are unlikely to occur later due to extreme situations. If there is a deficiency in some observations, we can either take data after the periods in which these deficiencies are present, spanning 30 periods, or eliminate these deficiencies using methods based on value assignment or estimation.

We inserted the water buffalo milk production data in Excel, row by row, based on global and leading countries' data from 1961 to 2023. In the final four columns, we listed t, t_1, t_2, and t_3 with their respective rank numbers after a one-period delay, making them suitable for analysis. We generally make the data stationary if it follows a normal distribution and contains

no deficiencies or outliers, and adjust the first difference if it does not (Uzundumlu & Dilli, 2023).

This study analyzed the p and q values, which yielded the BIC values produced by SCAN and ESACF in the SAS 9.4 program. Subsequently, we determined that the ARIMA model provided the most suitable p and q values. In this study, we found the most suitable models based on the results of the AIC (Akaike Information Criterion), BIC (Bayesian Information Criterion), DW (Durbin Watson Test), HQC (Hannan-Quinn Criterion), MAE (Mean Absolute Error), MAPE (Mean Absolute Percentage Error), SSE (Sum of Squared Estimate of Errors), MSE (Mean Squared Error), RMSE (Root Mean Square Error), SBC (Schwarz's Bayesian Criterion), and R^2 (Coefficient of Determination) (Uzundumlu & Dilli, 2023; Uzundumlu et al., 2024).

The AIC and BIC are the most favored criteria for selecting the best ARIMA models, while there are other criteria as well (SAS, 2014). We determined the maximum evaluation of these criteria by using the results of the smallest AIC, BIC, SBC, SSE, MSE, MAE, MAPE, RMSE, DW closest to 2, and the highest R^2 (Uzundumlu & Dilli, 2023).

Results

Production Competition

Based on HHI, HHI-1, and concentration ratios, production competitiveness was assessed and is presented along with the leading water buffalo milk-producing countries over the 1961–2023 period (Table 2).

Table 2. The distribution of water buffalo milk production in the world

Years	HHI	HHI^{-1}	CR$_1$	CR$_2$	CR$_3$	CR$_4$	CR$_5$	Leader Countries	Country Count
1961-1970	0.43	2.30	60.73	85.57	90.65	95.00	96.93	India, Pakistan, China, Egypt, Nepal	21
1971-1980	0.38	2.27	61.26	85.64	90.63	95.43	97.40	India, Pakistan, China, Egypt, Nepal	21
1981-1990	0.44	2.02	66.54	88.95	93.46	96.75	98.24	India, Pakistan, China, Egypt, Nepal	21
1991-2000	0.42	2.06	64.63	90.22	94.31	97.30	98.51	India, Pakistan, China, Egypt, Nepal	20
2001-2010	0.43	2.00	65.69	91.13	94.62	97.66	98.79	India, Pakistan, China, Egypt, Nepal	20
2011-2020	0.45	1.90	67.39	93.70	96.19	98.06	99.09	India, Pakistan, China, Egypt, Nepal	21-23
2021-2023	0.55	1.82	69.57	95.07	97.24	98.21	99.15	India, Pakistan, China, Nepal, Egypt	20-22
2024-2028	0.56	1.80	69.88	95.34	97.45	98.32	99.20	India, Pakistan, China, Egypt, Nepal	20-23

Source: (FAOSTAT, 2025).

Between 1961 and 1970, 21 countries participated in water buffalo milk production. India held the largest share (60.73%), followed by Pakistan (24.84%), China (5.07%), Egypt (4.35%), and Vietnam (1.94%). Together, these five countries accounted for 96.93% of global output. The Herfindahl-Hirschman Index (HHI) during this period was 0.43, indicating an oligopolistic market, while the CR5 concentration ratio was 0.96, reinforcing the dominance of few producers.

By 2027, the number of producing countries is projected to remain relatively stable (20-23). India, maintaining a leading position since 1961 with around 66% of total output until 2010, increased its share to 70% in the 2020s, a level it is expected to retain through 2028. Pakistan, consistently the second-largest producer, is anticipated to sustain its 25% market share.

China, which ranked third globally with a 5% share between 1961 and 2028, experienced a gradual decline in share post-1990s, reaching 3% in the 2000s. Despite this, China remains the third-largest producer, and it is expected to retain this position with a projected share of 2.8%.

Egypt, which consistently ranked fourth until the 2000s with a 3–4% share, saw a drop to 2% in the 2010s and fell below 1% after 2020, slipping to fifth position. Nonetheless, it is expected to remain within the top five producers. Nepal, with a long-term share of around 2%, declined to 1–1.5% in the 1980s and is forecasted to hold approximately 1% after 2020, placing it fourth in global production.

Recent years have seen the HHI increase from 0.42 to 0.55, indicating rising market concentration and declining competitiveness. An HHI of 0.42 denotes moderate concentration, while 0.55 suggests more significant consolidation. In parallel, the CR5 has approached 99.20%, meaning the top five producers nearly dominate the entire market. This high concentration could reduce market competition and may influence global pricing dynamics.

In conclusion, India, Pakistan, China, Egypt, and Nepal are projected to retain their status as the principal water buffalo milk producers in the coming five years, with high market concentration and limited entry from other producers reinforcing an oligopolistic structure.

Actual and/or forecasted water buffalo milk production in the worldwide and five leader countries

Estimates of water buffalo milk production levels for the worldwide and five leading countries, and their minimum and maximum production levels are explained in this section.

Water buffalo milk production in the world

Historical and projected production volumes worldwide from 1961 to 2028 are presented (Figure 1).
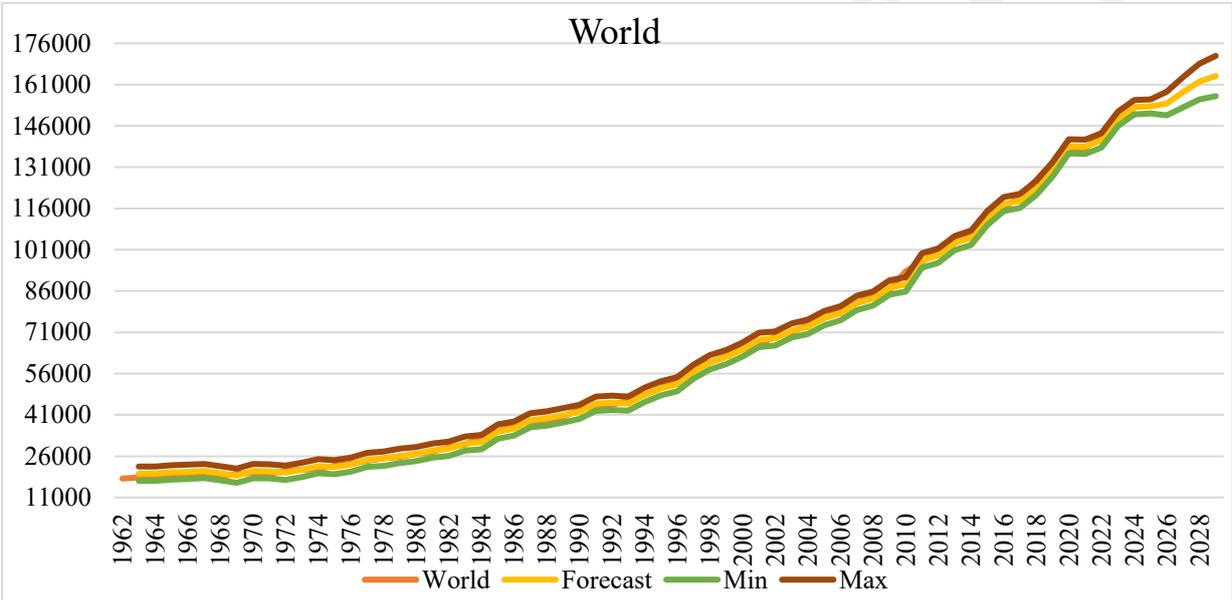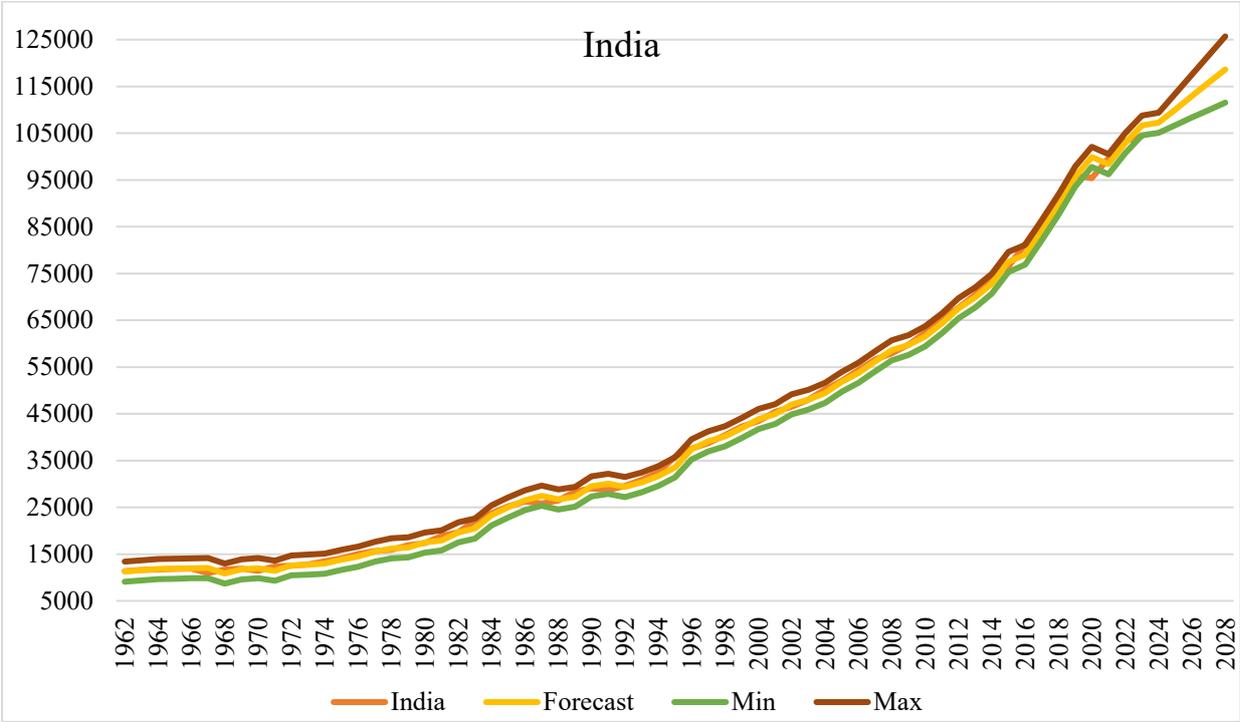

Figure 1. Water buffalo milk production and forecasts of the World between 1961-2028 (1000 tons)

Worldwide production of water buffalo milk increased from 17.86 million tons in 1961 to 150.34 million tons in 2023, a 3.49% annual average growth over 62 years. The best model for the period of 2024 to 2028 is ARIMA (5,1,1). According to this model, the predicted output amounts for each year are as follows: 153.05, 154.07, 158.24, 162.12, and 164.11 million tons, respectively. In comparison to the 2024-2028 and 2019-2023 periods, we forecast an increase of 10.11% in the 2024-2028 period.

Water buffalo milk production in India

Production quantities and forecasts in India from 1961 to 2028 are presented (Figure 2).

Figure 2. Water buffalo milk production and forecasts of India between 1961-2028 (1000 tons)

India's production of water buffalo milk increased from 11.09 million tons in 1961 to 104.39 million tons in 2023, a 3.68% an average annual growth over 62 years. The best model for 2024–2028 is ARIMA (1,1,1). During this period, the predicted output amounts were 107.23, 110.08, 112.93, 115.77, and 118.62 million tons, respectively. In comparison to the 2024-2028 and 2019-2023 periods, we suggest an increase of 12.12% in the 2024-2028 period.

Water buffalo milk production in Pakistan

Production quantities and their predictions in Pakistan between 1961 and 2028 are shown (Figure 3).
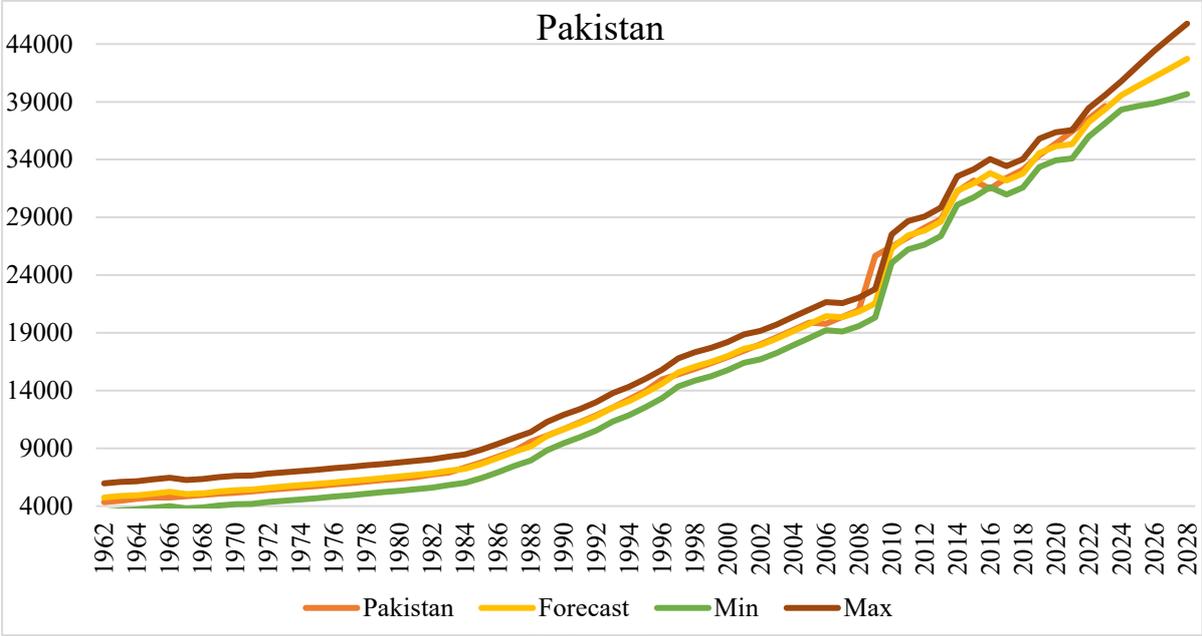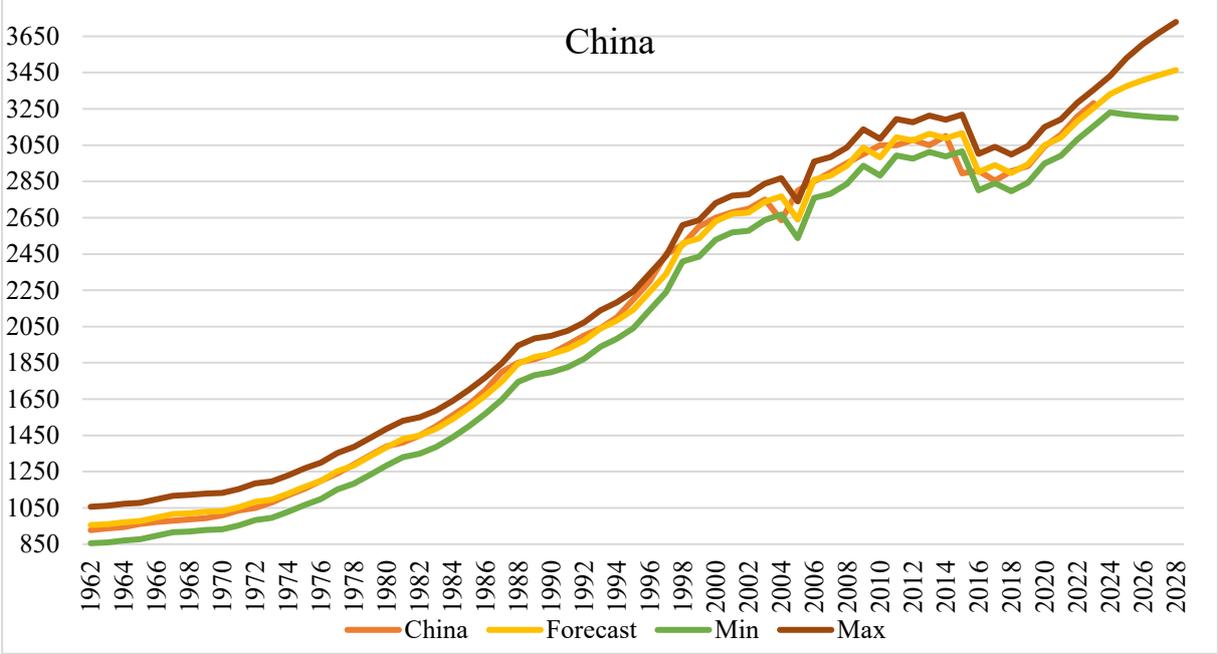

Figure 3. Water buffalo milk production and forecasts of Pakistan between 1961-2028 (1000 tons)

Pakistan's output of water buffalo milk climbed from 4.21 million tons in 1961 to 38.64 million tons in 2023, representing a 3.64% yearly average increase over 62 years. The best model for 2024-2028 is ARIMA (5,1,2). During this time period, the estimated production volumes were 39.56, 40.37, 41.14, 41.92 and 42.72 million tons, respectively. Compared to the 2024-2028 and 2019-2023 periods, we estimate an increase of 13.90% for the 2024-2028 period.

Water buffalo milk production in China

Production data and projections in China over the period 1961–2028 are illustrated (Figure 4).
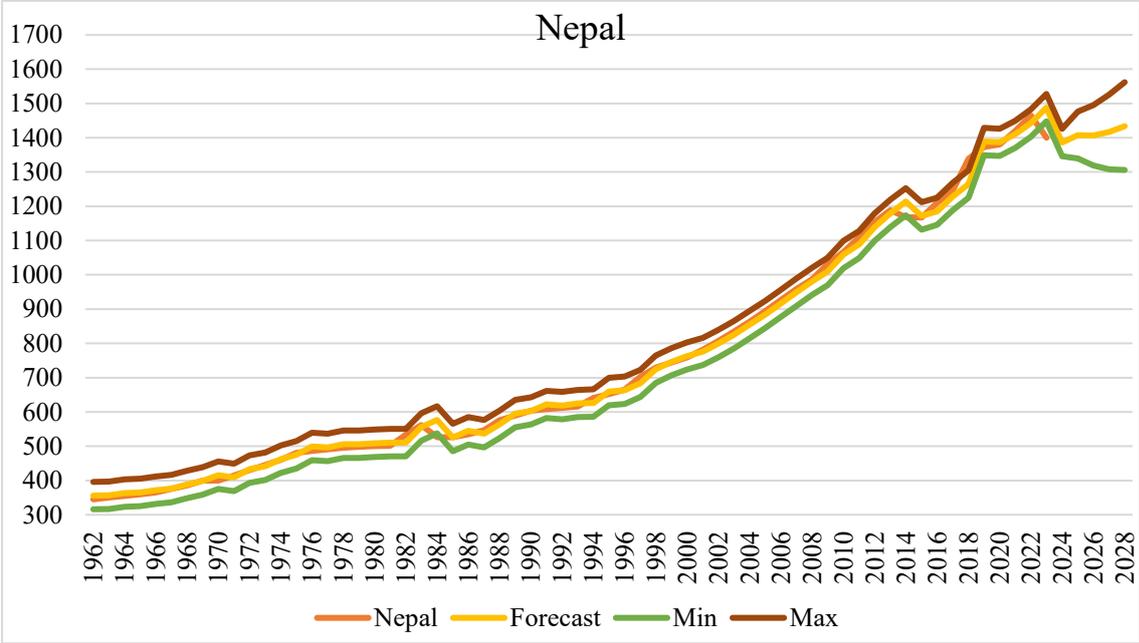

Figure 4. China's water buffalo milk production and forecasted output between 1961 and 2028 (1000 tons)

China's water buffalo milk production has increased from 917 thousand tons in 1961 to 3.25 million tons in 2023, reflecting a 2.08% annual average growth over 62 years. The best model for 2024-2028 is ARIMA (1,1,5). During this period, production is estimated at 3.33, 3.37, 3.41, 3.44 and 3.46 million tons respectively. Compared to the 2024-2028 and 2019-2023 periods, we predict an increase of 9.61% for 2024-2028.

Water buffalo milk production in Nepal

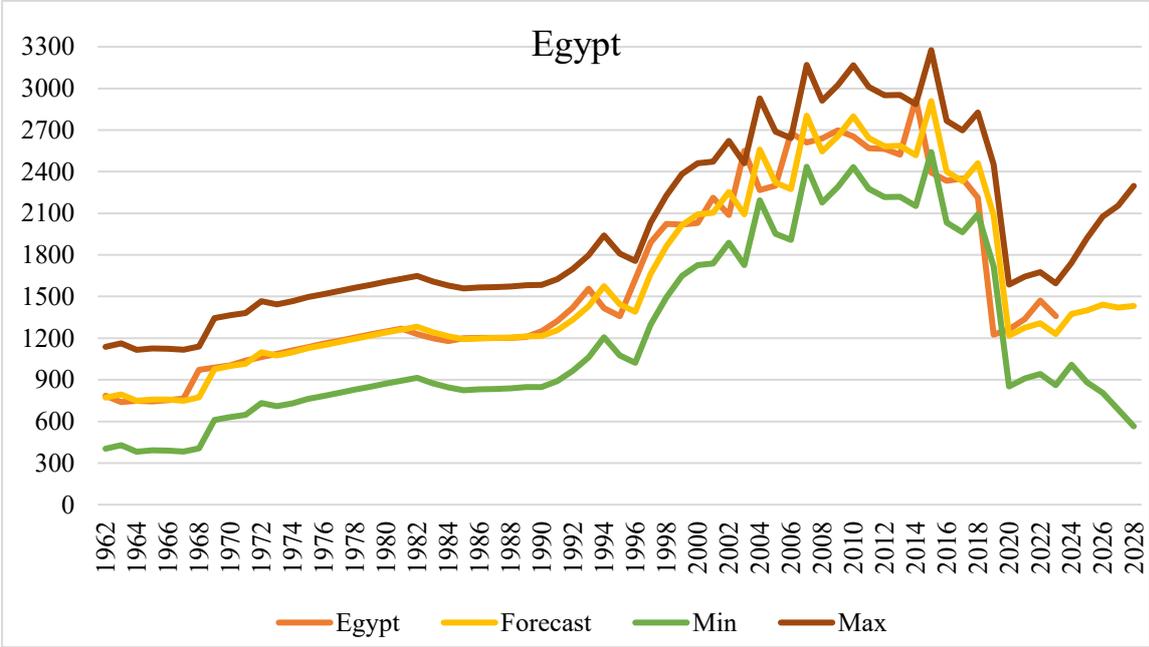Production quantities and projections for Nepal from 1961 to 2028 are shown (Figure 5).

Figure 5. Nepal's water buffalo milk production and forecasted output between 1961 and 2028 (1000 tons)

Nepal's water buffalo milk production increased from 340,000 tons in 1961 to 1.40 million tons in 2023, a 62-year average annual growth of 2.30%. The best model for 2024-2028 is ARIMA (3,1,1). During this period, production is estimated at 1.51, 1.54, 1.55, 1.58 and 1.61 million tons respectively. Compared to the 2024-2028 and 2019-2023 periods, we forecast a 0.91% decrease for 2024-2028.

Water buffalo milk production in Egypt

Egypt's production quantities along with their projected trends from 1961 to 2028 are presented (Figure 6).
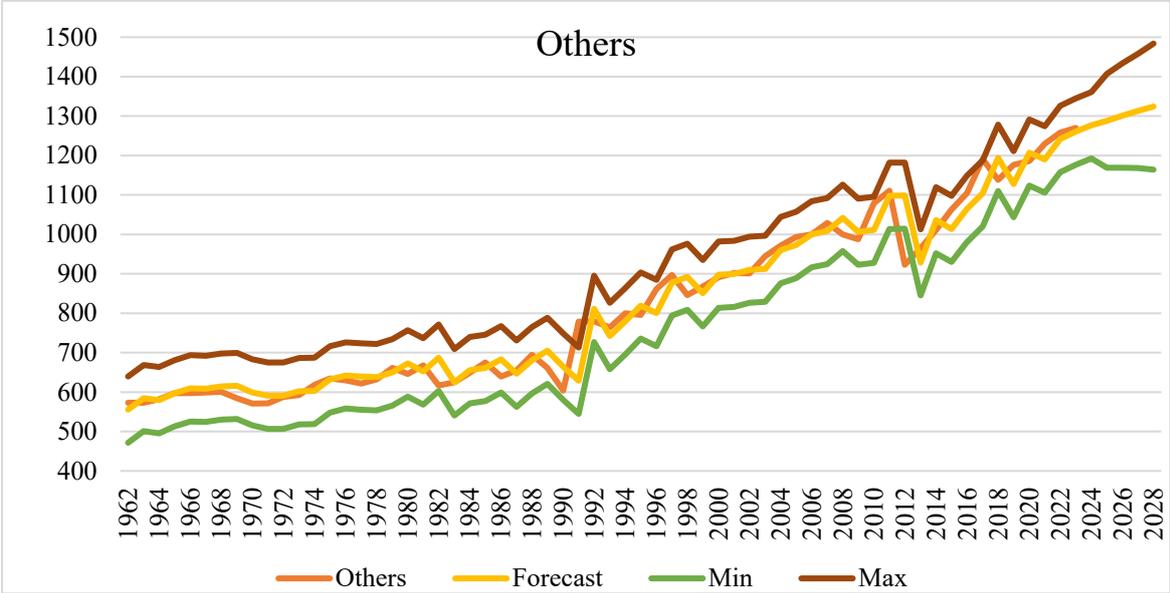

Figure 6. Egypt's water buffalo milk production and forecasted output between 1961 and 2028 (1000 tons)

Egypt's water buffalo milk production has increased from 761 thousand tons in 1961 to 1.36 million tons in 2023, reflecting a 0.96% annual average growth over 62 years. The best model for 2024-2028 is ARIMA (4,1,0). During this period, production was estimated at 1.37, 1.40, 1.44, 1.42 and 1.43 million tons respectively. Compared to the 2024-2028 and 2019-2023 periods, we forecast a decrease of 6.82% for 2024-2028.

Water buffalo milk production in other countries

The production volumes and future projections of other countries over the period 1961–2028 are shown (Figure 7).

Figure 7. The Other's water buffalo milk production and forecasted output between 1961 and 2028 (1000 tons)

The category "Others" includes the total water buffalo milk production of countries producing less than the top five (India, Pakistan, China, Egypt, and Nepal), such as Italy, Brazil, Myanmar, Iran, and the Philippines. The water buffalo milk production of other countries has increased from 544 thousand tons in 1961 to 1.26 million tons in 2023, reflecting a 1.30% annual average growth over 62 years. The best model for 2024-2028 is ARIMA (1,1,1). During this period, production is estimated at 1.28, 1.29, 1.30, 1.31and 1.32 million tons respectively. Compared to the 2024-2028 and 2019-2023 periods, we forecast an increase of 7.90% in the water buffalo milk production for the 2023-2027 period.

Discussion

Kim & Oh (2024) reported a 2.1% annual growth in global milk production from cow, buffalo, sheep, goat, and camel between 2015 and 2022, with water buffalo milk alone increasing by 3.9% annually during the same period. Consequently, water buffalo milk's share

in global milk output rose from 13% in 2015 to 15% in 2022. These authors also projected that while overall milk production growth is expected to slow to 1.5% annually by 2032, water buffalo milk production will continue to expand at a comparatively higher rate. Supporting this trend, VMR (2024) estimated that the global water buffalo milk market will grow from USD 98 billion in 2023 to USD 147 billion by 2030, reflecting a 9% compound annual growth rate. This expansion is particularly significant in regions where water buffalo milk is an integral part of local diets and dairy traditions. Key factors influencing the yield and quality of water buffalo milk include genetic traits, feed quality, and production practices. These findings underscore the growing economic importance of water buffalo milk within the global dairy sector and point to its increasing contribution to future market dynamics.

India's water buffalo milk production has consistently shown strong growth and accurate forecastability using ARIMA-based models. Studies like those by Subbanna et al. (2021) and Devi et al. (2022) show that the model is good at identifying long-term patterns, and using combined methods like ARIMA-NNAR makes predictions even more accurate. Venu et al. (2024) also confirmed ARIMA's superiority over SES, ETS, and Seasonal Naive methods, especially in terms of lower MAPE values and better trend tracking. According to USDA (2024), India is projected to produce 110.7 million tons of water buffalo milk by 2024, reflecting the dominance of buffaloes in its dairy sector. Despite limited meat demand domestically, buffalo meat production has grown due to the utilization of surplus and aged animals, although hygiene issues remain a barrier to export (Sharma et al., 2023). From 2018 to 2023, dairy buffalo numbers increased by 7.63% (FAOSTAT, 2025), suggesting that with continued policy support and quality control, India will sustain or surpass current production projections.

Our study used the ARIMA (5,1,2) model to forecast water buffalo milk production in Pakistan for 2024–2028, estimating a 13.90% increase compared with 2019–2023, with production rising from 39.56 to 42.72 million tons. These results are consistent with (Qasim et al. (2019), who linked milk output to buffalo population growth and stable yield per animal. In comparison, Mishra et al. (2022) predicted much higher numbers using an ARIMA (1,2,0) model but had an average error of 20.43% for 2019–2023, suggesting that they might have overestimated. Considering the 15.83% increase in buffalo numbers between 2018 and 2023 (FAOSTAT, 2025), our projections, grounded in national data and realistic assumptions, are expected to be more accurate and reliable.

China's water buffalo milk production rose from 917 thousand tons in 1961 to 3.25 million tons in 2023, with a steady annual growth of 2.08%. Using the ARIMA (1,1,5) model, we forecast production for 2024-2028 to gradually increase from 3.33 to 3.46 million tons, representing a 9.61% rise compared with 2019–2023. These estimates are more cautious than those of Mishra et al. (2022), whose ARIMA (1,2,1) model predicted much higher numbers for 2019–2025 but had a 35.74% average error between 2019 and 2022, indicating that they often overestimated. Given the 13.84% growth in China's buffalo population over the last five years (FAOSTAT, 2025), and assuming modest gains in animal numbers and productivity, our projections are likely to reflect actual trends more accurately.

Nepal's water buffalo milk production increased from 340,000 tons in 1961 to 1.40 million tons in 2023, reflecting an average yearly growth rate of 2.30%. Employing the ARIMA (3,1,1) model, we project production for 2024–2028 to fluctuate between 1.51 and 1.61 million tons, somewhat lower than the preceding period, with an anticipated 0.91% reduction in output. Mishra et al. (2022) used an ARIMA (1,2,2) model to predict lower numbers, showing only a 3.55% difference from the real data for 2019–2022, which means their predictions were very accurate. Nonetheless, a notable reduction in Nepal's milk buffalo population-decreasing by 44.44%, from 1.53 million to 0.85 million between 2018 and 2023 (FAOSTAT, 2025)-suggests that output levels may either stabilize or diminish further. In light of the significant decrease in milking animals, we anticipate that our estimates will accurately mirror the actual trends, with minor divergence.

Egypt's water buffalo milk production has shown slow but steady growth since 1961; however, recently, there has been a significant decline in the number of dairy buffaloes, which decreased by 52.53% between 2018 and 2023 (FAOSTAT, 2025). Using the ARIMA (4,1,0) model, our forecast for 2024–2028 shows a slight production decrease of 6.82% compared to 2019–2023, with estimated values ranging from 1.37 to 1.44 million tons. These estimates are consistent with those of Omar et al. (2024), who projected similar figures based on water buffalo milk's 21–23% share of total milk production. The ongoing water crisis, driven by climate change, population growth, and reduced Nile River flow, especially due to projects like Ethiopia's Grand Renaissance Dam, has had a major impact on buffalo farming. Although the number of animals is declining, Egypt continues to report water buffalo milk yields that are nearly twice as high as those of other countries. If these productivity levels are sustained, production may remain relatively stable despite further reductions in the herd size.

The water buffalo milk production of countries outside the top five global producers has increased steadily, growing from 544 thousand tons in 1961 to 1.26 million tons in 2023, with an average annual growth rate of 1.30% (FAOSTAT, 2025). Based on our ARIMA (1,1,1) model, production for the 2024–2028 period is forecasted to increase gradually from 1.28 to 1.32 million tons, representing a 7.90% increase compared with the 2019–2023 period. Among these countries, Bangladesh and Italy are the leading contributors, jointly accounting for 46.1% of the group's total water buffalo milk output. Bangladesh alone has increased its production by 6.85 times over the past two decades, from 44,794 tons in 2002 to 351,700 tons in 2023, driven by governmental incentives and a growing interest in local buffalo farming (Habib et al., 2023). Italy, where buffalo farming is especially prominent in the Campania region, has seen a 72.3% increase in production since 2003, largely due to the rising global demand for Mozzarella di Bufala, a high-value cheese with strong domestic and international markets (Romano et al., 2021; Cappelli et al., 2021). These trends show that, despite regional variability, most countries in this group, including Mongolia, Sri Lanka, and Myanmar, have experienced a consistent upward trajectory in water buffalo milk production. This study suggests that, supported by consumer demand and targeted policy interventions, water buffalo milk production in these emerging producer nations is likely to continue growing in the coming years as well.

Conclusion

Water buffalo milk production worldwide increased from 17.86 million tons in 1961 to 150.34 million tons in 2023, with a 3.49% annual average growth over 62 years. Based on the findings of the present study, world water buffalo milk production is forecasted to reach 164.11 million tons by 2028 with India, Pakistan, China, Egypt, and Nepal expected to account for 99.20% of this total. Considering the unique characteristics of water buffalo milk and dairy products, which have a significantly high demand in the world with the changing consumption habits of society, we expect an increase of 10.11% in the 2024-2028 period compared to the 2019-2023. Verified market reports data predicts a 9% compound annual growth in the water buffalo milk market, projected to reach USD 98 billion to USD 147 billion by 2030, primarily involving domesticated water buffaloes, affecting local cuisine and dairy products. According to our forecast, India (69.88%), Pakistan (25.46%), China (2.11%), Egypt (0.87%) and Nepal (0.87%), the leading water buffalo milk producing countries, are expected to maintain their positions until 2028.

Declarations

Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Author contributions

Veysel Fatih Özdemir: Data collection, writing – review & editing, conceptualization. Ahmet Semih Uzundumlu: Data collection, statistical analysis, writing – review & editing, supervision. Duygu Tosun: Data collection, statistical analysis.

Use of artificial intelligence (AI)

No generative artificial intelligence tools were used in the preparation, writing, or analysis of this manuscript.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

References

Akgul I. Analysis of Time Series, and ARIMA Models. Istanbul: Der Publications, Turkey, 2003.

Alsuwaylimi AA. Comparison of ARIMA, ANN and Hybrid ARIMA-ANN Models for Time Series Forecasting. Information Sciences Letters 2023; 12(2): 1003–1016. https://digitalcommons.aaru.edu.jo/isl/vol12/iss2/62

Araghinejad S. Time Series Modeling. In: Data-Driven Modeling: Using MATLAB® in Water Resources and Environmental Engineering. Springer, 2013. Chap. 4, p.85–137.

Baye MR, Prince JT. Managerial Economics and Business Strategy. 10th ed. New York: McGraw-Hill Irwin, USA, 2021.

Becskei Z, Savić M, Ćirković D, Rašeta M, Puvača N, Pajić M, Đorđević S, Paskaš S. Assessment of Water Buffalo Milk and Traditional Milk Products in a Sustainable Production System. Sustainability 2020; 12(16): 6616. https://doi.org/10.3390/su12166616

Cappelli G, Di Vuolo G, Gerini O, Noschese R, Bufano F, Capacchione R, Rosini S, Limone A, De Carlo E. Italian Tracing System for Water Buffalo Milk and Processed Milk Products. Animals 2021; 11(6): 1737. https://doi.org/10.3390/ani11061737

Costa A, Negrini R, De Marchi M, Campanile G, Neglia G. Phenotypic Characterization of Milk Yield and Quality Traits in a Large Population of Water Buffaloes. Animals 2020; 10(2): 327. https://doi.org/10.3390/ani10020327

Deb GK, Nahar TN, Duran PG, Presicce GA. Safe and Sustainable Traditional Production: The Water Buffalo in Asia. Front Environ Sci. 2016; 4: 38. https://doi.org/10.3389/fenvs.2016.00038

Devi M, Rahman UH, Weerasinghe WPMCN, Mishra P, Tiwari S, Karakaya K. Future Milk Production Prospects in India for Various Animal Species Using Time Series Models. Indian J Anim Res. 2022; 56(9): 1170–1175. https://doi.org/10.18805/IJAR.B-4409

Emakpor OL, Edo GI, Jikah AN, Ikpekoro VO, Akbo JJ, Ainyanbhor IE, Essaghah AEA, Ekokotu HA, Oghroro EEA, Akpoghelie PO. Buffalo Milk: An Essential Natural Adjuvant. Discover Food. 2024; 4: 38. https://doi.org/10.1007/s44187-024-00114-7

Ermetin O. Evaluation of the Application Opportunities of Precision Livestock Farming (PLF) for Water Buffalo (Bubalus bubalis) Breeding: SWOT Analysis. Arch Anim Breed. 2023; 66(1): 41–50. https://doi.org/10.5194/aab-66-41-2023

FAOSTAT. Food and Agriculture Organization of the United Nations. Milk Production in the World. Washington, DC: PAHO, 2025. http://www.fao.org/faostat/en/#data/QC

Habib MA, Rahman MS, Khatun A, Ali MY. The Scenario of Buffalo Production and Research in Bangladesh. J Buffalo Sci. 2023; 12: 28–37.https://doi.org/10.6000/1927-520X.2023.12.04

Kim S, Oh S. Outlook of the Global Dairy Industry and Its Current Situation: V. Milk Production and Trade after 2020. J Dairy Sci Biotechnol. 2024; 42(1): 1–8. https://doi.org/10.22424/jdsb.2024.42.1.1

Kontopoulou VI, Panagopoulos AD, Kakkos I, Matsopoulos GK. A Review of ARIMA vs. Machine Learning Approaches for Time Series Forecasting in Data Driven Networks. Future Internet 2023; 15(8): 255. https://doi.org/10.3390/fi15080255

Krugman PR, Wells R. Economics. 6th ed. London: Macmillan International Higher Education, 2021.

Minervino AHH, Zava M, Vecchio D, Borghese A. Bubalus bubalis: A Short Story. Front Vet Sci. 2020; 7: 570413. https://doi.org/10.3389/fvets.2020.570413

Mishra P, Matuka A, Abotaleb MSA, Weerasinghe WPMCN, Karakaya K, Das SS. Modeling and Forecasting of Milk Production in the SAARC Countries and China. Model Earth Syst Environ. 2022; 8: 947–959. https://doi.org/10.1007/s40808-021-01138-z

Montgomery DC, Jennings CL, Kulahci M. Introduction to Time Series Analysis and Forecasting. 2nd ed. Hoboken, New Jersey: John Wiley & Sons; 2015.

Omar MA, Hassan FAM, Shahin SE, El-Shahat M. The Usage of the Autoregressive Integrated Moving Average Model for Forecasting Milk Production in Egypt (2022–2025). Open Vet J 2024; 14(1): 256–265. https://doi.org/10.5455/OVJ.2024.v14.i1.22

Özdemir G. A Research on Satisfaction Levels of Water Buffalo Breeders in Sivas Province, Türkiye. Tekirdag Ziraat Fak Derg. 2024; 21(2): 444–456. https://doi.org/10.33462/jotaf.1291935

Pineda PS, Flores EB, Herrera JRV, Low WY. Opportunities and Challenges for Improving the Productivity of Swamp Buffaloes in Southeastern Asia. Front Genet. 2021; 12: 629861. https://doi.org/10.3389/fgene.2021.629861

Qasim M, Amin M, Akram MN, Omer T, Hussain F. Forecasting Buffalo Population of Pakistan Using Autoregressive Integrated Moving Average (ARIMA) Time Series Models. Proc Pakistan Acad Sci A J Comput Phys 2019; 56(3): 27–36.https://www.ppaspk.org/index.php/PPAS-A/article/view/86

Romano E, De Palo P, Tidona F, Maggiolino A, Bragaglio A. Dairy Buffalo Life Cycle Assessment (LCA) Affected by a Management Choice: The Production of Wheat Crop. Sustainability 2021; 13(19): 11108. https://doi.org/10.3390/su131911108

SAS. SAS 13.2 User's Guide: The ARIMA Procedure. SAS Institute Inc., Cary, NC, USA, 2014. Available from: https://support.sas.com/documentation/onlinedoc/ets/132/ARIMA.pdf.

Sharma I, Arora K, Kumar S, Bhoi P, Vatta K. Global Trade Competitiveness of Indian Buffalo Meat: Trends and Determinants. Buffalo Bull. 2023; 42(1): 105–124.

Subbanna YB, Kumar S, Puttaraju SKM. Forecasting Buffalo Milk Production in India: Time Series Approach. Buffalo Bull. 2021; 40(2): 335–343.

Ukav I. Market Structures and Concentration Measuring Techniques. Asian J Agric Ext Econ Sociol. 2017; 19(4): 1-16.https://doi.org/10.9734/AJAEES/2017/36066

USDA. Dairy and Products Annual-2023. US Department of Agriculture Report, 2024.

Uzundumlu AS, Karabacak T, Ali A. Apricot Production Forecast of the Leading Countries in the Period of 2018–2025. Emir J Food Agric. 2021; 33(8): 682–690. https://www.ejfa.me/index.php/journal/article/view/2744

Uzundumlu AS, Dilli M. Estimating Chicken Meat Productions of Leader Countries for 2019–2025 Years. Ciência Rural 2023; 53(2): e20210477. http://doi.org/10.1590/0103-8478cr20210477

Uzundumlu AS, Pınar V,Tosun NE, Kumbasaroğlu H. Global Pistachio Production Forecasts for 2020–2025. KSU J Agric Nat. 2024; 27(5): 1105–1115. http://doi.org/10.18016/ksutarimdoga.vi.1397897

Venu V, Anjitha PK, Vipin PR, Ramdas ER, Senthilkumar R, Sreenath B. Temporal Trends and Future Projections: A Deep Dive into India's Buffalo Milk Production Through Time Series Modelling. J Dairy Foods Home Sci. 2024. http://doi.org/10.18805/ajdfr.DR-2199

VMR. Global Buffalo Milk Market Forecast. Verified Market Reports, 2024. Available from: https://www.verifiedmarketreports.com/product/buffalo-milk-market/

Zhang Y, Colli L, Barker JSF. Asian Water Buffalo: Domestication, History and Genetics. Anim Genet. 2020; 51(2): 177–191.https://doi.org/10.1111/age.12911