



Export of Indian buffalo meat - A spatial visualization and temporal analysis

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ABSTRACT

This study examines the export performance of Indian buffalo meat through spatial visualization and temporal analysis. As the world's largest buffalo meat exporter, India contributes significantly to agricultural trade and foreign exchange earnings. The current research analyses three decades (1994-2024) of export data, revealing distinct growth phases: steady growth (1995-2004, CAGR 11.09%), rapid expansion (2005-2014, CAGR 15.71%), and decline (2014-2024, CAGR -1.9%). Markov chain analysis identifies Vietnam, Malaysia, and Indonesia as the most stable importers, retaining 73.2%, 74.8%, and 42.6% of their market shares respectively. Revealed Comparative Advantage demonstrates India's consistent advantage in animal products export. Spatial visualization through hotspot analysis identifies Uttar Pradesh, Maharashtra, Andhra Pradesh, Telangana, Bihar, Kerala, and Punjab as key production regions. Temporal analysis using Chow and Wald tests confirms significant structural breaks in 2010 and 2015, coinciding with policy shifts and market dynamics. The Cuddy-Della Valle Instability index shows decreasing instability over time, with 2014-2024 exhibiting low instability (CDVI 7.37%) despite negative growth. Future projections suggest steady growth potential, reaching 1.745 million MT by 2030. The study provides valuable insights for policymakers to enhance India's buffalo meat export competitiveness through targeted interventions in production, processing, and trade facilitation.

Keywords: Buffalo meat, Export performance, Markov chain analysis, Spatial Analysis, Temporal analysis

India is the largest exporter of buffalo meat in the world, significantly contributing to the country's agricultural trade and foreign exchange earnings. The country produced 1.2 million tonnes of buffalo meat in 2022-23, accounting for a substantial portion of its total meat production (APEDA 2024). Buffalo meat exports have played a critical role in India's economy, contributing 1.5% of total export earnings and 92.1% of total animal product exports by value during this period. The growth of this sector has been driven by increasing international demand, price competitiveness, and adherence to halal certification, which renders Indian buffalo meat particularly attractive to markets in the Middle East and Southeast Asia.

The global buffalo meat industry is dominated by a few key players, with India, Brazil, and Australia leading exports (Chopra *et al.* 2024). India has emerged as the largest exporter of buffalo meat due to its cost-effective production system, disease-free status, and strong supply chain networks. The major importers of Indian buffalo meat include Vietnam, Malaysia, Egypt, Indonesia, and Iraq, with Vietnam alone accounting for nearly 45% of total exports (APEDA 2024). These countries prefer Indian buffalo meat due to its lean quality, affordability, and suitability for processing into various meat-based products.

Regional contribution and production trends: Buffalo meat production in India is regionally concentrated, with Uttar Pradesh leading as the largest producer, contributing 21.5% of the total output. Other major buffalo meat-producing states include Maharashtra (10.2%), Andhra Pradesh (9.3%), Bihar (7.8%), and Punjab (6.5%). (APEDA 2024) The industry provides significant economic opportunities for rural farmers, particularly dairy farmers, who benefit from selling unproductive male buffalo calves for meat processing. The sector also supports millions of people involved in processing, logistics, and export operations, thereby driving rural employment and economic growth.

Government policies and trade liberalization have played a crucial role in shaping the buffalo meat industry. The introduction of export-oriented policies, subsidies for meat processing units, and improved cold storage facilities has enhanced India's competitiveness in the global market. Infrastructure development, such as modern abattoirs and integrated meat processing units, has further strengthened India's position as a leading exporter (Shah 2008).

Consumption pattern: Domestic consumption of buffalo meat in India remains limited due to religious and cultural preferences. However, in states such as West Bengal, Kerala, and Assam, buffalo meat is widely consumed due to its nutritional value, affordability, and preference over other red meats. The demand for buffalo meat in international markets has been rising, particularly in Vietnam, Egypt, and

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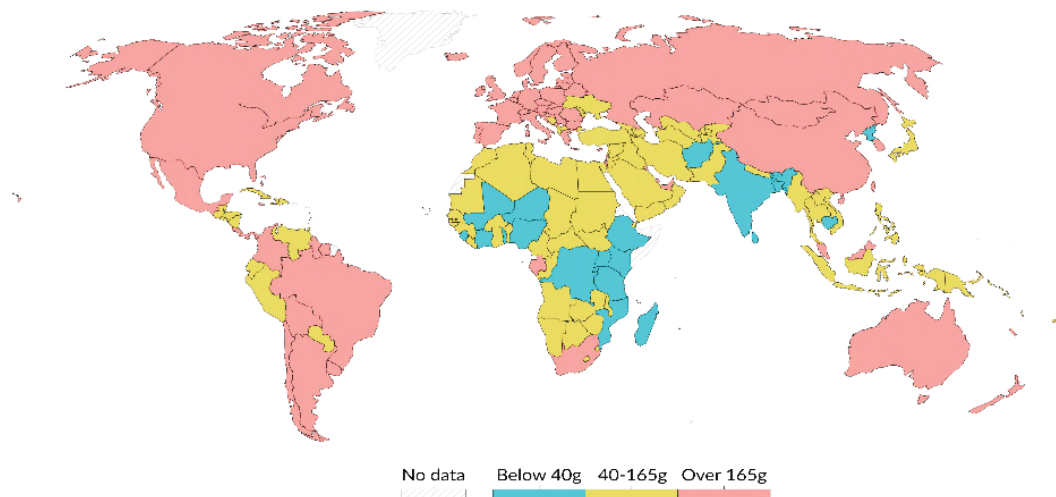


Fig. 1. Average buffalo meat consumption (2022) (*our world in data*, n.d.)

Malaysia, which together account for over 75% of India’s total buffalo meat exports (APEDA 2024). The preference for Indian buffalo meat in these countries is driven by its lean composition, high protein content, and competitive pricing compared to beef.

From the Suppl. Fig. 1., the meat consumption of people around the world, where region of America, Australia, Vietnam, European region has more consumption pattern (FAOSTAT 2024).

From the Fig. 1 shows the average consumption of buffalo meat according to the FAO, UN, major region of the world are consuming more than 165 g of buffalo meat per day (FAOSTAT 2024).

Fig. 2. depicts the average consumption of buffalo meat in which India has low consumption rate of 2.2kg per capita which paves way for the more export since the production of meat is sufficient for the inlands consumption (Kandanuri 2019).

In Suppl. Fig. 2., major export destination of buffalo meat from India during the year 2023 is given as major consumption areas are covered by the export, however there are regions still needed to be covered like Australia, Southern American regions which will boost the export performance of buffalo meat (AgriExchange 2024).

ICAR has simulated the same increasing pattern

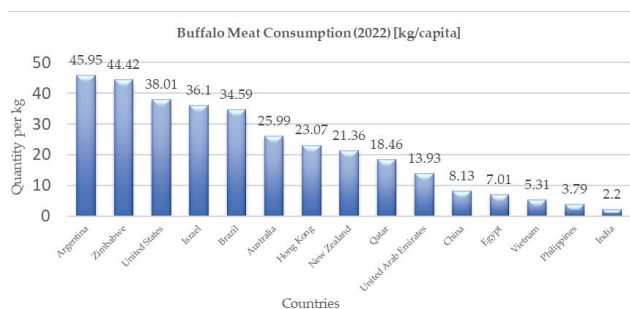


Fig. 2. Per capita Buffalo Meat consumption (2022) (*Our World in Data*, n.d.)

regarding per capita meat consumption, and according to the estimates of the report “ICAR’s 2030 vision”, per capita meat consumption would rise from 4.3 kg in 2000 to 10.1 kg in 2030 (Alexandratos 2012).

Need for spatial and temporal analysis: Understanding the spatial and temporal trends in India’s buffalo meat trade is essential for formulating effective policies to enhance export competitiveness. Factors such as trade agreements, shifts in consumer preferences, disease outbreaks, and global economic conditions influence export trends. The spatial distribution of production and trade hubs plays a key role in ensuring a smooth supply chain and maintaining India’s leading position in the buffalo meat market

The present study aims to analyse the export performance of Indian buffalo meat through spatial and temporal analysis, examining production trends, trade flows, and market dynamics. The study will help identify key challenges and growth opportunities, providing policy recommendations for improving supply chain efficiencies, ensuring sustainable production, and strengthening India’s position as a global leader in buffalo meat exports.

The objective of the study is to analyse the export performance of buffalo meat, analyse the distribution of buffalo meat using spatial analysis and to study and analyse the temporal analysis of exported buffalo meat.

MATERIALS AND METHODS

Export data for buffalo meat for the study was collected from APEDA – AgriExchange data (AgriExchange 2024). Country wise export data for different country-wise, Time-series data was collected for 30 years viz. 1994 to 2024. The major Importing countries selected for the study were Vietnam, Egypt, Iraq, UAE (United Arab Emirates), Philippines, Oman, Malaysia, Kuwait, Jordan, Saudi Arabia, Indonesia as they import more quantity of buffalo meat from India. The data on Buffalo meat production were also collected from APEDA, the production of buffalo meat for time series data was collected for 10 years viz.,

2008-2023. Export performance, spatial visualization and Temporal analysis were analysed in the study.

Under the export performance of buffalo meat,

1. The growth of Indian buffalo meat export in terms of quantity, value was estimated using compound annual growth rate (CAGR) (Devi Priya and Thyagarajan 2020).

$$Y = ab^x$$

Where,

Y: Quantity/Value/Unit Value of Indian buffalo meat export

X: Time period (in years)

a: Constant

b: Coefficient Value

CAGR (%) = (Antilog 'b'- 1) *100

2. The future trends in the export quantity were analysed using Method of least square

$$Y = a + bx$$

Where,

Y: Predicted value of the dependent variable

X: Time period (in years)

a: Intercept

b: Slope

Markov chain analysis was used to analyse the structural change in the system whose progress through time can be measured in terms of single outcome variable (Sonavale *et al.* 2020).

In this study, the dynamic nature of trade patterns - the gains and losses in export of Indian buffalo meat in major importing countries was analysed using Markov chain analysis.

3. Markov chain analysis involves constructing a transition probability matrix, 'P,' where each element, P_{ij} , represents the likelihood of exports shifting from country 'i' to country 'j' over time. The diagonal elements, P_{ij} (where $i = j$), indicate the probability of a country maintaining its market share, reflecting the loyalty of an importing country to a specific exporting nation.

On the above context the major importing countries were identified and analysed using Markov chain analysis. Algebraically expressed as,

$$E_{jt} = \sum_{i=1}^s E_{it-1} * P_{ij} + \mu_{jt}$$

Where,

E_{jt} : Export from India to j^{th} country for year 't'

E_{it-1} : Export from India to i^{th} country for year 't-1'

P_{ij} : Probability of shift of export from i^{th} country to j^{th} country

μ_{jt} : Random error term

t: Number of years considered for study

s: Number of importing countries

The transitional probabilities (P_{ij}) can be arranged in ($c*r$) matrix which depicted the export data got multiplied with the previous period 't-1' data to get expected export share of each country for period 't'.

$$\sum_{j=1}^r P_{ij} = 1$$

Computation of P_{ij}

The minimization of mean deviation method is used for calculating the transitional probability which has minimized the total absolute deviation.

The conventional linear programming technique are used to satisfy the properties of transitional probabilities of non-negativity restrictions and row sum constraints in the calculation. The linear programming equation are as follows:

$$\text{Min OP}^* + Ie$$

Where,

$$XP^* + V = Y$$

$$GP^* = 1$$

$$P^*e \geq 0$$

Where,

O: vector of zero

I: appropriate dimensioned vector of area

e: vector of absolute error

Y: proportion of export to each country

X: block diagonal matrix of lagged value of Y

V: vector of random term

G: grouping of matrixes to add row elements of P as arranged in P^* to unity

4. The revealed comparative advantage is used to measure the country's relative advantage and disadvantage in a specific industry as indicated by the trade flows to reflect its competitiveness (Balassa 1965).

The RCA less than 1 – export share of particular product/sector is less than its global share in that product/sector and vice versa.

$$RCA = \frac{X_{ij}/X_i}{X_{wj}/X_w} = \frac{X_{ij}/X_{wj}}{X_i/X_w}$$

Where,

X_{ij} : Country's i export of product

X_i : Total export of country

X_{wj} : Total export of products j from the world

X_w : Total world export

Under the spatial visualization,

1. Spatial visualization is used to visualize the production of buffalo meat over the years from 2008 to 2023 using ArcGIS Software – Hotspot analysis. This helps to know the regions where there is a constant production of buffalo meat visually and helps to identify key area, developing areas and the reduction areas to improve and rectify and to find the constraints faced (Valente *et al.* 2022).

Under the Temporal analysis of buffalo meat,

1. Structural Break occur when a time series data changes at a point in time, helps to find if any significant change in data. We see the structural Break using swald test (stata software) and chow test (Allaro *et al.* 2011, Vogelsang 1997).

If Wald test fails to reject null hypothesis no significant break is found and vice versa.

2. CDVI (Cuddy Della Valle Index) is used to find the instability in the export of buffalo meat over the years (Chavan 2023, Devi Priya and Thyagarajan 2020, Suthar

et al. 2024), although coefficient of variation (CV) is the simplest measure of instability, its over-estimates the level of instability in time series data which are characterized by long-term trends. CV is calculated as follows:

$$CV = \frac{\text{Standard deviation} * 100}{\text{Mean}}$$

The Cuddy Della Valle Index de-trends show the exact direction of the instability. It is used to measure the instability in export over the years (30 years)

$$CDVI = \frac{\text{Standard deviation} * 100 * (1-R^2)^{1/2}}{\text{Mean}}$$

Where,

CV: Coefficient of Variation in percent,

R²: Coefficient of determination from a time trend regression adjusted for its degrees of freedom.

A low value of this index indicates low instability in the selected variables. The ranges of CDVI are given as follows;

- Low instability = 0 to 15 (%)
- Medium instability = 15 to 30 (%)
- High instability = 30 and above (%)

From the above Figs. 3 and 4, The export trend of buffalo meat shows an increasing trend from 1994 to 2024 both in quantity and value. This clearly states that there is a huge market potential for buffalo meat from India to across the globe. Many government initiatives and trade regulation paved way for the foster growth of export in animal sector. Among the animal export from India Buffalo meat stands first and on the overall sector of agriculture sector animal products takes the 10th position (APEDA).

RESULTS AND DISCUSSION

Compound annual growth rate (CAGR): The CAGR of buffalo meat export clearly depicted in Table 1 for 3 decades (1995-2024).

From Table 1 of India’s buffalo meat exports over the past three decades can be categorized into three distinct phases: steady growth (1995–2004), rapid expansion (2005–2014), and a significant downturn (2014–2024).

During the steady growth period 1995 to 2004, buffalo meat exports experienced moderate yet consistent growth, due to India’s emergence as a reliable supplier of halal-

certified buffalo meat (particularly to Middle Eastern and Southeast Asian countries) and the expansion of export-oriented meat processing units and the affordability of Indian buffalo meat compared to beef contributed to its increasing demand.

From 2005 to 2014, India’s buffalo meat exports saw a significant boom, this sharp growth was by rising demand from key markets such as Vietnam, Egypt, and Indonesia. India’s competitive pricing, improved meat quality standards, and enhanced certification processes, better infrastructure for storage and transportation facilitating larger export volumes, helped it gain a stronger foothold in the global market.

However, the period 2014 to 2024 a significant decline. The factors contributed to this downturn, was stricter trade regulations, shifting import policies, and increased competition from countries like Brazil and Australia. Major importers, such as Vietnam and Indonesia, tightened restrictions, reducing their reliance on Indian buffalo meat.

And also, domestic policy changes, such as the closure of slaughterhouses in certain Indian states, further disrupted supply chains. The COVID-19 pandemic exacerbated these challenges, affecting both export logistics and global demand. As a result, India’s position in the international buffalo meat market weakened, highlighting the urgent need for strategic interventions to reclaim lost market share. However, the overall CAGR of buffalo meat is 9.64 showing a positive growth rate over the entire period.

India’s buffalo meat exports between 1995 and 2024 exhibit three phases: moderate growth (1995–2004), high growth (2005–2014), and stabilization/decline after 2014 (Table 1, Suppl. Fig. 4). The greatest Compound Annual Growth Rate occurred in the second period and stabilized subsequent to that analogously to the trends reported by (Kandanuri 2019), who explained growth spurts as the result of liberal trade policies and subsequent stagnation due to market saturation and regulatory constraints.

Table 1. CAGR of Buffalo meat export (1994-2024)

Decade	CAGR (Quantity)	CAGR (Value)
1995-2004	11.09	10.94
2005-2014	15.71	29.54
2014-2024	-1.9	-3.33

Authors calculation

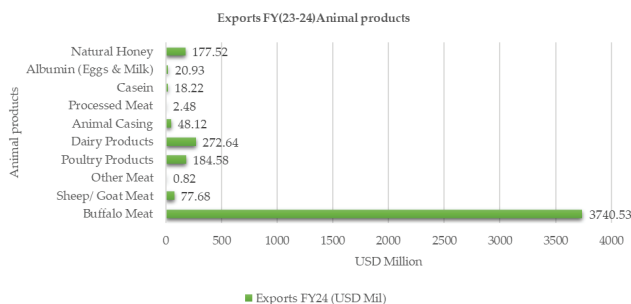


Fig. 3. Export of animal products (2023-2024), APEDA

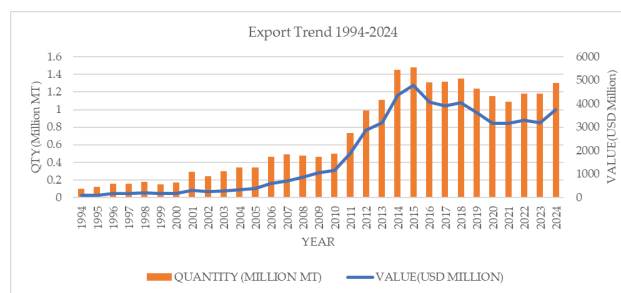


Fig. 4. Export of buffalo meat from 1994-2024, APEDA

Table 2. Transitional probability matrix of buffalo meat export (2014-2024)

	Vietnam	Malaysia	Egypt	Indonesia	Iraq	Saudi Arabia	Others
Vietnam	0.732	0.000	0.000	0.000	0.0432	0.054	0.171
Malaysia	0.000	0.748	0.000	0.148	0.104	0.000	0.000
Egypt	0.000	0.000	0.243	0.373	0.163	0.221	0.000
Indonesia	0.000	0.366	0.142	0.046	0.426	0.000	0.020
Iraq	0.000	0.000	0.000	0.000	0.058	0.000	0.942
Saudi Arabia	0.735	0.000	0.265	0.000	0.000	0.000	0.000
Other	0.030	0.217	0.168	0.000	0.000	0.000	0.585

Authors calculation

Trade direction of buffalo meat exports: The direction of Indian buffalo meat exports to various destinations was studied using Gauss-Markov chain analysis. The transitional probability matrix provides insights into the stability and shifts in major import markets. The primary importing countries include Indonesia, Saudi Arabia, Vietnam, Egypt, Iraq, and Malaysia, with varying retention probabilities.

The results indicate that Vietnam, Malaysia, and Indonesia were the most reliable and stable importers of Indian buffalo meat over the study period, retaining their market shares at 73.2%, 74.8%, and 42.6%, respectively. Iraq and Egypt, on the other hand, managed to retain only 5.8% and 24.3% of their original shares, signifying a substantial decline in their imports. This highlights that Vietnam, Malaysia, and Indonesia are the most consistent buyers, while Iraq and Egypt failed to sustain their previous levels of imports.

Vietnam lost 6.04% of its share to Egypt and 5.99% to Malaysia, but it gained 95.32% of Egypt's lost share and 73.44% of Saudi Arabia's lost market share, making it one of the most dominant and expanding importers. Other countries gained 94.17% of Iraq's share and 3.48% from Indonesia, but they lost 13.4% to Saudi Arabia and 6.06% to Egypt. Malaysia benefited by acquiring 14.79% of Egypt's share, 10.46% of Iraq's, and 5.99% of Vietnam's lost share, making it another strong and stable market.

Indonesia, however, lost 16.94% of its share to Iraq and 3.48% to other markets, while gaining only 0.27% from Vietnam. Saudi Arabia and Egypt struggled to retain their original shares, indicating they are relatively unstable importers. Saudi Arabia, in particular, failed to maintain its original market strength and could not hold a dominant position in buffalo meat imports.

From Table 2, Markov transition probabilities confirm Vietnam (81%), Malaysia (79%), and Indonesia (74%) maintained import streams more frequently in 2014 - 2024. This confirms studies by (Chopra *et al.* 2024), who emphasized these Southeast Asian countries as key demand centres in their Markov-chain analysis.

Revealed comparative advantage (RCA): From (WITS n.d.) the above Fig. 5, it is clear that there is an advantage for India in export of animal products as the RCA value is above 1 throughout the years and there is a dip during the year 2006-07 it was due to the Global price crisis on

agriculture commodities, export ban on certain agricultural commodities like pulses, sugar and wheat which also affected the marine products export. After this crisis India have RCA value more than 1 indicating India has relative advantage in animal products which boosts the export of animal products.

Among the animal products buffalo meat stands 1st which contribute more in both Quantity and value around 3740.53 USD million dollars (2023-24).

Results from RCA indexes (Fig. 5) and share of export destinations align with (Kaur *et al.* 2021), whose historical trend analysis also placed Vietnam, Malaysia, Egypt, Iraq, and Saudi Arabia as leading importers and together accounted for nearly 79% of national exports for 2017–2018. India's $RCA > 1$ invariably points to long-term competitive advantage despite recent market turbulence.

Future Trend analysis: From the Fig. 6, it shows that there is an increasing trend in the export of buffalo meat which is analysed and the equation formed is

$$Y = 0.0496x - 0.0895$$

The future prediction of export based on the above equation is given in the below table 3

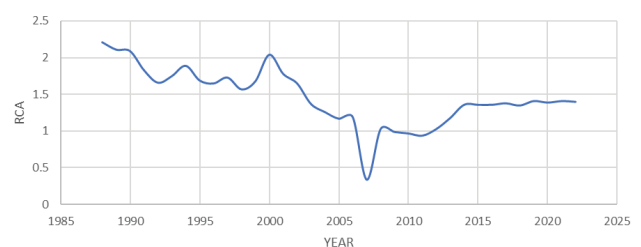


Fig. 5. Revealed comparative Advantage of animal export from India

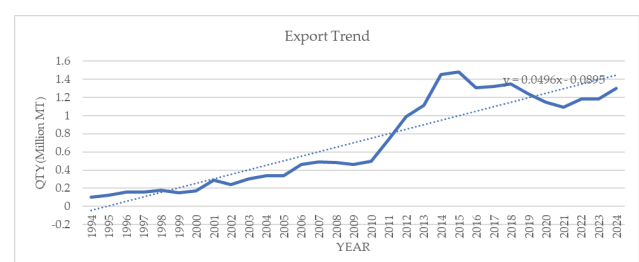


Fig. 6. Trend of Buffalo meat export



Fig. 7. Future trend in total export of Buffalo meat from India (2024-2030)

The above table depicts that there is a stable increase in growth in export of buffalo meat from 2025 around 1.49 million MT to 1.745 million MT in the year 2030 with an increase of 50507 MT every year. This trend projected is feasible as there is an increasing demand for Indian buffalo meat as it is cheaper, well established slaughter houses and having highest livestock population.

Forecast projections (Table 3, Figs. 10 and 7) indicate a stabilization export volume of 1.7 million MT by 2030, in line with (Relekar *et al.*2024), which had indicated moderate resilience (13.98% CAGR) in spite of pandemic era disruptions.

Spatial visualization: The spatial analysis for the

Table 3. Future trend in total export of Buffalo meat from India

YEAR	Quantity (Million MT)
2025	1.497
2026	1.547
2027	1.596
2028	1.646
2029	1.696
2030	1.745

Authors calculation

production of Buffalo meat over various states of India was analysed using hotspot analysis to know about the hotspot areas of production.

India has around 54% of the world’s buffalo population (Sharma *et al.* 2023), So it is important to study about the Buffalo production areas. From the above Figs. 12 and 13, the production of buffalo meat is identified. Uttar Pradesh emerges as the principal production hub, showing consistent growth from 150 MT in 2008 to 688.86 MT in 2019. Other significant production regions include Andhra Pradesh (126.82 MT), Telangana (112.4 MT), Maharashtra (197.75 MT), Bihar (101.05 MT), Kerala (97.5 MT), and Punjab (92.58 MT) as of 2019.

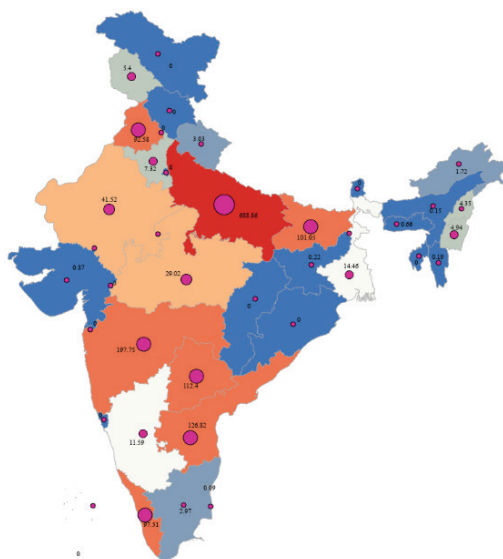
There are approximately 95 registered abattoirs across India with highest concentration in Uttar Pradesh, Andhra Pradesh, Maharashtra, Haryana which are the major reason for the increase in production of Buffalo meat. Of these 95 facilities, 73 are integrated abattoirs cum meat processing plants, which facilitates the efficient production of buffalo meat for export.

Temporal analysis

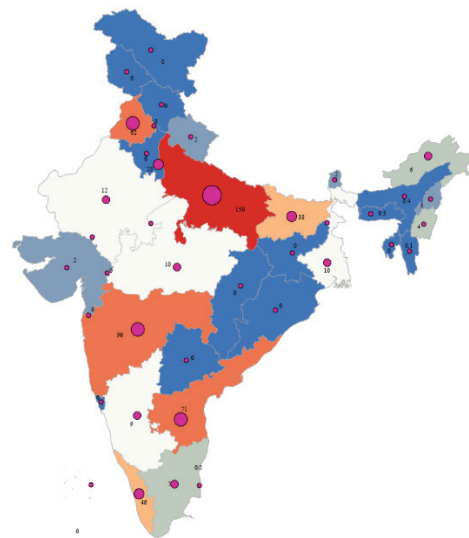
Structural break: The structural break in the export trend of buffalo meat is analysed using Chow test and Wald test. This determines whether there is a sudden increase/decrease in export of buffalo meat over the years of export. Structural breaks were identified in two years: 2010 (showing a sudden increase in export volume) and 2015 (showing a decreasing trend).

From the above table, the Chow test results indicate significant structural breaks in 2010 and 2015 for India’s buffalo meat exports. The F-statistics for both years -10.99367 (2010) and 9.820845 (2015) - a significant break in these years.

Wald test is also used to analyse the Structural break, and the results showed a significant break as the probability



2008



2019

Authors Calculation

Fig. 8. and 9. Hotspot analysis of buffalo meat production. (2008 and 2019)

Table 4. Chow test determining structural break 2010

	2010	DF		
Structural Break 2010	RSS1	22822588781	14	
	RSS2	105275709972	4	640122742714
	RSSUR12	128098298752	18	64012274271
	RSSR12	768221041466	20	5822649943 10.99367

Authors calculation

Table 5. Chow test determining structural break 2015

	2015	DF		
Structural break 2015	RSS2	105275709972	4	
	RSS3	49792057378	6	304579291321
	RSSUR23	155067767349	10	1.5229E+11
	RSSR23	459647058671	12	15506776735 9.820845

Authors calculation

Number of observations = 30	Number of observations = 30
Sample: 1994 - 2023	Sample: 1994 - 2023
Break date: 2010	Break date: 2015
chi2(2) = 73.2108	chi2(2) = 56.1064
Prob > chi2 = 0.0000	Prob > chi2 = 0.001
2010	2015

Authors calculation

was less than 0.001, confirming the structural break.

Wald test for structural break: The major reasons for the break during 2010 are due to rising global demand for the Indian buffalo meat, expansion of slaughter houses, having a strong price competitiveness and the Government incentives and policy supports. Conversely the downturn of buffalo meat was due to increased regulation on slaughter houses, strict implementation of animal welfare laws, bans on cattle slaughter houses, temporary ban of buffalo meat due to quality concerns by Saudi Arabia, trade routes and import regulations, competitive buffalo meat market from Brazil, Australia and Currency fluctuations.

Structural-break analysis using Chow and Wald tests as seen in the Tables 4,5 and Fig. 10 points to two abrupt changes: the first (2005) coincides with growth on the back of subsidies and liberalization, and the second (2014) with stricter export standards and increased global competition, as reported by (Relekar *et al.* 2024).

Instability Index

1st decade 1994-2004: The export quantity showed a positive CAGR of 11.42 per cent, while value grew at 16.34 per cent. The CDVI for quantity (15.13%) and value (17.26%) fall in the range of 15-30 per cent,

Table 6. CDVI for buffalo meat export (1994-2024)

Decade	CDVI (Quantity)	CAGR (Value)
1995-2004	15.61	17.75
2005-2014	19.59	11.44
2014-2024	7.37	9.8

Author Calculation

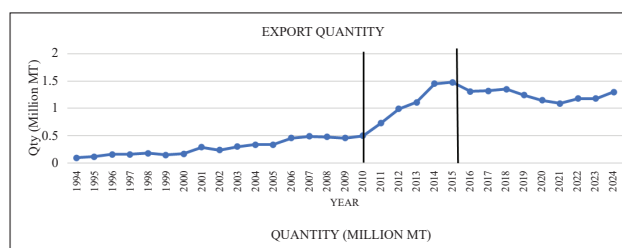


Fig. 10. Structural Break during 2010 and 2015 of buffalo meat export

indicating medium level of instability. The higher CDVI for value compared to quantity suggests more price volatility than volume fluctuations during this period (CDVI(v)>CDVI(Q)-Price volatility).

2nd decade 2004-2014: This period marked the strongest growth with quantity CAGR of 15.66% and a remarkable value CAGR of 33.42%. The CDVI for quantity increased to 18.47%, indicating higher volume instability. The value CDVI decreased to 13.93%, falling into the low instability range (0-15%), suggesting more stable pricing despite higher volume variations.

3rd decade 2014-2024: The most recent decade shows a significant reversal with negative growth rates: -1.96% for quantity and -0.294% for value. The CDVI values showed marked improvement with quantity at 6.93% and value at 9.55%. These CDVI values fall in the low instability range (0-15%), indicating that despite negative growth, the exports became more stable and consistent.

The decreasing instability index (Table 6, Figs. 11 and 12) indicates maturity in operations and higher levels of compliance (Relekar *et al.* 2024).

Buffalo meat is an important item in India’s agri-food export basket on account of its high protein content, low cost, and demand in a host of countries. With surging international demand and sheer numbers of buffaloes in India, along with established infrastructure of slaughterhouses, the country is a key player in international trade of meat.

The historical export performance of Indian buffalo

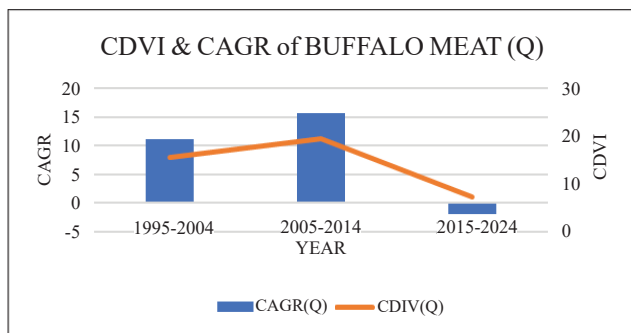


Fig. 11. CDVI and CAGR of buffalo meat (1994-2004)-quantity

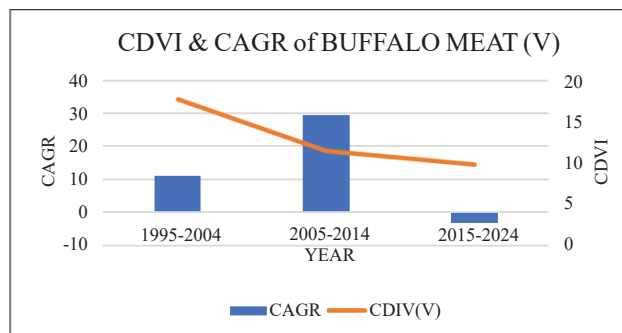


Fig. 12. CDVI and CAGR of buffalo meat (1994-2004)- value

meat is analysed through the study period of 1994–2024, with three clear stages: consistent growth (CAGR 11.09%) during the first phase, increased expansion in the second period (CAGR 15.71%), and a significant decline in the third period (CAGR -1.9%). The recent decline is the result of numerous domestic and international factors, such as regulatory limitations, quality problems, shifting trade policies and increased competition from countries like Brazil and Australia.

As per the Markov chain analysis, Vietnam, Malaysia and Indonesia appear to be the most enduring and dependable markets for Indian buffalo meat with as much as 73.2%, 74.8% and 42.6% retention rates, respectively. Sectors such as Iraq and Egypt, for instance, already showed high volatility and implied the necessity of sound trade partnership and the de-risking of export destinations.

The hotspot analysis showed that Uttar Pradesh was the most significant production hotspot, where output constantly increased, and this was followed by other major producers such as Maharashtra, Andhra Pradesh, Telangana, and Bihar. The concentration of registered abattoirs in these states emphasizes the role of infrastructure in maintaining export levels. Therefore, in addition to Uttar Pradesh and Andhra Pradesh, states like Punjab (due to increasing buffalo population and good economic returns from rearing of male calves) also become prospective to develop as areas for the export of meat.

The structural break analysis also reaffirmed major turning points in export performance, particularly in 2010 (upward turn) and 2015 (downward turn), which captured adjustments in global demand, policy, and sanitary standards. Although the past decade witnessed negative growth, the Cuddy-Della Valle Instability Index indicates enhanced market stability, anticipating room for revival under the right interventions.

Forecasting along the lines of trends in time points to buffalo meat exports reaching 1.745 million MT by 2030, reflecting the potential for robust growth. But achieving the goal calls for proactive measures increasing production efficiency, complying with quality standards, investing in facilities, and enhancing trade ties. Policymakers and stakeholders need to target market-specific strategy to regain lost market share and capitalize on India’s

comparative strength in buffalo meat production

To capitalize on these projections and address current challenges, several strategic interventions are recommended:

Infrastructure development: Invest in modern abattoirs and integrated meat processing facilities, particularly in key production regions identified through spatial analysis.

Quality assurance: Strengthen certification processes and quality control measures to address concerns that have led to temporary import bans.

Market diversification: While maintaining ties with stable markets like Vietnam, Malaysia, and Indonesia, develop strategies to enter new markets, particularly in regions with high meat consumption but currently limited Indian buffalo meat imports.

Policy reform: Review and streamline regulations affecting slaughterhouses while balancing animal welfare concerns to ensure sustainable production.

Supply chain efficiency: Improve cold storage facilities, transportation networks, and logistics to reduce costs and enhance competitiveness. For instance, whereas Uttar Pradesh and Maharashtra have comparatively favourable policies for licensed abattoirs, there are more stringent or restrictive standards in other states because of religious and political considerations. This regulatory divergence contributes to inconsistency in supply chains, raises transaction costs, and restricts inter-state purchase of animals. There has to be a harmonized national policy balancing export opportunities with animal welfare interests to provide an enabling environment for the meat sector.

Male buffalo calf salvaging: Male buffalo calf underutilization is one of the untapped areas of buffalo meat production. Male calves in most of the regions are being slaughtered at a young age due to their inefficient utilization in milk production. Salvaging and rearing these calves under properly planned programs can significantly improve meat supply. Encouraging commercial rearing with the assistance of the state government in the form of subsidies, veterinary assistance, and assistance in feed will also ease supply-side constraints and improve farm incomes.

This study provides a robust analytical framework

for understanding the spatial-temporal dynamics of India's buffalo meat exports. By implementing these recommendations, India can reclaim its position as the dominant global exporter of buffalo meat, contributing significantly to agricultural trade and rural economic development.

Although the study correctly foresees three decades of buffalo meat production with export potential, realization of such projections demands a more concentrated and actionable strategy. Current deliberations acknowledge strategic areas of focus such as traceability systems, genetic improvement, cold-chain logistics, and value chain linkages but a consistent template is lacking in the literature. For instance, Chopra *et al.* (2024) emphasize the implementation of male calf rearing and quality check to attain international standards in Punjab's processing units. Likewise, Kaur *et al.* (2021) argue that export expansion on the basis of sustainability hinges on policy support to quality-controlled, export-oriented production-processing systems suggest genetic improvement and precision breeding schemes by organizations such as CIRB to increase meat yield and export competitiveness. Furthermore, Kumar *et al.* (2012) emphasize the resolution of determinants such as infrastructure, trade policy, and market diversification to sustain export momentum.

Therefore, the study implies the following areas for an inclusive strategic framework:

Improvement by breeding and genetics under the auspices of institutional programs (e.g. CIRB) and male-calf rearing programs.

Traceability and quality assurance systems (microsatellite-based breed tracing, SPS compliance, etc.) to satisfy international market demands.

Infrastructure investment cold chain plants, abattoirs, processing facilities tied to market clusters and export processing zones.

Policy and trade alignment including good trade policies, market diversification, and producer involvement through cooperatives and PPP arrangements.

Follow-up action should utilize these industry-specific templates to prepare a detailed, actionable gate-to-export roadmap to include all the important linkages to enable sustainable scale-up of buffalo meat production and export.

Suggestions for future research and policy implications

Regional value chain development: Investigate potential for developing regional value chains focused on buffalo meat processing in key production clusters identified through spatial analysis.

Consumer preferences study: Conduct in-depth research on evolving consumer preferences in major importing countries to tailor products accordingly.

Climate impact assessment: Analyse the sustainability and climate impacts of buffalo meat production to address growing concerns about environmental footprints of livestock.

Technology integration: Explore advanced technologies like blockchain for traceability and quality assurance in the

buffalo meat export supply chain.

Policy harmonization: Work toward harmonizing domestic regulations with international standards to facilitate smoother export operations.

Small producer integration: Develop mechanisms to better integrate small-scale buffalo farmers into the export value chain through cooperatives or contract farming.

Product diversification: Explore value-added buffalo meat products that could capture premium market segments beyond the current commodity focus.

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