Geo-based visual network analysis of food fertilizer trade patterns among BIMSTEC member nations during 2005–2022

Journal of Chinese Economic and Foreign Trade Studies

15

Md. Monzur Hossain
Department of Finance and Banking, Faculty of Business Studies, Comilla University, Cumilla, Bangladesh

Subir Kumar Sen
Department of Commerce, Faculty of CLMIS, Tripura University, Agartala, India

Kareem M. Selem
Hotel Management Department, Faculty of Tourism and Hotels, Suez Canal University, Ismailia, Egypt, and

Md Shafiul Hossain
Department of Business Administration, Bangladesh Institute of Business and Technology, Narayanganj, Bangladesh

Abstract

Purpose – The purpose of this paper is to analyze food fertilizer products' trade networks among Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC) member nations during 2005–2022.

Design/methodology/approach – To explore the nature of revealed comparative advantage, intra-sectorial trade specialization and intra-industry trade, this paper used Balassa, Lafay and Grubel-Lloyd indexes. On the other hand, economic networks were used to investigate fertilizer trade centrality in global trade networks.

Findings – This paper concluded that Thailand and India have the most diversified fertilizer trade markets. In contrast, Nepal and Bhutan exhibited high import centrality toward a few source regions. Hence, significant scope exists to diversify fertilizer export and import markets within BIMSTEC member nations to avoid region-specific dependence on international trade.

Originality/value – This paper lies apart in its precise emphasis on linking national resource security issues with import-export policy formulation for food fertilizers, where earlier studies have not been examined. Dealing with this intersection allows the existing paper to offer a reenergized perspective on

The authors acknowledge the grant received under Major Research Project Scheme (02/31/2019-2020/MJ/RP) from Indian Council of Social Science Research (ICSSR), New Delhi, India.

Conflict of interest: The author declares no competing interests.

Ethical statement

1) This material is the authors' own original work, which has not been previously published elsewhere.
2) The paper is not currently being considered for publication elsewhere.
3) The paper reflects the authors' own research and analysis in a truthful and complete manner.

Journal of Chinese Economic and Foreign Trade Studies
Vol. 19 No. 1, 2026
pp. 15-39

1754-4408
DOI 10.1108/JCEFTS-11-2024-0083

harmonizing resource sustainability with economic objectives. Hence, this fills a primary void in the existing literature by suggesting hands-on strategies and expanding current knowledge.

Keywords Fertilizer trade, Economic networks, BIMSTEC, Food products, ANOVA

Paper type Research paper

1. Introduction

World Trade Organization seeks to facilitate trade movements in seamless, foreseeable and unrestricted manners (Paudel *et al.*, 2023). The growing number of regional agreements can be observed, as they provide additional trade prospects for the nations involved (Fusacchia *et al.*, 2022). This agreement strongly impacts agricultural commerce, as (Wani *et al.*, 2024), under the Bay of Bengal Initiative for Multi-sectorial Technical and Economic Cooperation (BIMSTEC), nations defend agricultural markets (Marwah *et al.*, 2023). BIMSTEC is a regional organization of seven South Asian and Southeast Asian Bay of Bengal nations (Beltran-Peña *et al.*, 2020). BIMSTEC includes Bangladesh, India, Myanmar, Nepal, Bhutan, Sri Lanka and Thailand (Ojha, 2022). Through cooperation and integration, the organization promotes regional cooperation in trade, investment, technology, tourism, cultural exchange and growth and development.

BIMSTEC includes seven member nations and holds a population of around 1.5 billion, nearly 24% of the world's population (Marwah *et al.*, 2023). Moreover, these people within the BIMSTEC region are laboriously reliant on agriculture, and their main foods are linked with agriculture (e.g. rice, wheat, fish and meat) (Ojha, 2022). BIMSTEC is strengthening trade networks among member nations to ensure food security and overall regional development (Ghonkrokta, 2021). In this era of modern technology, the agriculture sector has the right to be sophisticated (Misra and Ghosh, 2024). According to Williamson *et al.* (2024), the world's population is expected to reach 9.7 billion by 2050, resulting in a 70% rise in existing food consumption. The global population has been experiencing fast growth, resulting in a heightened need for sustenance (Ojha, 2022). Food production demands have been intensified by climate change (Beltran-Peña *et al.*, 2020), resulting in more frequent and severe extreme weather events that endanger food production (Williamson *et al.*, 2024).

Moreover, there have been volatile circumstances and recurrent occurrences, leading to a rise in food prices (Liu *et al.*, 2025). Consequently, fertilizers' efficient use becomes crucial to enhance agricultural production and ensure food security within the constraints of limited arable land (Misra and Ghosh, 2024). Fertilizers are essential commodities in global markets and are critical for economically producing viable crops (Liu *et al.*, 2025). According to Williamson *et al.* (2024), they will ensure food security for more than eight billion people globally by 2025. Ensuring an adequate supply of fertilizers, in terms of quantity and proper nutrient balance (Bai *et al.*, 2022), is essential for addressing disparities between the nutrients provided (Liu *et al.*, 2025) by soils and organic sources and the nutrients required for optimal crop growth (Wani *et al.*, 2024).

Subsequently, agriculture sectors and fertilizer businesses are encountering unprecedented problems because of the current global climate change trends (Paudel *et al.*, 2023). Global supply-and-demand fluctuations for fertilizer minerals increase competition and worsen food security concerns (Liu *et al.*, 2025). As fertilizers have the magical capacity to enhance the productive capacities of agricultural land (Li *et al.*, 2025), nations take various approaches based on their specific needs and circumstances regarding fertilizer production, use, import and export (Bayssi *et al.*, 2024). Some nations produce fertilizers in quantities that meet their demand and necessity (Theresa *et al.*, 2025). Thus, BIMSTEC can play a dynamic role in ensuring higher fertilizer availability to increase food productivity within member nations (Das and Bhowmik, 2024).

Fertilizers are traded at an average of US$94.6bn worldwide (Daher *et al.*, 2019). Fertilizer exports are growing at a pace of 48.9% on average (Ambroziak and Stefaniak, 2022).

When considering the global trade scenario for fertilizer exports and imports, it becomes clear that Russia and China were the biggest fertilizer exporters in 2022 (Alexander *et al.*, 2023), accounting for more than 10% of total exports. Otherwise, the top three fertilizer importers from exporting nations are the USA, India and Brazil, accounting for 16.87%, 10.50% and 8.46% of global total trade, respectively (Sinha and Panigrahy, 2024). This trend shows that these nations rely heavily on agriculture, requiring fertilizers and steady supplies imported from outside (Daher *et al.*, 2019). Among the top ten fertilizer importers (Table 1), India ranks third with US$8bn.

In addition, several challenges and circumstances significantly affect international trade in fertilizers and need to be considered (Moersdorf *et al.*, 2024). After COVID-19, human interaction forms were regulated or outlawed worldwide (Sinha and Panigrahy, 2024). Global fertilizer trades were hit hard by fluctuating foreign exchange rates, a shortage of agricultural supplies and a change in farming demand worldwide (Khatri *et al.*, 2024). A further issue is existing geopolitical tensions resulting from the Russia–Ukraine War, which the world is experiencing (Moersdorf *et al.*, 2024). It has escalated to an issue in goods' supply chains that can be dealt with worldwide. Most BIMSTEC members relied heavily on food. In 2022, India was the second among the top ten fertilizer importers, and Thailand was the ninth (Misra and Ghosh, 2024).

Moreover, as the importance of fertilizer in this regard is widely recognized, this paper focuses on how BIMSTEC member nations are working to expand fertilizers' trade networks among themselves. The existing paper attempts to examine fertilizer trades' specialization among BIMSTEC member nations using the Balassa Index (BLI) and Lafay Index (LFI) and investigate intra-industry trades using the Grubel-Lloyd Index (GLI). Besides, this paper's other objective is to analyze fertilizer products' trade networks among BIMSTEC member nations to identify the relative positions of the member nations, combining trade patterns, nodes' centrality and topological characteristics of fertilizers' trade networks. There are three reasons why this paper is to be conducted in bridging the existing gaps. First, almost all BIMSTEC member nations rely on agriculture.

2. Literature review

There is an abundance of resources for trade network analysis. Sophisticated network measures examine diverse global trade patterns (Wani *et al.*, 2024). Within economic network analysis, primary metrics operated include in-degree and out-degree; shortest path length, network density, betweenness centrality, proximity centrality and modularity-based

Table 1. Top-ten exporters and importers of fertilizers at world and BIMSTEC levels

	Fertilizer imports			Fertilizer exports	
Nation	World (%)	BIMSTEC (%)	Nation	World (%)	BIMSTEC (%)
Brazil	15.73	0.005	Russia	11.00	2.10
India	11.92	0.002	Canada	9.11	1.06
The USA	9.30	0.01	China	6.42	2.46
China	3.35	0.002	The USA	5.59	0.14
France	3.23	0.00009	Morocco	3.73	1.81
Australia	2.73	0.01	Saudi Arabia	2.41	2.10
Indonesia	2.20	0.002	Germany	3.58	0.06
Canada	2.19	0.0004	Egypt	2.73	0.36
Thailand	2.00	0.0004	Oman	1.92	0.99
Turkey	1.95	0.0009	Belgium	2.60	0.025

Source(s): Compiled by authors from the OEC database

Table 2. Indicators' description of network topologies

Topological items	Definition	Formula
Network density	The proximity of trade flows between each nation	
Average path length	International trade effectiveness	$L = \frac{2}{N(N-1)} \sum_{j \leq i}^{N} d_{ij}$
Network diameter	Trade network size	$Dia = max_{ij} d_{ij}$
Degree	The quantity of international trade that takes place directly	$C_{sum,i} = C_{out,i} + C_{in,i}$
Betweenness centrality	A nation's capacity to exert control over trade movements	$BC_k = \sum_{j \neq i \neq k} \frac{n_{ij}^k}{g_{ij}}$
Closeness centrality	Nation's resilience in the face of external influences on its ability to resist interference	$CC_i = \frac{N}{\sum_{i=1}^{N} d_{ij}}$
Eigenvector	Normalized eigenvectors that correspond to maximal eigenvalues of adjacent matrices	$E_i = \lambda^{-1} \sum_{j=1}^{N} A_{ij} e_j$
Clustering coefficient	The concentration of nations that are part of global trade networks	$CC_i = \frac{2E_i}{K_i(K_i - 1))}$
Modularity	How much a trading network's communities are divided	$Q = \frac{1}{2m} \sum_{ij} \left(A_{ij} - \frac{k_i k_j}{2m} \right) \delta(C_i, C_j)$

Source(s): Compiled by authors

grouping of nodes (Table 2). In investigating the evolution of world trade networks, Wani *et al.* (2024) found increasingly dense, reciprocal and clustered and identified financial crises during 2007–2008 as turning points for trade network evolutions worldwide. Chen *et al.* (2024) found that Europe, North America, Russia, Japan, China and South Korea hold core positions as the most influential top traders.

On the other hand, world trade networks can be negatively affected by external factors. Salem *et al.* (2025) highlighted COVID-19 and the Russia–Ukraine war. Moreover, climate change creates an imbalance in production, demand and supply (Bai *et al.*, 2022). Trade networks are investigated using different indices, with BLI, LFI and GLI indexes being the most common in this paper. Further, Balassa (1965) introduced the relative competitive advantage index (RCA) to help nations construct trade patterns. Osburg *et al.* (2024) proved how each product's advantage varies in different marketplaces and creates comparable ranges across nations. These criticisms emphasized increasing returns and imperfect competition in explaining trade flows (Elish and Ahmed, 2025).

In addition, nations with trade surpluses in cereals notice low RCA values for cereal preparations. Moreover, Torok *et al.* (2018) used global coffee trade competitiveness based on RCA and BLI. Bacsi *et al.* (2023) noticed that the enormous coffee exporters are Brazil, Vietnam and Colombia; however, unreasonable specialization patterns are marked in Uganda, Ethiopia and Honduras. Regarding LFI, Kuzmenko *et al.* (2022) examined trade performances between the European Union and Russia in agri-food sectors. They found a notable decrease in the value of Russian agricultural imports in certain commodity groups. Hence, this can be attributed to geopolitical instability (Bas, 2025). Via LFI, Ambroziak and Stefaniak (2022) analyzed Italian trade specializations in agri-food production and noted that the food industry is different from region to region.

Likewise, Kuzmenko *et al.* (2022) examined international wine trade patterns, using LFI to measure comparative advantages and identify significant changes in global wine markets.

Notably, traditional wine nations (i.e. Italy, France, Portugal and Spain) have seen shifts in their specialization patterns (Sánchez-Hernández, 2023). Italy has increased its focus on sparkling wines, while new wine-producing nations have gained prominence in international markets. Intra-industry trade analyses posed significant challenges to traditional trade theories (Malimba *et al.*, 2024). If exports and imports co-occur, then they constitute intra-industry trades. When Grubel and Lloyd (1975) examined Organization for Economic Cooperation and Development nations' trade statistics, economists officially acknowledged the importance of intra-industry trade in the mid-1970s. When quantifying trade among industries, GLI is still frequently used, even though it has been extended and empirically criticized (Malimba *et al.*, 2024).

Biernacka (2021) used GLI to examine V4-EU-28 furniture manufacturing intra-industry mutual trade. Findings proved that nations have robust intra-industry trade and no significant import–export disparity. Fanelli and Giglio (2021) used GLI to analyze Indonesian spice commodity trade in international markets. Blondeel *et al.* (2021) found that each nation wants to have an energy export relationship rather than an import relationship with others to hold more geopolitical power. Wu *et al.* (2022) analyzed industrial robot trade networks where China, Japan, Germany and Italy are in these networks' centers. Otherwise, import markets for such products are highly diversified, and export markets are increasing over time (Carrasco and Tovar-García, 2021). In terms of plastic waste trade, Biernacka (2021) stated that trade patterns shifted to their center of gravity after many nations banned plastic.

Further, Bai *et al.* (2022) found that many nations imposed export restrictions on medical device trade during COVID-19 to ensure their domestic supply. Using BLI, Torok *et al.* (2018) found that coffee production was focused, and its trade was happening in developed nations, where Brazil and Colombia are the largest exporters of coffee worldwide. Regarding seafood trade, China and Thailand are the world's leading seafood exporters, and Russia, China, Ukraine and Azerbaijan have high levels of interdependence under Eurasian sub-networks. Furthermore, wheat trades in the third rank after rice and corn. These studies also added that climate change creates vulnerability in food trade networks (Salem *et al.*, 2025). The fertilizer industry has been affected by cartels that manage production to correspond with demand, maintaining market prices far above marginal production costs (Gutiérrez-Moya *et al.*, 2023). This oligopolistic framework arises from the concentration of production within a restricted number of nations and firms (Bai *et al.*, 2022).

Recently, Li *et al.* (2023) underscored the importance of sustaining stability in fertilizer trade systems for ecosystem equilibrium and comprehensive food security. In response, the European Union enacted a law in 2019 to standardize safety, quality and labeling requirements for fertilizers, establish pollutant limits and foster circular economies (Nicastro *et al.*, 2024). The global availability of fertilizers is essential for food production in diverse economies (Penuelas *et al.*, 2023). However, a disruption in supply may result in considerable food shortages, with grain output potentially decreasing by as much as 50% (Li *et al.*, 2023). Gutiérrez-Moya *et al.* (2023) reported that from 2017 to 2022, global demand for fertilizers composing nitrogen, phosphorus and potassium increased by 6.23%, 8.73% and 10.68%, respectively. Moreover, China represents 20% of the global population yet, possessing merely 10% of the world's arable land (Xu *et al.*, 2024), has a significant interest in obtaining fertilizers at reasonable rates (Gutiérrez-Moya *et al.*, 2023).

In addition, Li *et al.* (2023) performed a sophisticated network analysis of global trade, including three principal phosphorus-based commodities: phosphate rock, phosphorus fertilizers and phosphoric acid. They used node centrality indices to analyze trade network dynamics and determine the elements affecting structural changes over time. BIMSTEC is vital in increasing business activities and gross domestic product growth among member nations (Ojha, 2022). As a member nation, India holds the first position as the largest populated nation worldwide (Chaudhary and Paudel, 2024).

The above discussion of previous literature reflects that trade networks are crucial in establishing demand-supply balances and fostering economic development through solid collaboration among nodes. Furthermore, different literature echoes the potential of BIMSTEC as an emerging trade bloc that can ensure an enhanced trade network for economic development among member nations. Hence, this paper finds its objective with relevant gaps in this field to analyze the significance of fertilizer trade networks, as fertilizers are one of the prime products among these member nations.

3. Methods

Data was extracted from the OEC database (Accessed from: https://oec.world/) at the country level during 2005–2022. This paper has taken the fertilizer commodity [HS Code: 31 (Harmonized System 1992 for 2-digit)] of BIMSTEC because fertilizer is one of the leading agricultural items of BIMSTEC member countries. Accordingly, our analysis framework was decided and presented in Figure 1. Competitiveness is fundamental to achieving success in domestic and international markets (Shoukat *et al.*, 2024). The concept of comparative advantage arises from the involvement of numerous countries in global trade, even in the

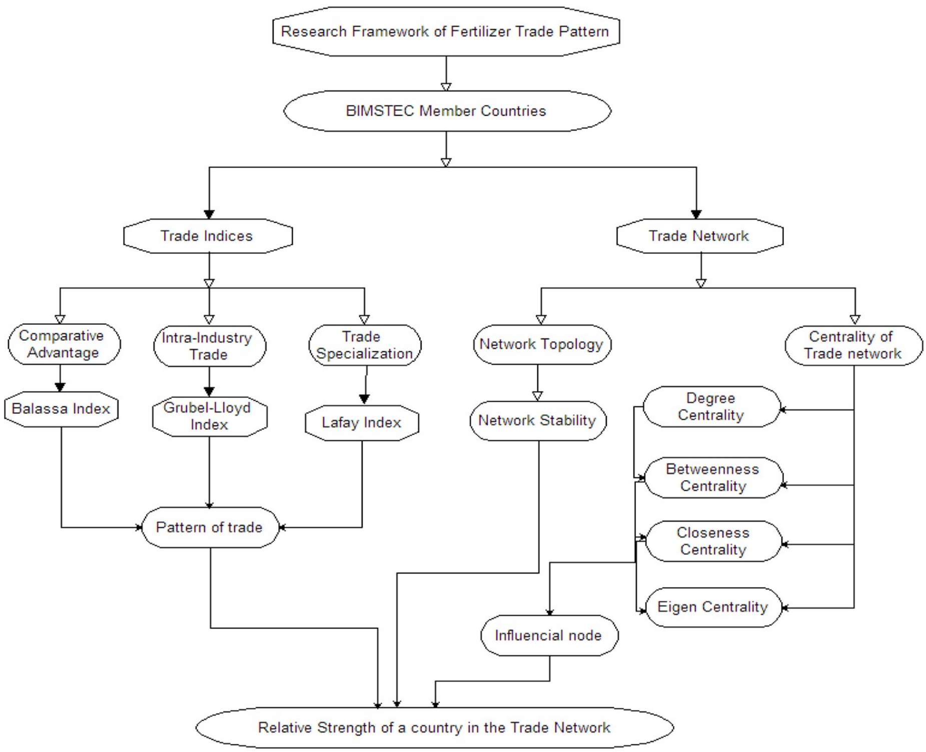


Figure 1. Conceptual framework
Source: Prepared by authors

absence of an absolute production advantage (Akram *et al.*, 2024). Comparative advantage does not inherently indicate the presence of competitive advantage simultaneously (Lugo-Arias *et al.*, 2024).

The concept of competitiveness has transitioned from an emphasis on price competitiveness (Tonelli *et al.*, 2024), which entails the examination of price, production costs and exchange rates, to a more comprehensive perspective that incorporates non-price factors (Lugo-Arias *et al.*, 2024). Because of the difficulty of quantifying these factors, we have opted to concentrate on comparative advantage indices. Adigwe (2022) noted that the RCA index fails to identify the fundamental sources of countries' comparative advantage in international trade. Adigwe (2022) identified a significant concern regarding the RCA index: the considerable disparities in country sizes.

When each nation's exports of a specific product make up a significant share of its overall exports yet account for only a minor percentage of global exports, the RCA index will produce disproportionately elevated values. Despite its limitations, Balassa's RCA index is widely used for assessing international trade specialization and comparative advantage, because of its straightforward construction and the clarity of its results (Xue *et al.*, 2024). LFI has limitations, including its failure to elucidate the reasons for nations' comparative advantages or disadvantages in trade. LFI, as a relative measure, necessitates careful interpretation (Masalegooyan *et al.*, 2022).

A simplified assumption posits that trade surpluses in specific product categories. As such, this paper applied BLI and LFI and analyzed intra-industry trade. GLI was used to investigate fertilizer trade patterns among BIMSTEC member nations. RCA and intra-industry trade methods were assessed for comparative advantages of fertilizers among BIMSTEC member nations. Initially, RCA was purified by Balassa (1965). The RCA index was widely recognized and used to gauge specialization in international trade (Adigwe, 2022). The RCA index is used to ascertain the relative strengths or weaknesses of export industries in different nations, as follows:

$$BI_{ij} = \left[\left(\frac{X_{ij}}{X_i} \right) \Big/ \left(\frac{X_{wj}}{X_w} \right) \right]$$

In mathematical terms, BI_{ij} it refers to BLI "j" in nation "I." X_{ij} represents export values; X_i represents the overall export value; X_{wj} represents the total world export value of sector "j"; and X_w represents worldwide export values. If index scores are one or higher, then nations will have competitive advantages in that industry; the proportion of that sector's exports is greater than that of global trade. If index scores are below 1, then the sector does not possess comparative advantage. LFI considers exports and imports, enabling control of intra-industry trades and re-exports flows as follows:

$$LFI_j = 100 \left\{ \frac{x_j - m_j}{x_j + m_j} - \frac{\sum_{j=1}^{N} (x_j - m_j)}{\sum_{j=1}^{N} (x_j + m_j)} \right\} \frac{x_j + m_j}{\sum_{j=1}^{N} (x_j + m_j)}$$

where x_j = a specific product exports and m_j = imports of a specific product.

In this view, Lafay indices are symmetrical across all products in nations, and for any given country, all sectors' indices must equal 0. Thus, products' normalized trade balance departure from the nation's overall trade balance, and its proportion of trade is related to this product specialization index in each country. If LFI is positive, then this sector is highly specialized; trade balances are positively affected. According to Ambroziak and Stefaniak (2022), harmful levels suggest reliance on imports. GLI measures intra-industry trade in any industry or national economy. This indicator calculates an industry's trade volume by combining exports and imports. The absolute difference between exports and imports for particular industries is employed to compute net exports. Thus, GLI is defined formally as:

$$GL_i = \frac{(X_i + M_i) - |X_i - M_i|}{(X_i + M_i)} = 1 - \frac{|X_i - M_i|}{X_i + M_i} = 1 - B_j;\ for\ all\ i = 1,\ 2,\ \ldots,\ n;$$

where X_i is an export product of I, and M_i is it an imported product of I.

The index values range from 0 to 1, with a value of 0 indicating only intra-industry trade and a value of 1 indicating exclusively intra-industry trade. GLI quantifies the proportion of intra-industry trade within a specific sector or the entire economy. Different nations are represented as nodes; export and import relations between these nations are calculated as normalized values of exports and imports. Further, this paper used Louvain community detection algorithms to prepare the cluster of nations from trade networks and extracted the community structures of said trade networks. Normalized export and import percentages of member nations to different source regions are treated as network weights. The relative thickness of each edge in export and import networks signifies source nations' dependencies on destination regions. Based on the three well-known indices found during 2005–2022, this paper has attempted to run a one-way ANOVA as follows:

$$x_{ij} = \mu + \alpha_i + \varepsilon_{ij},\ \text{Where}\ \varepsilon_{ij} \sim \mathrm{N}\left(o,\ \sigma_\varepsilon^2\right)$$

We first run the one-way ANOVA model to determine whether there are any statistically significant differences between the different trades indices used. However, before applying the result of one-way ANOVA, it is always necessary to check the two restrictive assumptions under which one-way ANOVA is performed. Accordingly, the Shapiro–Wilk and Bartlett's tests of homogeneity of variances, respectively, will be applied. Hence, this assumption is satisfied one-way ANOVA will be replaced by the Kruskal–Wallis with Dunn test for posthoc pairwise comparison. Moreover, when both assumptions are not pleased, Welch's one-way ANOVA with Games–Howell post hoc estimation will be appropriate to make the result robust.

Different countries are represented as export and import relations between these countries are described as edges, and the weights of each edge are calculated as the normalized value of exports and imports. Further, this paper used the Louvain Community Detection Algorithm to prepare the cluster of countries from trade networks and extracted the community structure of the said trade network (Alves *et al.*, 2024). Normalized export and import percentages of member countries to different source regions are treated as network weights. The relative thickness of each edge in export and import networks signifies the dependencies of source countries to destination regions.

Edge denotes the connections or links among entities (e.g. countries, regions or economic groups) that enable the flow of goods, services, capital and information. Edges may be categorized as physical (e.g. transportation routes) or economic (e.g. trade agreements). Edge density, the most popular metric for describing networks, shows how closely connected the vertex interactions are by comparing the absolute number of edges to the theoretical maximum number of edges. Generally, denser networks have more edges and higher densities, whereas sparser networks have fewer edges and lower densities. Network densities are determined using the following formula:

$$D = \frac{2E}{N(N-1)}$$

where N is the total number of vertices in networks; and E is the number of edges connected to the vertices through connection points.

Greater edge densities indicate highly integrated commerce networks in which countries interact with numerous others. The network diameter (Dia) is the most significant distance between two nodes/countries. Yuvaraj *et al.* (2021) examined trade networks' multilayered structure and topological features, including network diameter. Trade networks can have small diameters, showing that trade links shrink over time despite their complexity, enabling speedier global market exchanges (Wang *et al.*, 2023).

$$Dia = max_{ij} d_{ij}$$

Here, d_{ij} is the shortest path (i, j), and the maximum is derived from the entirety of potential pairs of nodes within networks.

The average path length denotes the mean of all conceivable shortest routes connecting each pair of nodes within networks, often termed the geodesic distance. To illustrate the efficacy of international trade, researchers can look at networks' average path length (L), which is the mean of all the shortest distances. The formula for calculating the average shortest path length L is specified as follows:

$$L = \frac{2}{N(N-1)} \sum_{j \leq i}^{N} d_{ij}$$

N is the total number of nodes (countries or regional trade blocs); and d_{ij} is the shortest path (i, j).

The global clustering coefficient of networks is defined as the ratio of the number of triangles to the number of triplets inside networks. The formula for calculating the average shortest path length L is specified as follows:

$$C_{Global} = \frac{\text{Number of triangles}}{\text{Number of triplets}}$$

Triangle: It is a configuration of three nodes that are interconnected with one another.

Triplet: It is a collection of three nodes with a minimum of two interconnected, while the third node may or may not be linked to others.

There is a high probability of reciprocal trade agreements when the global clustering coefficient is high, as it shows that nations in trade networks have interconnected trading links. The clustering coefficient quantifies the degree of proximity between two countries connected to the same country within trade networks. The mean clustering coefficient is defined as follows:

$$C_{avg} = \frac{1}{N} \sum_{i=1}^{N} CC_i$$

Here, N is the total number of nodes in trade networks.

A high ACC in trade networks indicates that countries will likely establish closely connected clusters, increasing trade frequency among proximate entities. Modularity (Q) quantifies the extent to which communities within networks are divided and allows for comparison between these communities and the entire network. Trade network modularity is key to understanding global trade dynamics.

$$Q = \frac{1}{2m}\sum_{ij}\left(A_{ij} - \frac{k_i k_j}{2m}\right)\delta(C_{i,} C_j)$$

The measure of community unity ($\delta(C_i, C_j)$) is used for nodes i and j. If nodes i and j are in the same community, then $\delta(C_i, C_j) = 1$. Otherwise, $\delta = 0$. A_{ij} is any adjacency matrix element. $A_{ij} = 1$ if node i is connected to node j; 0 otherwise. m is the total number of edges, and ki, kjis node i and j's degrees. Q is 0–1, and a more significant number indicates network clustering. Communities are defined as clusters of nodes, including countries, regions or companies, that exhibit stronger connections among themselves compared to nodes in different clusters. Trade network communities consist of countries or entities that maintain robust trade relationships among themselves (Wang and Dai, 2021). Betweenness centrality quantifies the extent to which nodes are situated on the shortest path connecting other nodes in network theory. Betweenness centrality, within trade networks, quantifies countries' significance in enabling trade between further nations (Wang *et al.*, 2022). Betweenness centrality measures the intermediary of countries in networks, and it is calculated by the following equation:

$$C_B(i) = \sum_{\substack{1 \le j \le k \le N \\ s \ne j \ne k}} \frac{n_{jk}(i)}{n_{jk}}$$

Here, n_{jk} = The number of shortest or quickest paths to get from node j to node k.

n_{jk} (i) = The number of shortest paths connecting nodes j and k via node i.

Betweenness centrality quantifies the degree to which nodes are situated on the shortest paths connecting other nodes. Closeness centrality is a metric quantifying the distance between a given node and all other nodes. It stands for the convenience and ease of connections between the focused node and the other nodes. The fundamental formula Cc is an equation:

$$C_C(N_i) = \frac{1}{\left[\sum_{j=a}^{n} d(Ni, Nj)\right]}(i \ne j)$$

Here, C_C (N_i) = Closeness centrality of node N.

$d(N_i, N_j)$ = shortest distance between node N_i and Nj.

Closeness centrality identifies the most influential countries within trade blocs. Closeness centrality reflects the degree of integration among countries within trade blocs. High centrality may signify countries' robust integration with other members and its pivotal role in blocs' economic cooperation. Eigenvector centrality is a measure used to assess the significance of nodes within networks by considering its connections to other influential nodes. This measure is relevant in evaluating nodes' position with international trade realms (Wang *et al.*, 2022). In many cases, the importance of nodes in networks is increased by connecting with other vital nodes and calculated by the following equation:

$$E_i = \lambda^{-1}\sum_{j=1}^{N} A_{ij} e_j$$

Here, E_i = It is eigenvector centrality of node i.

A_{ij} = This represents the elements of adjacency matrix A, representing the trade relationship between node i and j. If there is no relationship between two nodes, then $A_{ij} = 0$.

e_j = It is eigenvector centrality of node j.
λ = It is largest eigenvalue of the adjacency matrix A.

Eigenvector centrality identifies the most significant trade hubs or countries within networks. Degree centrality is used to analyze the degree of monopoly in the export market and the degree of competition in the import market of the international gas trade network (Wang *et al.*, 2022). One measure of nodes' importance is the degree, which is the sum of all the nations or areas with which it has direct trade relationships. The weighted degree represents the total trading volume between node i and all other nodes (Csum,i). Numbers received and delivered by node i in the directed network, denoted as out-degree (Cout,i) and in-degree (Cin,i). The fundamental formula $C_{sum,i}$ is equation, as follows:

$$C_{sum,\,i} = C_{out,\,i} + C_{in,\,i}$$

4. Results and discussions

This paper analyzes the specialization of fertilizer trades at the BIMSTEC level. The following two panels show trade networks of fertilizer products among BIMSTEC member nations with other world nations (Figures 2 and 3). Nodes' magnitude corresponds to their impact on trade networks. The spatial location of nodes inside networks corresponds to its spatial location within networks. These networks indicate that the closer one is to its center, the greater their status is. Our findings demonstrated that fertilizer trade network diagrams for exports exhibit noticeable trends of sparseness compared to previous diagrams. Hence, this suggests a drop in network density and a decline in trade connections between nations.

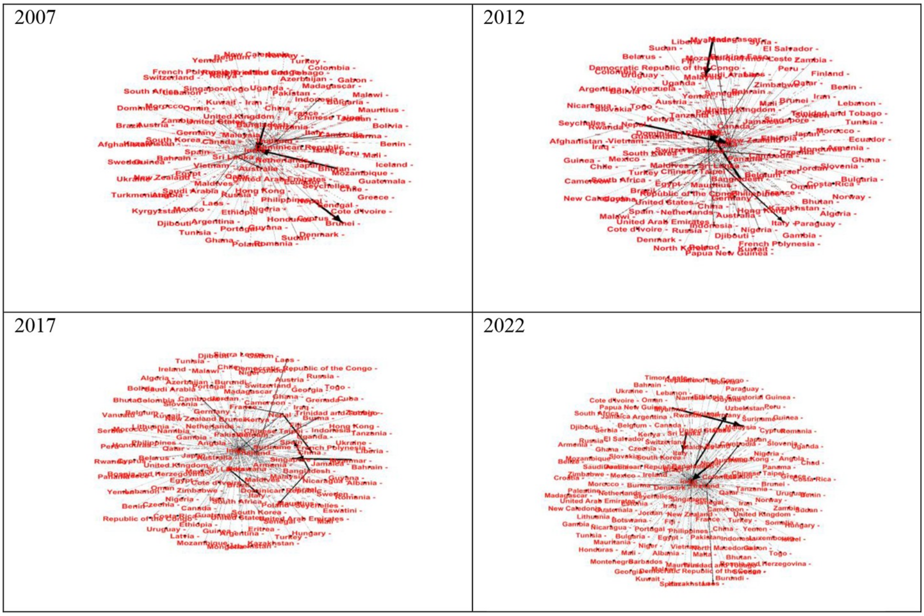


Figure 2. Topological diagram of fertilizer export trade networks
Source: Prepared by authors from the OEC database

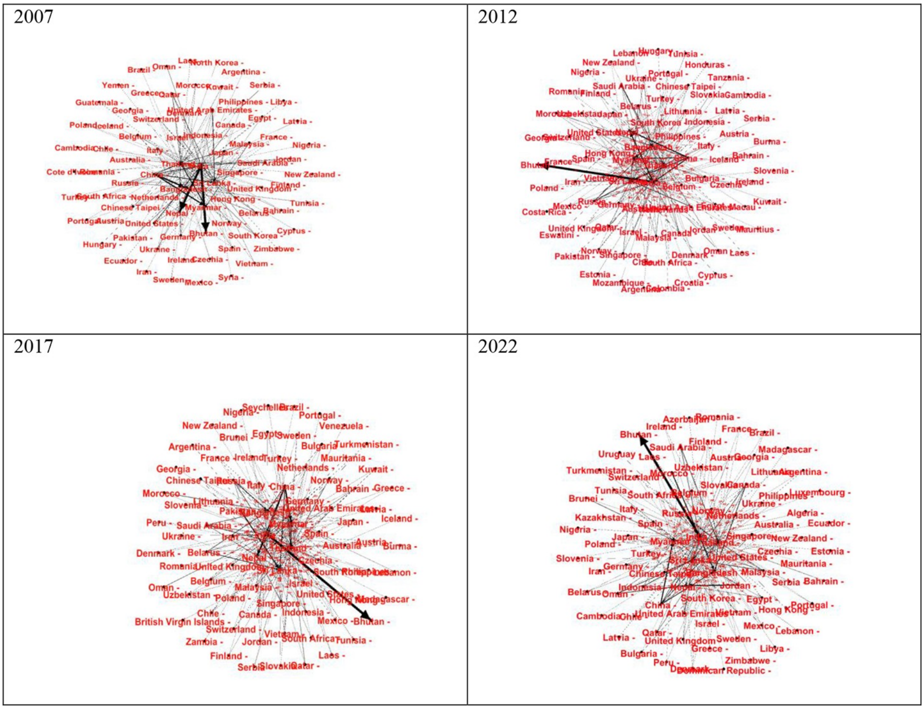


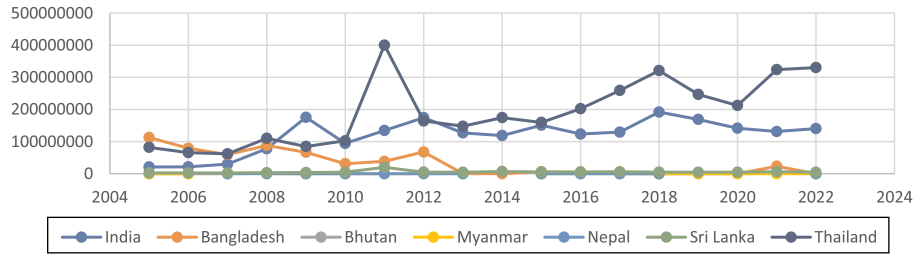
Figure 3. Topological diagram of fertilizer import trade networks
Source: Prepared by authors from the OEC database

However, India has consistently held central positions in networks depicted; its edge density is the utmost among BIMSTEC member nations of fertilizer export and import networks. Hence, they exert the most significant influence on the BIMSTEC-level fertilizer trade network and possess higher sway (Figures 2 and 3).

According to Figure 4, India consistently ranked first in fertilizer trade among BIMSTEC member nations during 2005–2022. India witnessed substantial yearly growth in fertilizer exports during 2005–2009. However, this pattern was reversed in 2010. The export level peaked in 2018 and has gradually decreased since then. Although there were occasional variations, the export levels in the following years were relatively consistent. Thailand's exports exhibited linear trajectories, reaching their highest point in 2022. Sri Lanka achieved its peak export levels in the early stages. Sri Lanka and Thailand are formidable rivals among fertilizer exports within BIMSTEC member nations. However, India remains the top importer of fertilizers among BIMSTEC member nations.

In 2022, India will have the most significant import volume. Findings revealed a progressive import rise during 2005–2008, followed by a sharp decrease in the subsequent year. India's import levels reached their lowest point in 2005 and their maximum in 2022. Thailand has become the second-largest importer of fertilizers among BIMSTEC member nations. In 2022, Thailand imported more fertilizers than in previous years. In 2022, Nepal and Sri Lanka had a similar level of imports. The peak of Bangladesh's imports is projected to occur in 2022. Findings revealed a progressive import rise from 2006 to 2008, followed by

Panel A. Fertilizer exports (USD) at BIMSTEC level



Panel B. Fertilizer imports (USD) at BIMSTEC level

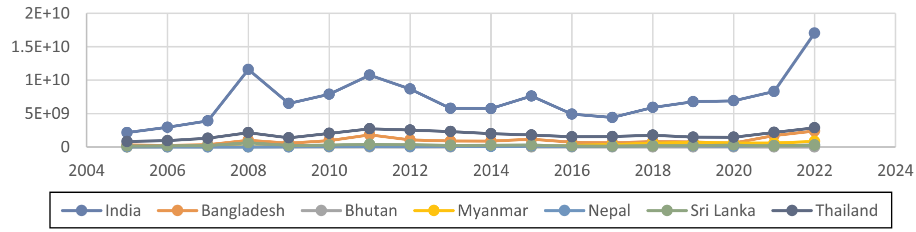


Figure 4. Fertilizer trade (exports and imports) patterns at BIMSTEC level during 2005–2022
Source: Prepared by authors from the OEC database

a sharp fall in the subsequent year. Between 2015 and 2020, there were minor fluctuations in its import levels, but there was a subsequent increase in imports during the latter two years (see Figure 4 and Supplements A and B).

From the above panel, India and Thailand, among BIMSTEC member nations, were the significant exporters. Moreover, when export trends for other member nations are almost close to zero or decreasing (i.e. Myanmar), India and Thailand continue to enjoy an increase in the export market. Findings observed that the growth rate of imports was nearly constant except for India. According to economic integration theory, FTAs can offer additional advantages to participating nations. Provisions include economic scale enhancement, increased market competition provisions and goods specialization in which comparative advantages are detected.

4.1 Relative competitive advantage analysis at BIMSTEC level

BLI trends (Figure 5 and Supplements C–E) proved that Bangladesh achieved mean RCA scores of 0.51219256 during 2005–2022. Considering Figure 5, it is reasonable to consider Bangladesh to possess a significant competitive advantage in the fertilizer trade. This paper further observed that the variation coefficient of the RCA index is the lowest for Thailand, followed by India. In contrast, other BIMSTEC member nations faced a relatively high coefficient of variation in RCA indices. By comparing the RCA index scores of India and Thailand on fertilizer trade, these two nations were more competitive than other BIMSTEC member nations. Regarding RCA index scores computation, nations' ability to become more competitive is influenced by large shares of fertilizer exports in overall exports.

4.2 Trade specialization of fertilizers analysis at BIMSTEC level

Theoretically, LFI lies between $-\infty$ and $+\infty$, and the negative value of such an index implies that respective nations hardly enjoy any trade specialization. LFI scores among

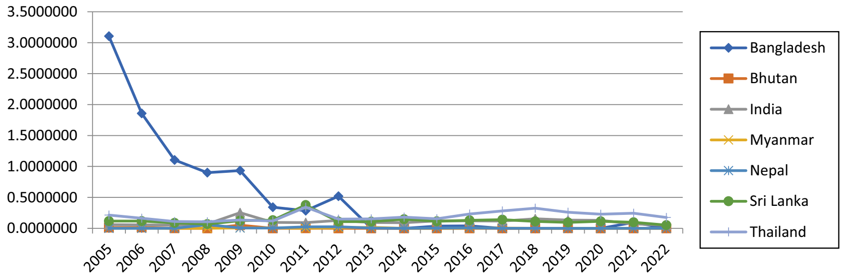


Figure 5. Relative competitive advantage index scores among BIMSTEC member nations
Source: Prepared by authors from the OEC database

BIMSTEC member nations are presented in Figure 6. Findings transpired that LFI never reached a positive level for any BIMSTEC member nations. LFI score variations were high for Bangladesh, Myanmar and Sri Lanka, whereas they were relatively low for Thailand. The possible reason behind such variations is mainly because of the increase in fertilizer imports by all BIMSTEC member nations, as they failed to meet fertilizers' domestic demands through productive capacity enhancement in their respective countries.

4.3 Intra-industry trade of fertilizers analysis at BIMSTEC level
Intra-industry trade patterns at the BIMSTEC level have been conducted using GLI. Accordingly, GLI lies between 0 and 1 (Figure 7). These figures show that initially, Bangladesh started with GLI index score of more than 0.5. However, it gradually decreased within 2010, reaching close to 0, whereas only Thailand experienced an increasing trend of GLI scores.

4.4 One-way welch ANOVA results of fertilizer trade at BIMSTEC level
Table 3 findings confirmed that results are significant for all these indices, and it is concluded that statistically significant differences exist between all three indices mentioned above at the national level during 2005–2022. Accordingly, post-hoc Games–Howel estimations at the national level are performed. Table 4 findings found that they are statistically significant for all three indices. Hence, it is concluded that there exists a statistically significant difference between all three indices mentioned above at the national level during 2005–2022.

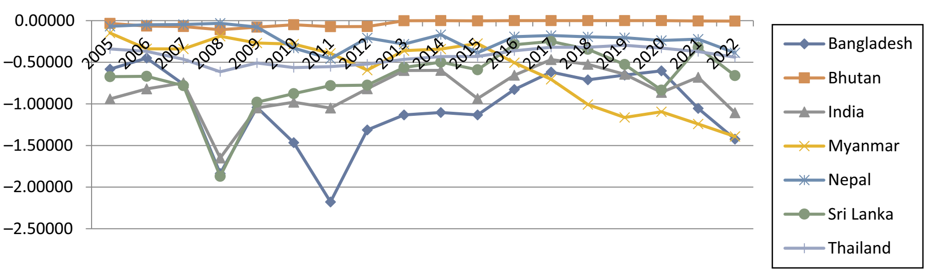


Figure 6. Lafay index scores among BIMSTEC member nations
Source: Prepared by authors from the OEC database

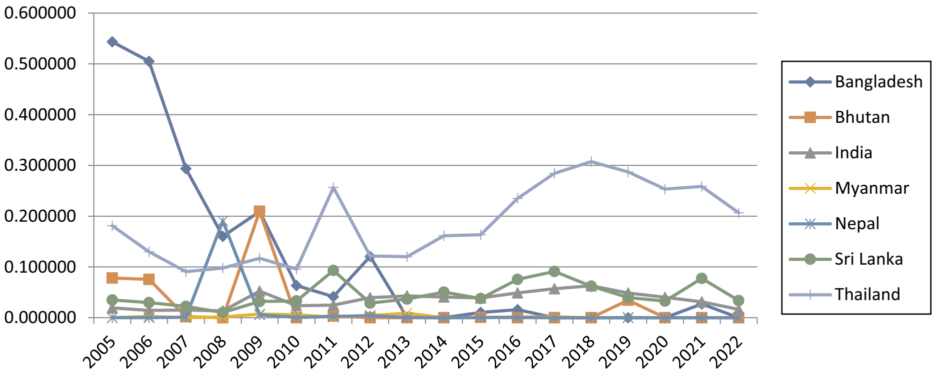


Figure 7. Grubel–Lloyd Index scores among BIMSTEC member nations
Source: Prepared by authors from the OEC database

Accordingly, the post-hoc Games–Howel estimation at the national level is performed. Table 4 found that of 21 central pairs of nations for all three indices, there are 11, 14 and 7 statistically significant differences compared to BLI, GLI and LFI indexes, respectively. Moreover, findings also found that seven unique pairs exist only for LFI and not for the other two indices. Four unique pairs of differences exist for BLI and LFI indices but not for GLI and four other unique pairs where statistically significant differences exist for BLI and GLI indices but not for LFI. Finally, only three pairs of statistically significant cells are found where all three indices are present.

4.5 Topological properties of trade networks

The basic topological properties of trade networks for each year are shown in Table 1. For fertilizer trade among BIMSTEC member nations, there were 107 export nations with 172 trade interactions in 2007, which grew to 148 export nations with 220 interactions in 2022. On the contrary, there were 79 importers with 194 trade interactions in 2007, which grew gradually to 87 importers with 252 interactions in 2022. In contrast, in the case of import, the number of nodes was lower than the number of export nodes. However, in the case of edges, the import edges are higher than the export edges, as BIMSTEC member nations have a higher dependence on importation because of their higher population and consumption. However, these nations from which BIMSTEC member nations used imports were lower and selective, for which the number of import nodes was lower.

Based on the graphs, fertilizer networks among BIMSTEC member nations are highly sparse. From 2007 to 2022, network densities fell from 3.03% to 2.02% for exports but increased from 6.29% to 6.73% for imports. Hence, the number of nations participating in these networks is significant; nevertheless, trade exchanges between these nations are minimal. These networks' density indicated that trade networks for fertilizers are minimal, accounting for less than 10% of the total conceivable trade contacts. Average clustering coefficients (Table 5) provided information about interconnection degrees between different groupings of nations. Hence, this ranges from 0.89 to 0.93 for exports and around 0.77–0.86 for imports. Average clustering coefficient values indicate that BIMSTEC member nations are highly connected in fertilizer exports and imports in global markets. Looking toward the average path length indicates convenience or complexity in connecting nodes.

Table 3. Summary of welch ANOVA findings on trade indices' parameters among BIMSTEC member nations during 2005–2022

Number	Trade indices	Statistic	Bangladesh	Bhutan	India	Myanmar	Nepal	Sri Lanka	Thailand	F-statistic	Prob (F-statistic)
1	Balassa	*Mean*	0.512	0.004	0.104	0.003	0.008	0.124	0.199	(41.86,6,33.55)	0.000
		N	18	18	18	18	18	18	18		
4	Lafay	*Mean*	−1.05	−0.03	−0.84	−0.59	−0.20	−0.68	−0.42	(85.07,6,48.46)	0.000
		N	18	17	18	18	18	18	18		
5	Grubel-Lloyd	*Mean*	0.111	0.024	0.035	0.002	0.011	0.046	0.187	(37.89,6,32.88)	0.000
		N	18	17	18	16	12	18	18		

Source(s): Prepared by author

Table 4. Summary of Games–Howell post-hoc estimation related to trade indices among BIMSTEC member nations during 2005–2022

Nations	Bhutan	India	Myanmar	Nepal	Sri Lanka	Thailand
Bangladesh	L		L	L		L
Bhutan		B, L	L	L	B, L	B, L, G
India			B, G	B,L		B, L, G
Myanmar				L	B, G	B, G
Nepal					B, L	B, L, G
Sri Lanka						B, G

Source(s): Prepared by authors from the OEC database

Table 5 findings proved that BIMSTEC member nations have gradually shortened the average path length in fertilizer importations. In 2012, the average path length for fertilizer exports increased significantly (2.089 in 2012), but it has been shortened by member nations (2.01 in 2022). BIMSTEC member nations have been increasing their effectiveness in global fertilizer trade networks by shortening the average path length between nodes. Moving toward modularity, Table 5 shows a consistent positive score over decades that indicate strong connections among BIMSTEC member nations' communities in these networks. Notably, connection tightness is increasing steadily in fertilizer exports by nations. The number of communities in networks shows that BIMSTEC member nations have established their communities over the period. Finally, BIMSTEC member nations maintain a balance diameter ranging from 3 to 4, indicating balanced tightness, closeness and connections in trade networks.

4.6 Trade network centrality analysis

Betweenness centrality measures how efficiently nodes act as a bridge among other nodes in trade networks. In numbers, the higher the score, the more the nations or nodes effectively connect to other nodes in these networks. Table 6 findings dictated BIMSTEC member nations' betweenness from 2007 to 2022, within five years. Sri Lanka's role had a score of 0.056 in exports, which improved in 2012 and 2017. Regarding fertilizer imports, Sri Lanka had 0.19 in 2007, surprisingly moving to 0.6227, meaning a vital role as an intermediary (Table 6). Bangladesh has a consistent

Table 5. Fertilizer trade network statistics

	2007		2012		2017		2022	
Items	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports
Nodes	107	79	124	86	137	84	148	87
Edges	172	194	202	247	214	244	220	252
Density	0.0303	0.0629	0.0264	0.0675	0.0229	0.0699	0.0202	0.0673
Global clustering coefficient	0.0395	0.1230	0.0337	0.1304	0.0262	0.1180	0.0202	0.1109
Average clustering coefficient	0.9305	0.8443	0.9280	0.8641	0.9129	0.7932	0.8989	0.7767
Average path length	1.651	2.0899	2.086	2.0552	2.030	2.04819	2.013	1.99411
Modularity	0.5965	0.3847	0.6434	0.2971	0.7196	0.3433	0.7316	0.3250
Number of communities	4	3	5	3	6	5	5	5
Network diameter	3	3	4	4	3	4	4	3

Source(s): Prepared by authors from the OEC database

Table 6. Fertilizer trade network betweenness centrality from 2007 to 2022

	2007		2012		2017		2022	
Nation	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports
Bangladesh	0.0376	0.3826	0.0163	0.3619	0	0.1681	0.0136	0.2613
Bhutan	0	0	–	0	–	0	–	0
India	0.8363	0.6976	0.8299	0.7395	0.8499	0.747	0.9223	0.8981
Myanmar	–	0	0	0.1148	0.0147	0.3644	0	0.157
Nepal	0	0.0256	0.0163	0.0924	0	0.0946	0	0.4022
Sri Lanka	0.0561	0.1958	0.1265	0.6227	0.1284	0.2233	0.0405	0.1354
Thailand	0.611	0.4745	0.5436	0.3619	0.605	0.4614	0.4616	0.3007

Source(s): Prepared by authors from the OEC database

downward shift in exports (0.037–0.013), whereas it has an outperforming score in acting as a bridge in terms of fertilizer imports in 2007. Thailand is in better shape than Bangladesh and Sri Lanka in exports and imports. Although betweenness scores have average values (0.55) in fertilizer exports and (0.40) in fertilizer imports over time, Thailand's role as a bridge has decreased in exports (0.611–0.4616) and imports (0.4745–0.3007).

Highlighting the most critical intermediary with consistent betweenness scores over the decades, India scored 0.83 for exports and 0.69 for imports in 2007. Consistently, it maintained its role as an essential intermediary and improved even more in cases by scoring 0.92 in export and 0.89 in import. In the case of Nepal and Myanmar, there needs to be more clarity regarding acting as an intermediary in networks. Myanmar, in 2012, started its journey as a bridge in fertilizer importation, scoring 0.11; it improved its role (0.36) in 2017. Similarly, Nepal was a notable export intermediary in 2007, 2012 and 2017.

Closeness centrality describes how strongly nodes are connected with their immediate neighboring nodes. Hence, the greater the closeness centrality, the more strongly nodes are linked with their neighbors. Table 7 shows closeness centrality scores among BIMSTEC member nations in terms of fertilizer trade from 2007 to 2022. Except for Bhutan, the remaining nations show similar patterns of closeness and centrality. These nations used a good range of scores in fertilizer trade in 2007 (ranging from 2.4 to 2.5), which has shifted downward to 0.72 on average for all nations except Bhutan (Table 7).

Table 7. Fertilizer trade network closeness centrality from 2007 to 2022

	2007		2012		2017		2022	
Nation	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports
Bangladesh	1.6507	2.516	0.9556	0.7685	1.1373	0.6993	1.689	0.7246
Bhutan	0.3559	2.5159	–	0.0117	–	0.012	–	0.0116
India	1.6693	2.516	1.0191	0.7686	1.8415	0.7012	2.2531	0.7248
Myanmar	–	2.4116	0.0656	0.7685	1.8131	0.7011	0.5764	0.7247
Nepal	1.5051	2.4863	0.8862	0.7685	1.8027	0.6993	2.1231	0.7248
Sri Lanka	1.5641	2.5138	1.0143	0.7685	1.8236	0.7004	2.2352	0.7248
Thailand	1.656	2.516	1.0188	0.7685	1.8411	0.7012	2.2524	0.7247

Source(s): Prepared by authors from the OEC database

The eigenvector is the measure that indicates the importance of nodes in trade networks and shows what proportion it holds to establish their significance and power in these networks. Table 8 findings proved those BIMSTEC member nations' eigenvector scores from 2007 to 2022, where India has maintained its dominance, scoring one over decades in fertilizer imports and exports. This score indicates that India is the most significant node in BIMSTEC networks in terms of fertilizer trade with other nations (Table 8). In short, India holds the leading power and role in this trade network. However, Bangladesh, Sri Lanka and Thailand are seen to maintain a balance of power in trade networks, effectively increasing trade facilitation and economic growth in fertilizer trade.

Nodes' degree represents the number of trade partners a specific nation has. Nations with high connectivity will likely play a significant role in these networks, as they can influence more trade exchanges. Table 9 findings proved the degree of centrality among BIMSTEC member nations from 2007 to 2022, where India had the highest number of trade partners from 2007 to 2022 compared with other BIMSTEC member nations. Table 9 proved that there has been a consistent score of 2 and above over the decades regarding fertilizer exports and imports.

In the BIMSTEC trade bloc regarding fertilizer trades, India has efficiently maintained its strong position over time. Besides, other nations in the BIMSTEC trade bloc have good scores in degree centrality (e.g. Bangladesh, Thailand, Sri Lanka and Nepal). Bhutan also has a higher degree of centrality in terms of fertilizer exports. Overall strategies implied that BIMSTEC member nations are highly interconnected with each other in terms of fertilizer trade to facilitate trading in the long run (Table 9).

Table 8. Fertilizer trade network eigenvector centrality from 2007 to 2022

	2007		2012		2017		2022	
Nation	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports
Bangladesh	0.6731	0.1292	0.3945	0.189	0.0001	0.1615	0.0176	0.1223
Bhutan	0.7247	0.6982	–	0.7682	–	0.8457	–	0.9276
India	1	1	1	1	0.0039	1	1	1
Myanmar	–	0.1079	0.3328	0.2939	1	0.2934	0.0738	0.1159
Nepal	0.1091	0.6614	0.9138	0.5489	0.0065	0.437	0.988	0.2297
Sri Lanka	0.0385	0.0639	0.0282	0.1488	0.001	0.1843	0.0719	0.1043
Thailand	0.0131	0.0779	0.1051	0.1178	0.0006	0.1998	0.0161	0.1043

Source(s): Prepared by authors from the OEC database

Table 9. Fertilizer trade network degree centrality from 2007 to 2022

	2007		2012		2017		2022	
Nation	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports
Bangladesh	1.0676	1.0135	1.0174	1.3039	1.0189	1	1.0154	1
Bhutan	1.0211	1	–	1	–	1	–	1
India	2.8722	2.9521	2.0796	2.6216	1.0002	2.3248	2.0081	2.1528
Myanmar	–	1	1	1	1	1	1	1
Nepal	1.0769	1	1.1485	1	1.2245	1	1.2896	1
Sri Lanka	1.0319	1	1.0119	1	1.0238	1	1.0308	1
Thailand	1.0044	1.3497	1.0048	1.1535	1.0029	1.2248	1.0047	1.0949

Source(s): Prepared by authors from the OEC database

5. Conclusion

Our findings examined fertilizer trade networks among BIMSTEC member nations' usual features during 2005–2022. Economic network research methods found significant changes during the periods. Disruptions in trade partnerships led to a decline in overall commerce and a shift in trade connections (Ji *et al.*, 2024). Similar shifts have been observed in other economic areas, and financial network analysis tools have proven effective (Naeem *et al.*, 2024). Findings confirmed that Thailand and India have the most diversified fertilizer trade markets, whereas Nepal and Bhutan have high centrality to a few source regions.

This paper concluded that there is significant scope for diversifying the export market to avoid region-specific disturbances in international business. We used economic network analysis to examine topological characteristics among BIMSTEC member nations by creating weighted and directed networks. Findings indicated that trade ties among BIMSTEC member nations are becoming more robust because of the emergence of small-world phenomena. Findings also revealed that the close geographical and cultural linkages between BIMSTEC member nations substantially impacted their trade networks. Results validate the significance and immediacy of addressing the lack of infrastructure and enhancing interpersonal interactions (Ji *et al.*, 2024).

This paper also revealed that BIMSTEC has yet to fully contribute to promoting regional trade integration. The complex "spaghetti bowl" issues in BIMSTEC result in member nations navigating through numerous and diverse norms and regulations (Panke *et al.*, 2025). Hence, network analysis can capture evolutionary features and reveal predictive insights that many accounting methods cannot uncover (Ranta *et al.*, 2023). Finally, this paper is based on explanations of food fertilizer trade networks within BIMSTEC member nations during 2005–2022. However, this paper does not examine the processes or factors shaping networks' formation over time. Our analysis depicted the existing makeup and nature of trade networks, though short of how such networks arose or what dynamics caused their emergence. Therefore, future research should address a dynamic nature by focusing on how these networks evolve, providing insights into how they grow.

5.1 Practical and policy implications

This paper examines a controversial and little-investigated subject – the interaction of national resource security policies and food fertilizer trade regulations. This paper is unique in its emphasis on designing practical import–export policies customized to protect resource management national interests. This paper helps to bridge a significant knowledge gap by examining how worldwide market trends interact with domestic resource requirements to clarify policy structures needed for resource resilience. Incorporating environmental sustainability criteria and geopolitical threats in policy deliberations goes beyond standard economic evaluations. Similarly, this paper uses unique techniques that merge qualitative stakeholder feedback with quantitative trade data, giving a thorough approach seldom observed in this realm.

This paper highlights the overlooked part of agricultural policies, "the strategic function of food fertilizers in guaranteeing food security." This emphasis helps to show the existing paper as a significant addition to the increasing conversation on sustainable trade and resource management. Our visual network analysis offers a comprehensive tool for policymakers to enhance regional cooperation, optimize supply chains, align agricultural policies, promote environmental sustainability and ensure economic stability and growth. These insights can drive strategic decisions that benefit the farming sector and the region's economic development. Network analysis can reveal inconsistencies in fertilizer quality. Harmonizing regional quality standards can ensure that farmers receive consistent and reliable inputs. Stable and efficient fertilizer trade networks can enhance regional food security and political stability by ensuring that agricultural sectors in all member nations are well-supported.

Our policy implications can address nations' responsibilities in global networks, identifying bottlenecks and bridging nations that play crucial roles in governance. Higher network density indicates greater interconnection and trade diversity, potentially enhancing crisis stability. More prominent players with central positions may attract more trading partners, as seen in our 2005–2022 network analysis. COVID-19 resulted in minor trading communities' decline as actors joined larger groups, while the remaining communities consolidated around significant exporters. Shifts in structure because of COVID-19 may indicate the resilience of key participants and the tendency of less central actors to switch partners. Network backbones demonstrate shock transmission between regions. These network structures revealed whether nations create trade links based on cultural and political similarities, potential reactions to shocks or if alternative trade benefits are prioritized. Hence, this highlights the need for sustainability above growth and productivity in industry development, emphasizing added value and fair-trading circumstances.

5.2 Limitations and future research

Although this paper has emphasized fertilizer trade patterns among BIMSTEC member nations using a network-based approach, it is a static network-based approach analysis. Previously, Furusawa and Konishi (2007) and Goyal and Joshi (2006) studied trade network stabilities and evolutionary formation dynamics. They used game theory and economic frameworks and models. Thus, this paper does not explore these dynamics but recognizes the potential utility of these approaches for understanding trade network formation. As such, dynamic modeling frameworks may even incorporate other frameworks to offer causal explanations and predictive insights into how trade networks respond to future economic, geopolitical and infrastructural changes. Therefore, a significant avenue for improvement in future studies would be using dynamic networking models and longitudinal studies. This approach will witness which trade relations in the BIMSTEC and other regions develop, endure and alter.

References

Adigwe, E.O. (2022), "A comparative analysis of competitive trade in a cluster market of the European Union: the revealed comparative advantage (RCA) index", *Naše Gospodarstvo/Our Economy*, Vol. 68 No. 1, pp. 14-24.

Akram, H.W., Ahmad, A., Dana, L.P., Khan, A. and Akhtar, S. (2024), "Do trade agreements enhance bilateral trade? Focus on India and Sri Lanka", *Sustainability*, Vol. 16 No. 2, p. 582.

Alexander, P., Arneth, A., Henry, R., Maire, J., Rabin, S. and Rounsevell, M.D. (2023), "High energy and fertilizer prices are more damaging than food export curtailment from Ukraine and Russia for food prices, health and the environment", *Nature Food*, Vol. 4 No. 1, pp. 84-95.

Alves, H., Brito, P. and Campos, P. (2024), "Community detection in interval-weighted networks", *Data Mining and Knowledge Discovery*, Vol. 38 No. 2, pp. 653-698.

Ambroziak, A.A. and Stefaniak, J. (2022), "The position of China in trade in services within the European Union", *Oeconomia Copernicana*, Vol. 13 No. 2, pp. 335-354.

Bacsi, Z., Fekete-Farkas, M. and Ma'ruf, M.I. (2023), "A graph-based network analysis of global coffee trade—the impact of COVID-19 on trade relations in 2020", *Sustainability*, Vol. 15 No. 4, p. 3289.

Bai, X., Hu, X., Wang, C., Lim, M.K., Vilela, A.L., Ghadimi, P. and Xu, H. (2022), "Most influential countries in the international medical device trade: network-based analysis", *Physica A: Statistical Mechanics and Its Applications*, Vol. 604, p. 127889.

Balassa, B. (1965), "Trade liberalization and 'revealed' comparative advantage", *The Manchester School*, Vol. 33 No. 2, pp. 99-123.

Bas, T.G. (2025), "Globalization vs. globalization: learn lessons from two global crises, such as the Russia–Ukraine conflict and the COVID-19 pandemic, for the agro-food and agro-industrial sector", *Agriculture*, Vol. 15 No. 2, p. 155.

Bayssi, O., Nabil, N., Azaroual, M., Bousselamti, L., Boutammachte, N., Rachidi, S. and Barberis, S. (2024), "Green hydrogen landscape in North African countries: strengths, challenges, and future prospects", *International Journal of Hydrogen Energy*, Vol. 84, pp. 822-839.

Beltran-Peña, A., Rosa, L. and D'Odorico, P. (2020), "Global food self-sufficiency in the 21st century under sustainable intensification of agriculture", *Environmental Research Letters*, Vol. 15 No. 9, p. 095004.

Biernacka, J. (2021), "Analysis of intra-industry mutual trade in the furniture manufacturing industry between the V4 and the Eu-27 countries using the Grubel-Lloyd index", *Acta FacultatisXylologiaeZvolenres Publica Slovaca*, Vol. 63 No. 2, pp. 175-188.

Blondeel, M., Bradshaw, M.J., Bridge, G. and Kuzemko, C. (2021), "The geopolitics of energy system transformation: a review", *Geography Compass*, Vol. 15 No. 7, p. e12580.

Carrasco, C.A. and Tovar-García, E.D. (2021), "Trade and growth in developing countries: the role of export composition, import composition and export diversification", *Economic Change and Restructuring*, Vol. 54 No. 4, pp. 919-941.

Chaudhary, A. and Paudel, R.C. (2024), "Navigating economic growth challenges in developing countries: a case study of BIMSTEC", *Cogent Social Sciences*, Vol. 10 No. 1, p. 2431591.

Chen, W., Dai, Y., Liu, Z. and Zhang, H. (2024), "The evolution of global zinc trade network: patterns and implications", *Resources Policy*, Vol. 90, p. 104727.

Daher, B., Lee, S.H., Kaushik, V., Blake, J., Askariyeh, M.H., Shafiezadeh, H., … and Mohtar, R.H. (2019), "Towards bridging the water gap in Texas: a water-energy-food nexus approach", *Science of The Total Environment*, Vol. 647, pp. 449-463.

Das, S. and Bhowmik, K. (2024), "Change in productivity of cereals cropping and trade relationship among BIMSTEC countries", *Sustainable Agricultural Practices: economic and Environmental Implications*, Emerald Publishing Limited, pp. 11-26.

Elish, E. and Ahmed, H. (2025), "Evaluating India's FDI as a nonparticipant in the belt and road initiative: synthetic control method analysis", *Journal of Chinese Economic and Foreign Trade Studies*, Vol. 18 No. 1, pp. 1-23.

Fanelli, R.M. and Giglio, A. (2021), "The 'similarity'of Agri-food trade flows between the EU-28 and the asia-50", *The International Trade Journal*, Vol. 35 No. 6, pp. 558-586.

Furusawa, T. and Konishi, H. (2007), "Free trade networks", *Journal of International Economics*, Vol. 72 No. 2, pp. 310-335.

Fusacchia, I., Balié, J. and Salvatici, L. (2022), "The AfCFTA impact on agricultural and food trade: a value added perspective", *European Review of Agricultural Economics*, Vol. 49 No. 1, pp. 237-284.

Ghonkrokta, S.S. (2021), "BIMSTEC and role of northeast in promoting agriculture, trade and investment", *New Futures for BIMSTEC*, Routledge, India, pp. 101-115.

Goyal, S. and Joshi, S. (2006), "Bilateralism and free trade", *International Economic Review*, Vol. 47 No. 3, pp. 749-778.

Grubel, H.G. and Lloyd, P.J. (1975), *Intra-Industry Trade: The Theory and Measurement of International Trade in Differentiated Products*, The MacMillan Press Ltd, London.

Gutiérrez-Moya, E., Lozano, S. and Adenso-Díaz, B. (2023), “A pre-pandemic analysis of the global fertiliser trade network”, *Resources Policy*, Vol. 85, p. 103859.

Ji, G., Zhong, H., Nzudie, H.L.F., Wang, P. and Tian, P. (2024), “The structure, dynamics, and vulnerability of the global food trade network”, *Journal of Cleaner Production*, Vol. 434, p. 140439.

Khatri, P., Kumar, P., Shakya, K.S., Kirlas, M.C. and Tiwari, K.K. (2024), “Understanding the intertwined nature of rising multiple risks in modern agriculture and food system”, *Environment, Development and Sustainability*, Vol. 26 No. 9, pp. 24107-24150.

Kuzmenko, E., Rumankova, L., Benesova, I. and Smutka, L. (2022), “Czech comparative advantage in agricultural trade with regard to EU-27: main developmental trends and peculiarities”, *Agriculture*, Vol. 12 No. 2, p. 217.

Li, Q., Xu, M., Xu, L., Wu, X., Zhang, Y., Xin, J., … and Gao, J. (2025), “Organic fertilization leads to *n* limitation rather than *p* limitation in both vegetable soils”, *Agronomy*, Vol. 15 No. 1, p. 190.

Li, B., Ng, S.J., Han, J.C., Li, M., Zeng, J., Guo, D., Zhou, Y., He, Z., Wu, X. and Huang, Y. (2023), “Network evolution and risk assessment of the global phosphorus trade”, *Science of The Total Environment*, Vol. 860, p. 160433.

Liu, Y., Liao, Q., Shao, Z., Gao, W., Cao, J., Chen, C., … and Lin, Z. (2025), “Spatial distribution characteristics and influencing factors of cultivated land productivity in a large city: case study of Chengdu, Sichuan, China”, *Land*, Vol. 14 No. 2, p. 239.

Lugo-Arias, E., Lugo-Arias, J., Vargas, S.B., de la Puente Pacheco, M.A., Granados, I.B., Heras, C.B. and Hernández, D.T. (2024), “Determinants of the competitiveness of world palm oil exports: a cointegration analysis”, *Transnational Corporations Review*, Vol. 16 No. 3, p. 200063.

Malimba, N., Mutambara, T.E. and Marire, J. (2024), “Measuring intra-industry trade and productivity in the South African pharmaceutical sector”, *South African Journal of Economic and Management Sciences*, Vol. 27 No. 1, pp. 1-16.

Marwah, R., Ramanayake, S.S. and Yasmin, L. (2023), “Political economy of trade in BIMSTEC: a contemporary perspective”, *Millennial Asia*, Vol. 14 No. 3, pp. 434-454.

Masalegooyan, Z., Piadeh, F. and Behzadian, K. (2022), “A comprehensive framework for risk probability assessment of landfill fire incidents using fuzzy fault tree analysis”, *Process Safety and Environmental Protection*, Vol. 163, pp. 679-693.

Misra, S. and Ghosh, A. (2024), “Agriculture paradigm shift: a journey from traditional to modern agriculture”, *Biodiversity and Bioeconomy*, Elsevier, pp. 113-141.

Moersdorf, J., Rivers, M., Denkenberger, D., Breuer, L. and Jehn, F.U. (2024), “The fragile state of industrial agriculture: estimating crop yield reductions in a global catastrophic infrastructure loss scenario”, *Global Challenges*, Vol. 8 No. 1, p. 2300206.

Naeem, M.A., Senthilkumar, A., Arfaoui, N. and Mohnot, R. (2024), “Mapping fear in financial markets: insights from dynamic networks and centrality measures”, *Pacific-Basin Finance Journal*, Vol. 85, p. 102368.

Nicastro, R., Papale, M., Fusco, G.M., Capone, A., Morrone, B. and Carillo, P. (2024), “Legal barriers in sustainable agriculture: valorization of Agri-food waste and pesticide use reduction”, *Sustainability*, Vol. 16 No. 19, p. 8677.

Ojha, P. (2022), “BIMSTEC and its relevance to the landlocked countries”, *Bimstec*, Routledge, India, pp. 104-119.

Osburg, V.S., Yoganathan, V., Bartsch, F., Diallo, M.F. and Liu, H. (2024), “How sustainable luxury influences product value perceptions and behavioral intentions: a comparative study of emerging vs. developed markets”, *Journal of Business Ethics*, Vol. 191 No. 4, pp. 713-738.

Panke, D., Grundsfeld, L. and Tverskoi, P. (2025), “Exit from regime complexity? Regional international organizations under scrutiny”, *Global Studies Quarterly*, Vol. 5 No. 1, p. ksae078.

Paudel, D., Neupane, R.C., Sigdel, S., Poudel, P. and Khanal, A.R. (2023), "COVID-19 pandemic, climate change, and conflicts on agriculture: a trio of challenges to global food security", *Sustainability*, Vol. 15 No. 10, p. 8280.

Penuelas, J., Coello, F. and Sardans, J. (2023), "A better use of fertilizers is needed for global food security and environmental sustainability", *Agriculture and Food Security*, Vol. 12 No. 1, pp. 1-9.

Ranta, M., Ylinen, M. and Järvenpää, M. (2023), "Machine learning in management accounting research: literature review and pathways for the future", *European Accounting Review*, Vol. 32 No. 3, pp. 607-636.

Salem, R.A., Lila, S. and Lewaaelhamd, I. (2025), "The impact of Russian–Ukrainian conflict on international financial markets: a comparative analysis of oil-importing and oil-exporting countries", *Journal of Chinese Economic and Foreign Trade Studies*, pp. 1-20,

Sánchez-Hernández, J.L. (2023), "Wine and conventions: a fruitful Coupage", *Handbook of Economics and Sociology of Conventions*, Springer International Publishing, Cham, pp. 1-30.

Shoukat, M.H., Selem, K.M. and Cao, D. (2024), "How do corporate social responsibility initiatives enhance sustainability performance? Evidence from tobacco firms", *Environment, Development and Sustainability*, Vol. 26 No. 12, pp. 31371-31399.

Sinha, M. and Panigrahy, S.R. (2024), "Unveiling the urea market of the American continent", *Journal of Experimental Agriculture International*, Vol. 46 No. 1, pp. 129-136.

Theresa, M., Jose, A., Parameswaranpillai, J. and Radhakrishnan, E.K. (Eds) (2025), *Agricultural Sustainability through Nanotechnology*, CRC Press.

Tonelli, D., Rosa, L., Gabrielli, P., Parente, A. and Contino, F. (2024), "Cost-competitive decentralized ammonia fertilizer production can increase food security", *Nature Food*, Vol. 5 No. 6, pp. 1-11.

Torok, A., Mizik, T. and Jambor, A. (2018), "The competitiveness of global coffee trade", *International Journal of Economics and Financial Issues*, Vol. 8 No. 5, pp. 1-18.

Wang, J. and Dai, C. (2021), "Evolution of global food trade patterns and its implications for food security based on complex network analysis", *Foods*, Vol. 10 No. 11, p. 2657.

Wang, M., Wang, H. and Zheng, H. (2022), "A mini review of node centrality metrics in biological networks", *International Journal of Network Dynamics and Intelligence*, Vol. 1 No. 1, pp. 99-110.

Wang, X., Ma, L., Yan, S., Chen, X. and Growe, A. (2023), "Trade for food security: the stability of global agricultural trade networks", *Foods*, Vol. 12 No. 2, p. 271.

Wani, N.U.H., Rahman, A., Grover, V., Mirzakhidova, S. and Mirwais Rasa, M. (2024), "Regional trade expansion opportunities in Central and South Asia: exploring trade complementarity, diversification and similarity", *Cogent Economics and Finance*, Vol. 12 No. 1, p. 2363461.

Williamson, E., Ross, I.L., Wall, B.T. and Hankamer, B. (2024), "Microalgae: potential novel protein for sustainable human nutrition", *Trends in Plant Science*, Vol. 29 No. 3, pp. 370-382.

Wu, X., Wu, Z. and Hu, J. (2022), "Global competitiveness analysis of industrial robot technology innovations market layout using visibility graph", *Physica A: Statistical Mechanics and Its Applications*, Vol. 603, p. 127672.

Xu, A., Chen, Y., Wei, X., Effah, Z., Li, L., Xie, J., … and Anwar, S. (2024), "Does nitrogen fertilization improve nitrogen-use efficiency in spring wheat?", *Agronomy*, Vol. 14 No. 9, p. 2049.

Xue, R., Li, K., Wang, F. and Baron, C. (2024), "Research progress and hot-spot analysis of the economic complexity research based on Citespace", *Advances in Management and Applied Economics*, Vol. 14 No. 1, pp. 1-10.

Yuvaraj, M., Dey, A.K., Lyubchich, V., Gel, Y.R. and Poor, H.V. (2021), "Topological clustering of multilayer networks", *Proceedings of the National Academy of Sciences*, Vol. 118 No. 21, p. e2019994118.

Supplementary Material

The supplementary data for this article can be found online.

About the authors

Md. Monzur Hossain is an Assistant Professor in the Department of Finance and Banking, Faculty of Business Studies, Comilla University, Cumilla, Bangladesh. His research interests are International Trade, Regional Trade, Network Theory and Banking Sector.

Subir Kumar Sen is an Associate Professor in the Department of Commerce at Tripura University, India. His research interests include transport network analysis, trade network analysis and regional studies. He is a Reviewer for some journals, among them *Journal of Financial Services Marketing*.

Kareem M. Selem is a Lecturer in Hotel Management, Faculty of Tourism and Hotels, Suez Canal University, Egypt. He has a diverse experience in hospitality management, especially in upscale restaurants and hotels. His research interests are employee well-being, crisis management and disruptive innovations in the hotel industry. He is a Reviewer for some journals, among them the *International Journal of Contemporary Hospitality Management* (*IJCHM*), the *Journal of Hospitality and Tourism Management* (*JHTM*) and *Tourism Management Perspectives* (*TMP*). Kareem M. Selem is the corresponding author and can be contacted at: kareemselem91@yahoo.com

Md Shafiul Hossain is an Assistant Professor at Guest Faculty of Bangladesh Institute of Business and Technology, Narayanganj, Bangladesh. His research interests are Trade network, Regional Network, Auditing and Tax.