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Trends and flows - The Gravity model of India's Rice Trade

Kuppan Mohanakrishnan[*1], S. Ravichandran[2], R. Venkataraman[3] and S. Ramesh[4]

[1-3]Department of Agricultural Economics,
[4]Department of Agronomy, Annamalai University, Annamalainagar – 608002 (India)
*Corresponding author – krishnaneconomist@gmail.com
& ORCID - 0000-0002-6631-9191

Abstract

The virtual water trade is recently developing one because of sustainable use of water resource added in the SDG goals. Protection of water resource will be bigger issue in developing countries like India. Since, rice is the most stable food in Asian and African continents, India becomes largest producer and exporter in the world. This research paper examines the dynamics of India's rice export trade from 2014 to 2023, analysing growth rates, instability indices, market transition probabilities, net virtual water status and gravity model to identify the factor determinants among major importing countries. West African nations, including Côte d'Ivoire, Benin, and Senegal, exhibit high growth in rice imports from India. Contrastingly, imports by Bangladesh have declined. The application of the gravity model provides insights into key determinants of trade, such as GDP, geographical distance, population, arable land, and exchange rates. Results indicate a positive relationship between importing countries' GDP and demand for Indian rice, while distance negatively impacts trade volumes. Notably, the model highlights that countries with higher arable land tend to import more rice, suggesting a correlation between agricultural land availability and rice demand. This research contributes to understanding the interplay of economic, geographic and agricultural factors in international rice trade and underscores India's strategic role in meeting global rice demand despite market volatility.

Key words : Trends & flows, Rice trade, Gravity model. Net virtual water content.

Water is one of the most vital resources for life on earth, yet it is becoming increasingly scarce due to various factors such as population growth, climate change, and

[1]Research Scholar, [2]Associate Professor, [3]Professor and Head, [4]Associate Professor

unsustainable agricultural practices[22]. Water Scarcity was recognized by the United Nations[36] as a critical global issue, water scarcity refers to the lack of sufficient available water resources to meet the demands of water usage within a region. As demand for water continues to rise, particularly in agricultural production which accounts for approximately 70 per cent of global freshwater use innovative approaches to water management have become essential[11].

Allan,[1] introduced a tern 'virtual water' for the embedded water presented in the products, which is used in all the stages of production of that product. Virtual water trade presents an opportunity for nations facing water scarcity to leverage their comparative advantages in production while simultaneously addressing regional disparities in water availability. The concept of virtual water trade, which allows countries to manage their water resources more effectively through the international exchange of water-intensive products. Countries with abundant water resources can export water-intensive products, while those suffering from water stress can import these products, effectively transferring water resources from one region to another through the medium of trade (Allan, 2003). The evolution of this concept gained momentum with the advent of globalization and advanced trade practices, where the inter-connectedness of global supply chains brought to the forefront the local and remote water resources utilized in the production of commodities[16]. As countries began to import water-intensive crops, the hidden water cost within these global trade patterns came under scrutiny, leading to a paradigm shift in water resource management and policy[39].

In recent years, the virtual water concept has undergone significant developments, supported by cutting-edge research that quantifies water use across various sectors and geographies. Notably, the Water Footprint Network has been instrumental in formalizing the methodologies for calculating virtual water, further enriching the discourse surrounding water use efficiency and sustainability[16]. By understanding the virtual water content of various products, countries can identify opportunities to import water-intensive goods instead of producing them domestically, thereby conserving their limited water resources[17].

Rice is a staple food for more than half of the world's population, making it a critical commodity in the global agricultural trade[23], India, with its diverse agro-climatic conditions and substantial agricultural output, has consistently been one of the largest rice producers. India is the world's top exporter of rice, accounting for 30 per cent of global exports in 2023, while its imports account for less than one per cent of global imports.

The country's rice trade dynamics are influenced by a myriad of factors including economic growth, population changes, technological advancements in agriculture. Given the increasing global demand for rice, understanding the determinants of India's rice exports can provide valuable insights for stakeholders ranging from policymakers to exporters and researchers[21].

Understanding the trade trends and flows of India's rice exports is essential for formulating effective trade policies and strategies to enhance its competitive edge. This research aims to understand the Indias rice trade trend, stability, shifts and status of virtual water trade. Employed various analytical tools including the compound growth rate, Cuddy-Della Valle instability index, Markov chain, estimation of net virtual water content and gravity model to provide a comprehensive understanding of the factors influencing rice trade dynamics.

Table-1. Selection of product from India's total export volume (2014-2023)

Products	Total Export (MT)
Non-Basmati Rice	98074931.94
Basmati Rice	41554145.25
Wheat	24206207.82
Maize	20194935.07
Groundnuts	5965763.27
Fresh Onions	17082720.53
Fresh Grapes	1990931.41
Mango Pulp	1223303.43
Millet	1808975.31
Sugar	52035489.00

The major agricultural products that are exported from India during 2014 to 2023 has been collected from APEDA and presented sum total in table-1.

Rice (non-basmati rice & basmati rice) has highest export in terms of quantities, although it is one of the high-water intensive crop. Both non-basmati rice and basmati rice from India has been listed under one category as Rice in FAOSTAT, we have taken rice for this research. India's rice export and import data were collected from FAOSTAT database for the period 2014 to 2023 to estimate the growth rate, instability index, trade direction (Markov chain), virtual water content for export, import and gravity model.

Selection of Independent variables for Virtual water trade determinants :

A gravity model for virtual water trade usually extends the traditional model of bilateral trade by incorporating variables that specifically affect water use in trade, such as virtual water content.

Table-2. Source and references for independent variables of gravity model

Variables	Source	References
GDP	www.data.worldbank.org	(Head & Mayer, 2014; Shepherd, 2013)
Pop	www.data.worldbank.org	(Yang et al., 2006)
D	CEPII and www. trademap.org	(Shivaswamy et al., 2021)
ER	www.data.worldbank.org	(Baier et al., 2014)
AR	www.data.worldbank.org	(Fracasso, 2014)

Compound Growth Rate :

The growth rate for India's rice export (quantity) was analysed by using CAGR. (Agarwal *et al*., 2017; Mohanakrishnan *et al*., 2024) employed the compound annual growth rate to study the India's Trade performance of Poultry Products and poultry production, the same method was employed in this study,

$$y = a\, b^{t}\, e^{u}$$

Take the natural logarithm, it becomes

$$\log y = c + t \log b + e$$

It can be written as $\ln Y_t = \beta_1 + \beta_2 t + u_t$

β_1 and β_2 are estimated by ordinary least squares (OLS) method.
where, t – time variable, Y- growth rate of variables and b1- regression coefficient of t on Y.
The Compound Annual Growth Rate (CAGR) is obtained as a following way

$$CAGR\,(\%) = (Antilog\,\beta 1 - 1) * 100$$

The significance of CGR (r) is given by

$$t = \frac{r}{SE\,(r)} \text{ for } df\,(n-2)$$

where, $SE\,(r) = [100\,\beta * SE\,(ln\,\beta)]\,/\,ln\,e$ and ln e = 0.4343

Cuddy-Della Valle Instability Index (Ix):

The Instability Index was computed to examining the degree of instability for rice export from India. The Cuddy-Della index is the most commonly employed tool for measuring the instability of time series data and is widely accepted. John Cuddy and Della Valle created the indices in 1978 to quantify the instability of time series data. This index is an improved measure than coefficient of variation (CV) as it is inherently adjusted for trend, often observed in time series data. This index is measured in per cent, it means nothing but corrected CV. Similarly, the study was used by Suresh *et al.*,[34] to study the instability in India's meat export and (Mohanakrishnan et al., 2024) used in India's poultry production and export.

$$Ix\,(\%) = C.V\,x\,\sqrt{(1 - adj.R^2})$$

where,

Ix – Instability Index, C.V. – Coefficient of Variation, adj.R^2 – Adjusted R^2

Categorisation of Instability :

The Categorisation of instability done based on Cuddy-Della Valle index values as stated by Kihla *et al.*,[19]; Pokharkar *et al.*,[25] Sihmar[32].

Table-3. Categorisation of Instability

Categories	Low	Medium	High
Insteability Index (%)	0 - 15	15 – 30	More than 30

Markov chain analysis :

The first order Markov chain technique was used to examine the direction of trade in chicken products. The transitional probability matrix P must be estimated in order to perform the Markov chain analysis. The entries P_{ij} of the matrix P represent the chance that exports will shift from i^{th} country to j^{th} country over time. The diagonal members of the matrix calculate the chance that a country's export share will be retained, indicating an importing country's loyalty to a certain country's product. Shilpashree *et al.*,[30] utilised a similar technique to investigate the direction of trade for India's poultry product exports.

Calculation of virtual water content :

Virtual water content (VWC) of rice

is the basis to estimate the level of net virtual water trade between India and its trading partners. We adopted Mekonnen and Hoekstra's[22] method of virtual water content estimates. To determine the magnitude of virtual water import and export, we employed the calculation method described by Distefano & Kelly[8]; Fracasso[12]; Tamea *et al.*,[35]; Yang *et al.*,[38].

The dependent variable is the total amount of water embodied in the food products exchanged between India and partner countries (*i.e*, virtual water export / virtual water import). To obtain the Virtual Water Content on Export (VWCE) and Virtual Water Content on Import (VWCI) estimates of country-specific virtual water content (CVWC) for various crop products provided by Mekonnen & Hoekstra,[22] are multiplied by the quantity of exchanged in the international trade data from the FAOSTAT database[31].

$$\mathrm{VWE}_{\mathrm{pijt}} = \mathrm{Export\ Quantity} * \mathrm{CVWC}_{\mathrm{pi}}$$
$$\mathrm{VWI}_{\mathrm{pijt}} = \mathrm{Import\ Quantity} * \mathrm{CVWC}_{\mathrm{pj}}$$

The water footprint is measured for the study calculated by[18] for India. The average water footprint of rice was 3571 cubic meter per tonne.

Net Virtual Water Export (NVWT) (Trade balance) :

The net virtual water export is defined as

$$\mathrm{NVMT} = \sum(\mathrm{VWCE} * \mathrm{Export\ volume}) - \sum(\mathrm{VWCI} * \mathrm{Import\ volume})$$

This formula will give the net balance of virtual water trade for Indias rice trade, representing the net export (positive value) or net import (negative value) of water embodied in rice trade.

Estimation of gravity model india's virtual water trade for Rice export :

The gravity model of trade is a model of bilateral trade interactions where quantity and distance between nations effects enter multiplicatively[12,14].

Gravity model specification :

The gravity model for trade is commonly expressed as:

$$T_{ij} = \frac{GDP_i^{\alpha} \text{ x } GDP_j^{\beta}}{D_{ij}^{\gamma}}$$

Where,

T_{ij} - Trade flow from country i to country j, GDP_i and GDP_j – GDPs of the exporting and importing countries, D_{ij} is the distance between them and A, α, β and γ are parameters to be estimated.

virtual water trade for rice, the gravity model was extended by including variables such as total population (Pop) exchange rate (ER), arable land (AR)

$$VWCE_{ij} = A\, x\, GDP_j^{\alpha}\, x\, Pop_j^{\beta}\, x\, D_{ij}^{\gamma}\, x\, ER_j^{\delta}\, x\, AL_j^{\epsilon}$$

Where,

$VWCE_{ij}$ - Virtual water content of rice exported from India to country j, GDP_j - GDP of the importing country, Pop_j - Population of the importing country, D_{ij}-Distance between India and the importing country, ER_j- Exchange rate of the importing country, AL_j - Arable land in the importing country and A, α, β, γ, δ and υ are parameters to be estimated.

Gravity model estimation :

Panel data regression techniques used to estimate the parameters of the gravity model. Gretl software (version 2024c) was used to estimate Ordinary Least Squares (OLS), fixed effects models was employed to avoid heteroscedasticity in the panel data, decided on the nature of the data and the results of statistical tests (Breusch – Pagan test).

$$ln\,VWCE_{ij} = ln\,(A) + \alpha\,ln\,(GDP_j) + \beta\,ln\,(Pop_j) + \gamma\,ln\,(D_j) + \delta\,ln\,(ER_j) + \epsilon\,ln\,(AR_j) + u_{ij}$$

This approach will help in understanding how different factors impact the virtual water trade in rice and guide water resource management decisions.

The growth, instability, transitional probability matrix, net virtual water status and gravity model of virtual water trade analysis were estimated for Indias rice trade between 2014 to 2023. The results were furnished from table-4 to table-7.

Table-4. Growth & Instability of India's major rice importers (2014-2023) (per cent)

Importing Countries	CGR	Ix	Category of Instability
Saudi Arabia	0.69**	14.54	Low
Iran	1.25**	23.92	Medium
Benin	12.68**	20.48	Medium
Senegal	4.52**	40.07	High
Nepal	7.34**	31.92	High
Bangladesh	-1.72^{NS}	118.78	High
UAE	-2.98**	23.09	Medium
Côte d'Ivoire	14.78**	32.88	High
Iraq	6.11**	30.93	High
Guinea	9.72**	20.36	Medium
India's total export	8.46**	21.00	Medium

The growth rate and instability index of India's major rice importers from 2014 to 2023 were presented in table 4. The growth rate (CGR) and instability index (Ix) provide insights into the trends and stability of rice imports by various countries over the years. Except Bangladesh, all other importing counties have significant growth rate. West African countries such as Côte d'Ivoire (14.78 per cent), Benin (12.68 per cent) and Senegal (4.25 per cent) shown high growth rates but also considerable instability, because rice is the staple food grain in these countries[9] by market sensitivity, high distance trade and local conditions. Rakotoarisoa (2011) emphasizes that West African nations, including Benin and Côte d'Ivoire, have a high dependency on imported rice due to limited domestic production capacity. This dependence is reflected in the high stability of rice exports to these countries.

Saudi Arabia (0.69 per cent) and Iran (1.25 per cent) demonstrate moderate significant growth with substantial fluctuations, influenced by geopolitical and economic factors[26].

Nepal (7.34 per cent) and Bangladesh present contrasting trends; while Nepal shows growth with variability, Bangladesh (-1.72 per cent) has a non-significant declining growth with high instability (118.78), linked to increased domestic production in recent years and changing policies. The UAE and also highlight the diverse dynamics of rice imports, with the former showing a decline and the latter significant growth and fluctuations, reflecting broader market shifts.

Overall, India's total rice export growth rate of 8.46 per cent and an instability index of 21.00, reflect a positive trend with some fluctuations, influenced by both domestic and international market dynamics. This result aligns with Shailza *et al.*,[28] CGR results for 2011-2020 was 5.74 per cent and instability was 16.95 per cent and Suman,[33] reported that CGR and instability index for basmati rice export for 2001-2020 was 19.96 and 43.98 per cent respectively and non-basmati rice CGR and instability index was 12.74 and 63.46 per cent respectively. This clearly shows that rice export has significantly increasing over the years.

Markov *chain analysis :*

This analysis provides insights into the stability and shifts in trade patterns, helping to identify emerging markets and potential areas for strategic trade interventions[2]. The transitional probability matrix results were presented in table-5.

Table-5. Transitional Probability Matrix for India's Rice Export (2013-2024)

Countries	Saudi Arabia	Iran	Benin	Sen-egal	Nepal	Bang ladesh	UAE	Côte d'Ivoire	Iraq	Guinea
Saudi Arabia	**0.024**	0.148	0.059	0.095	0.062	0.439	0.079	0.017	0.033	0.042
Iran	0.174	**0.057**	0.000	0.062	0.162	0.000	0.141	0.096	0.272	0.037
Benin	0.017	0.028	**0.375**	0.227	0.000	0.001	0.008	0.140	0.001	0.203
Senegal	0.035	0.129	0.115	**0.112**	0.003	0.060	0.156	0.093	0.215	0.083
Nepal	0.084	0.000	0.156	0.111	**0.353**	0.005	0.036	0.155	0.004	0.095
Bangladesh	0.286	0.129	0.134	0.051	0.065	**0.022**	0.097	0.058	0.086	0.071
UAE	0.357	0.330	0.039	0.042	0.110	0.047	**0.064**	0.000	0.000	0.009
Côte d'Ivoire	0.000	0.043	0.320	0.340	0.000	0.000	0.000	**0.133**	0.000	0.165
Iraq	0.168	0.265	0.161	0.179	0.076	0.002	0.077	0.030	**0.002**	0.040
Guinea	0.462	0.028	0.196	0.000	0.023	0.024	0.171	0.000	0.020	**0.076**
SSP	**0.140**	**0.109**	**0.160**	**0.124**	**0.074**	**0.077**	**0.083**	**0.075**	**0.070**	**0.088**

The analysis of the transitional probability matrix for India's rice export from 2013 to 2024 sheds light on the dynamics of the export market and the stability of trade relationships with major importing countries. The probabilities indicate how exports are redistributed among various countries, reflecting both market stability and potential shifts in trade preferences. Côte d'Ivoire, Benin and Senegal show significant transition probabilities of 0.133, 0.375 and 0.115, respectively, with Benin demonstrating a stable yet growing demand for Indian rice. Kumar[20] reported that West African countries' rice imports are highly sensitive to global market changes and local economic conditions, which is reflected in these probabilities. Saudi Arabia and Iran exhibit moderate transition probabilities of 0.024 and 0.174, respectively, signalling relatively stable but moderate trade volumes with India. Nepal's high transition probability of 0.353 indicates a strong and stable market for Indian rice, supported by, who noted Nepal's increasing dependency on Indian rice imports due to seasonal variations and trade policies. Bangladesh, with a negative transition probability of -1.72 per cent, reflects a declining trend in rice imports. Since, the domestic production increased and changes in import policies.

Saudi Arabia lost its 43.9 per cent shares to Bangladesh and gained 46.2 per cent from Guinea. Likewise, each countries gains and loss to rest of the countries. Overall, India's total export transition probabilities reveal a positive trend with an average transition probability of 8.46 per cent, reflecting India's strong export performance despite some fluctuations[37] emphasized that India's rice export patterns are influenced by both domestic production variability and international market dynamics, which is consistent with the observed probabilities. The Steady State Probabilities means if the trends continue like this in future Benin will be most promising importer with 16.4 per cent, followed by Saudi Arabia (14.0 per cent) and Senegal (12.4 per cent).

Table-6. Virtual Water Content of Rice Trade – 2014 to 2023 (m^3 per year)

Year	VWC on Export (VWCE)	VWC on Import (VWCI)	NVWC
2014	39859555565	6420658	39853134907
2015	39105671042	4670868	39101000174
2016	35378114831	3571000	35374543831
2017	43282444769	6699196	43275745573
2018	41657946875	23311488	41634635387
2019	35064088233	20693945	35043394288
2020	52181601742	16080213	52165521529
2021	75990547897	13462670	75977085227
2022	79406845035	42255643	79364589392
2023	63795857864	21454568	63774403296

The virtual water content (VWC) of rice trade from 2014 to 2023, as illustrated in table 6, gives critical insights into the water consumption contained in India's rice export and import operations. The VWCE has increased from 3,985,955 m^3 in 2014 to a peak of 7,940,684 m^3 in 2022, then slightly decreased to 6,379,585 m^3 in 2023. But this development also highlights how much water is needed to grow rice, which raises questions about how sustainable water supplies may be, especially in areas with limited water supplies[22].

VWCI, on the other hand, has exhibited more fluctuations, indicating variability in import volumes over the years but it shares less than one per cent every year. The relatively stable but fluctuating import levels highlight the complexities of balancing domestic production with import needs[10].

Over the years, Net Virtual Water Content (NVWC) has generally remained positive, indicating that India is a net exporter of virtual water through rice trade. This is significant as it implies that India is transferring substantial volumes of water embedded in rice to other countries, which can have both economic benefits and environmental loss. The positive NVWC values highlight India's contribution to global food security by providing water-intensive rice to countries that may lack sufficient water resources for their own production[15]. Continuous export of virtual water can lead to local water stress, especially in regions where water scarcity is already a concern[5]. These findings suggest that while rice exports are economically beneficial, they must be balanced with strategies to ensure long-term water sustainability. These strategies could include improving irrigation efficiency, adopting drought-resistant rice varieties, and promoting water-saving techniques in agriculture[4]. India effectively exports large volumes of virtual water by exporting rice, contributing to the global water trade network. This has broader implications for global water security, as highlighted by studies from[13,27] emphasizing the importance of integrated water management strategies that consider both local and global water dynamics.

Heteroscedasticity :

Breusch-Pagan *test :*

The Breusch – Pagan test employed to detect heteroskedasticity in a random effect model of regression analysis.

Asymptotic test statistic: Chi-square(1) = 1.06743 p-value = 0.301527

The Null hypotheses was fixed as variance of the unit – specific error is equal to zero (no heteroscedasticity). The test static value was 1.0674 with the p value was 0.30, it is higher than 5 per cent significance level, it means the test statistic was non-significant and rejecting null hypothesis. This clearly indicates that there is no significant evidence of heteroskedasticity in this regression model. So, we followed random effect model in this study.

The estimation of the gravity model for India's rice trade, as presented in Table 7, elucidates several key factors influencing export dynamics. The gravity model includes coefficients for GDP of the importing country (ln imp GDP), geographical distance (ln dis), population of the importing country (ln imp pop), arable land (ln ara land), and exchange rate (ln imp exc. rate).

Table-7. Estimation of Gravity model of Indias Rice Trade

Variables	Coefficient
Cons	29.2798***
	(2.7813)
ln imp GDP	0.3368***
	(0.0337)
ln dis	–0.4027**
	(0.1439)
ln imp pop	–1.2050***
	(0.2600)
ln ara land	0.5159***
	(0.1273)
ln imp exc. rate	0.0193^{NS}
	(0.0351)
R square	0.1993
F stat	14.6796***
Observations	100
No. of years	10

#standard error in parentheses; Level of significant *** p<0.01 & ** p <0.05 and NS – Non-significant

The constant (Cons) at 29.2798 is highly significant, indicating a substantial baseline effect on India's rice exports. The coefficient for ln imp GDP is positive and highly significant at 0.3368, suggesting that countries with higher GDPs import more rice from India. This aligns with Head & Mayer[14], who noted the significance of economic size in trade volumes. The positive relationship reflects that wealthier nations have greater purchasing power and demand for rice imports.

Geographical distance (ln dis) has a negative coefficient of -0.4027, significant at the 0.05 level. This inverse relationship is consistent with traditional gravity model theory, which posits that greater distances reduce trade volumes due to higher transportation costs[7]. This finding is corroborated by Anderson & Van Wincoop[2], who emphasized the frictional effect of distance on trade. The importer population (ln imp pop) is negative and highly significant at -1.2050. This suggests that larger populations may not correlate with higher rice imports, possibly due to self-sufficiency in food production in populous countries, as noted by (Timmer *et al*., 1983). This inverse relationship could also be attributed to the diverse dietary patterns and agricultural policies in countries with large populations.

The positive and significant coefficient for arable land (ln ara land) at 0.5159 indicates that countries with more arable land tend to import more rice. This might be due to these countries' efforts to meet their consumption needs through imports, as supported by studies like (Timmer *et al*., 1983), which found that agricultural land availability influences import volumes. The coefficient for the exchange rate (ln imp exc. rate) is non-significant at 0.0193, suggesting that short-term fluctuations in exchange rates do not have a substantial impact on rice trade volumes. This finding aligns with Chen & Rogoff[6], who reported that certain agricultural commodities, including rice, are relatively insulated from exchange rate volatility.

The model's R-squared value of 0.1993 indicates that approximately 20 per cent of the variance in India's rice exports can be explained by the included variables. Despite this moderate explanatory power, the F-statistic of 14.6796 is highly significant, affirming the overall robustness of the model. This suggests that while the model captures key determinants of rice trade, other factors not included in the model may also play a role.

India's rice export demonstrates substantial growth, driven by high demand in specific regions, yet marked by variability due to diverse market conditions. Notably, West African nations display strong growth rates in imports but also experience medium to high instability, likely influenced by rice as staple food in their diets and sensitivity to global market shifts. In contrast, Middle Eastern countries have moderate growth rates coupled with significant fluctuations over the years, reflecting the impact of geopolitical factors on their import dynamics. Nepal's consistent demand for Indian rice underscores a stable, growing dependency, while Bangladesh, influenced by rising domestic production, shows a declining import trend. The transitional probability matrix, highlight the shifts in trade preferences among India's major importers, with West African countries generally maintaining stable import, and Nepal showing strong import stability. The steady state projections suggest West African nations and Saudi Arabia will continue to be reliable markets for India's rice exports. The gravity model further supports these observations by revealing key factors shaping India's rice export dynamics. Countries with higher GDPs exhibit higher demand, as wealthier nations have greater purchasing power. Distance negatively impacts trade volumes, as expected due to transportation costs, while larger populations correlate negatively with imports, likely due to a greater capacity for self-sufficiency in populous countries. Arable land availability positively influences import volumes, suggesting that agricultural land availability within these countries may bolster rice demand, despite exchange rate effects being less impactful in the short term.

Overall, the findings emphasize a dynamic but promising outlook for India's rice exports. The combined impact of economic, geographical and agricultural factors creates a complex yet robust market environment. This export trend shows that India will be net exporter of rice export. Since it is a high-water intensive crop, some decisions or policies need to be drawn to protect water sustainability.

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