The Geo-economics of Water Trade: Virtual Water Flows and their role in Sustainability: Case study on India-Saudi Arabia Rice Trade

Ananya Baruwa
Research Scholar
St. Joseph's University, Bangalore

Abstract

"The water used in the production process of an agricultural or industrial product is called the 'virtual water' contained in the product", A.Y. Hoekstra. Virtual water represents the hidden or indirect water use that consumers do not see but are consuming in the products they consume. The virtual water trade has led to the hidden costs of sustainability challenges like groundwater depletion, soil degradation and energy overuse. Saudi Arabia is the biggest importer of basmati rice from India. The country is dominated by vast desert regions such as the Rub' al Khali and the An Nafud Desert. The country receives less than 100mm of rainfall per year, which makes it impossible to grow water-intensive crops like rice. India, on the other hand, has rivers like the Ganga, Indus, Yamuna, Brahmaputra, and Cauvery river basins, which support irrigation. It also relies on groundwater extraction for its agriculture. Saudi Arabia and India have mutual economic interdependence because Saudi Arabia is one of India's largest crude oil suppliers, whereas India supplies more than one-third of Saudi Arabia's rice demand. Saudi Arabia imported about 1.4 million tonnes of rice from India in 2024, which is equivalent to 2.8 km³ of virtual water. This paper aims to study the impact of the hidden virtual water trade in the resource-scare economies of India and Saudi Arabia. It also explains how the sustainable goals like SDG 12 (Sustainable Consumption and Production) can be adopted between the two countries. The methodology used for this research is qualitative research through secondary sources, which includes: case studies and reference to research papers, articles and official government websites. This paper highlights the challenges of this bilateral trade, like for instance, Saudi Arabia 'imports' water security and India exports its scarce groundwater through their rice trade. These resource-scarce economies have no impactful sustainable bilateral efforts towards their unsustainable rice trade. The study puts forward that although frameworks like SDGs exist, they are not being effectively implemented and reveals a governance gap in establishing a sustainable trade between the two countries.

Keywords: India, Saudi Arabia, Rice Trade, Virtual Water and Sustainability

Introduction

Virtual water is the amount of water embedded in the production process of products. It is also called 'embedded water' or 'exogenous water'. The virtual water is the total volume of water that was used to produce a product and thus, it is relative to the production conditions, place, water use efficiency and time of production. For instance, the virtual water used in the production of rice is lower during the monsoon season. Thus, virtual water is an alternate source of water (Hoekstra, 2003). When the final output with embedded water is traded in domestic and international markets, it is termed as a Virtual Water Trade (VWT) (Shivaswamy et al.,2021).

It is unrealistic to produce water-intensive products domestically in a water-scarce country and thus, water-scarce economies achieve water security by importing high water-demanding products from water-abundant nations. Virtual water helps water-scarce counties to import water in a virtual form from water-abundant countries. It indirectly imports 'water security'. Countries rely on international markets for food supply to relieve the pressure on its natural resources, especially countries with arid topography such as Saudi Arabia. Virtual water redirects production of water-intensive crops to regions where the natural conditions are suitable for water efficiency sustainability in production. It satisfies the comparative advantage of water resources and recognises the optimal production sites so that food supply needs are met with minimum pressure on the environment (Renault, 2002).

The concept of virtual water in globalisation is useful to account for efficient management and utilisation of water resources. Virtual water could be the solution to prevent geopolitical problems and prevent wars over water among nations. It is an instrument to increase global water use efficiency and impact global water savings (Hoeksta and Hung, 2003). Virtual water trade focuses on the flow of food and the virtual water embedded in the food from production to consumption sites.

India exports commodities water-intensive commodities such as rice to Saudi Arabia, 63% of Saudi Arabia's rice imports come from India (Khan and Hassan, 2013). Whereas more than 18% of India's LPG imports are from Saudi Arabia. Saudi Arabia is India's 4th largest trade partner and India is Saudi Arabia's 2nd largest trade partner (India Brand Equity Foundation, 2025). Rice generates one of the highest water footprint among all agricultural commodities. 1kg of rice takes about 2,497 litres of water for its production. Virtual water is relative to production conditions like place, time of production and water use efficiency. Consequently, the production of rice in an arid region like Saudi Arabia requires 2.6 to 3 times the water needed to produce the equivalent amount of rice on a global scale. (Odnoletkova and Patzek, 2023). On the other hand, Saudi Arabia is one of India's crucial oil suppliers. Saudi Arabia meets India's energy needs and helps India deal with fluctuating oil prices and uncertainty in the global oil market. Thus, this bilateral trade has helped India diversify its energy sources (Saudi Arabia India Energy, 2025). Through this mutually beneficial trade, Saudi Arabia establishes India's energy security and India establishes Saudi Arabia's food security (India Brand Equity Foundation, 2025). On the other hand, virtual water trade adversely affects the water balance of the exporting country and economy (Nishad and Kumar, 2021). The virtual water trade between India and Saudi Arabia comes with a cost of sustainability challenges faced by India. The excessive rice production and export has led to depletion of domestic water resources, soil degradation and groundwater exploitation (Gowri, Shivakumar, 2021).

This study analyses the case study of the India- Saudi Arabia' rice trade and highlights the two countries' geo-economical interdependence. It emphasizes the virtual water breakdown of India's rice production into green and blue water footprint and highlights the sustainability challenges faced due to excessive production and export of virtual water. This paper also focuses on sustainable rice production measures that can help India deal with groundwater and other water resource depletion responsibly. This research gives insights on how the SDG 12 (Sustainable Consumption and Production) and other global sustainable frameworks can be adopted in the bilateral trade between India and Saudi Arabia.

Research Objectives

1. To examine the virtual water flow embedded in India's rice exports to Saudi Arabia.
2. To analyse the sustainability challenges of this bilateral trade and evaluate how SDG12 can be applied to make this bilateral trade more sustainable.

Literature Review

The research report titled, "Virtual Water Trade: Proceedings of the International Expert Meeting on Virtual Water Trade", by A. Y. Hoekstra (2003), elaborately explains the concept of virtual water and how virtual water can help mitigate global water scarcity. It highlights that virtual water can be helpful in effective global management of water. It presents that virtual water can be an alternative to prevent water wars and highlights the redistribution effects of virtual water trade. The report concludes that virtual water can make real global water savings, trading water-intensive commodities from water-abundant countries to water-scare countries.

The webpage titled, "Water Footprint Network", (2025, last updated) provides virtual water of commodities, countries, river basins and the world. It explains the concepts of green, blue and grey water footprint. The water assessment tool within the Water Footprint Network provides statistics of the total virtual water involved in the cultivation of rice. It gives a broad understanding of the use of virtual water in different commodities through graphical representation, numerical data and geographical representation via map It also significantly shows data on the breakdown of water footprint into three components: blue, green and grey water footprint. The webpage also provides insights on the sustainability of India's rice production and its impact on its river basins. It provides a compilation of reports and research reports built on virtual water and its use over diverse agricultural crops and related products. The webpage reveals that India is a highly water-stressed country and India's water footprint is 115% more than the global water footprint benchmark. The findings also reveal the total virtual water in India's rice production, which is 260, 10^9 m^3/yr.

The article, "Water Resources in Saudi Arabia: Trends in Rainfall, Water Consumption, and Analysis of Agricultural Water Footprint", by Natalia Odnoletkova and Tadeusz W. Patzek (2023), explains Saudi Arabia's water scarcity by analysing different factors of the country's sustainability challenges, such as its topographical dynamics, rainfall variability, national water consumption and agricultural water footprint through data and graphical representations. The article also examines the implications of these challenges on Saudi Arabia's food security. It highlights the country's heavy reliance on its non-renewable groundwater source. The article finds that it takes 2.6-3 times more water to produce crops in Saudi Arabia than it takes as a global average.

The research article, "India Rice Export and Virtual Water Trade", by Uma Gowri and Shivakumar K.M (2021), broadly studies the flow of virtual water in the production and export of rice in India. It underlines India's substantial virtual water trade (5185Mm^3) in the global rice exports. It also features the unsustainability in India's rice production such as groundwater depletion, soil degradation, and energy overuse. The research article quantifies the virtual water losses and the breakdown of water footprint in India's rice production. The study concludes that India's rice production is dependent on blue water footprint and highlights how the cost of virtual water is disregarded in the economic costs of rice. It also recommends sustainable solutions such as irrigation techniques, irrigation scheduling and crop selection methods.

The article, "How Rice Farmers Streamline Sustainable Practices with Farm Management Solutions", by Tracex Technologies (2025), highlights the problem of sustainability in the cultivation of rice. It brings up the problems such as environmental damages caused by the traditional rice cultivation which involves constant flooding of paddy fields and carbon emission. The article provides sustainable solutions to minimise the environmental effects of this production, for instance, the Direct Seeded Rice (SDR) and the Alternate Wetting and Drying (AWD) alternate agricultural techniques. The paper highlights the environmental benefits such as, reduction in water wastage and carbon footprint of implementing these techniques.

Methodology

The methodology used for this research is both qualitative and quantitative research through secondary sources, which includes: a case study and reference to research papers and research reports of A.K. Hoekstra. This research also involves content analysis of articles, reports, such as Water Footprint Network (WFN) reports, news articles, and official government websites, for instance, the Embassy of India and National Bank for Agriculture and Rural Development (NABARD), and reports of corporations like the India Brand Equity Foundation (IBEF). This study also used quantitative research with descriptive analysis of secondary sources like the World Integrated Trade Solution (WITS) data and WFN reports of water scarcity analysis and used graphical representations of data to explain the breakdown of virtual water. Quantitatively, the study applies the calculation of the virtual water flow between the two countries through equations derived from Chapagain and Hoekstra's reports and trade analysis statistical data from WITS.

Case Study: India-Saudi Arabia's Rice Trade

India and Saudi Arabia trade commodities from various sectors. For instance, India exports rice, petroleum products, vehicles and related equipment, textiles, chemicals, engineering goods, gems and jewellery to Saudi Arabia. Whereas, Saudi Arabia exports crude oil, fertilizers, plastic and chemicals to India. India and Saudi Arabia have a total economic trade worth US$ 31,283.69 in the financial year 2024-25. Saudi Arabia is one of India's crucial oil suppliers. It is India's third largest trade partner for crude oil after Russia and Iraq. In the financial year 2023-24, India imported 33.35 million metric tonne (MMT), which constituted 14.3% of the total crude oil imports. Saudi Arabia is also the third largest LPG exporter of LPG for India, after other Middle Eastern countries, i.e, Qatar and UAE. In 2023-24, India imported 3.43 MMT, which was about 18.57% of the total imports (Embassy of India, Riyadh, 2025). India looks forward to increasing its oil intake from Saudi Arabia to diversify its refiners from Russian oil due to tight Western sanctions. This increases the demand for Middle Eastern oil refiners, specifically the two largest OPEC producers: Saudi Arabia and Iraq (Verma, 2025). On the other hand, India's exports to Saudi Arabia valued US$11.75 billion in the financial year 2025. India exported Basmati rice worth US $1.20 billion to Saudi Arabia (India Brand Equity Foundation, 2025). India has a reliable supply chain with established export infrastructure to export rice which reduces the possibilities of food shortage. The traditional Saudi cuisine also heavily relies on premium Basmati rice that matches with Indian rice exports. India also provides high-quality rice at prices more attractive than other major rice-producing countries (Tabseer, 2025). This establishes a water-for-oil trade relationship between the two countries. India's total rice exports is valued at about 18,042,900,000 kgs according to the WITS 2024, which adds to about 30.91% of the virtual water export in rice among the top five exporters (Doomra and Bharti, 2024).

The calculation of virtual water flow of rice between India and Saudi Arabia can be derived by using the following equation:

$VWT^{(k)}_{(i\rightarrow j)} = Q^{(k)}_{(i\rightarrow j)} * WF^{(k)}_{i}$

This equation provides the virtual water flow ($VWT^{(k)}_{(i\rightarrow j)}$) in m^3 of commodity *k,* in this case, rice, exported from country *i,* India to country *j,* Saudi Arabia.

$Q^{(k)}_{(i\rightarrow j)}$ being the quantity of rice traded between India and Saudi Arabia in tonnes.

$WF^{(k)}_{i}$,being the water footprint of commodity *k*, rice in the producing country *i,* India in m^3/tonne.

To estimate India- Saudi Arabia virtual water flows for rice, the values of the annual export quantity between the two countries and India's unit water footprint for rice is substituted into the equation.

$VWT^{(k)}_{(i\rightarrow j)}$= 1405530 tonnes * 2020 m^3/ton

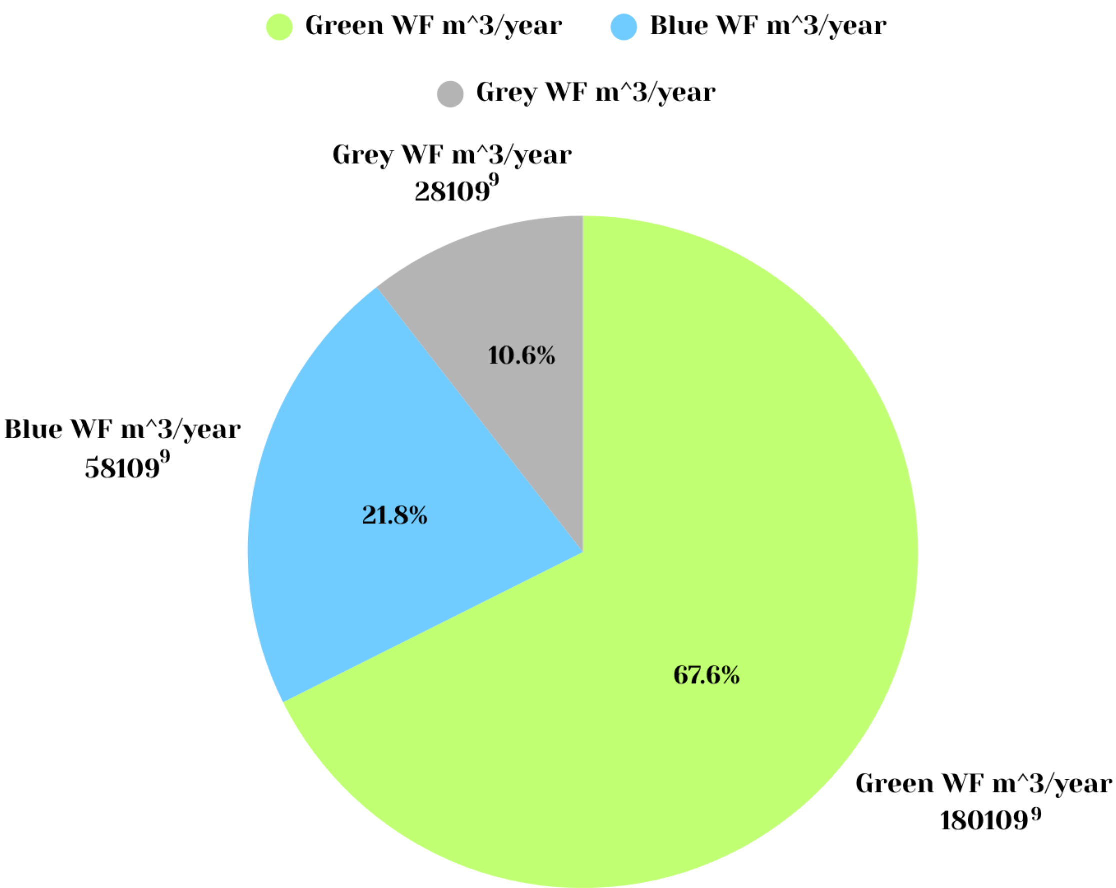
= 2,83,91,70,600 m^3

= **2.83 km^3/tonne**

By substituting the quantity of rice traded between India and Saudi Arabia, which is 1405530 tonnes in 2024 (WITS, 2024) and the water footprint per unit of per unit rice produced in India, which is 2020 m^3/ton (Chapagain and Hoekstra, 2010), we estimated the virtual water flow in the bilateral rice trade between India and Saudi Arabia at **2.83 km^3/tonne**.

"The water footprint is a measure of humanity's appropriation of fresh water in volumes of water consumed and/or polluted." The water footprint is a geographical indicator. This measure indicates the volumes of water use and pollution and the locations of the same. In short, water footprint is the amount of water used in the production of each of the goods and services we use. It is classified into three components. The green water footprint is the volume of rainwater embedded in the production process of a product. This indicator calculates the total water evapotranspirated from fields and the total volume of rainwater embedded in the crop. The blue water footprint refers to the volume of surface water and groundwater used in the production of a product. It includes the amount of freshwater evaporated and incorporated in the product. It also includes the amount of water taken from the ground and freshwater sources that cannot be replenished. The grey water footprint is the amount of freshwater required to deconcentrate water from pollutants to achieve a water quality standard. This component of virtual water footprint is an indicator for the freshwater pollution caused by the production process of a product. The global average water footprint of rice production is 2497 litres per kg. This consumption of water includes 68% of green water footprint, 20% of blue water footprint and 11 % of grey water footprint globally. Whereas, the total amount of virtual water in India's rice production is 260, 10^9 m^3/yr. The percentage water footprint breakdown of rice production in India into green water footprint, blue water footprint and grey water footprint is 67.6%, 21.8% and

10.6% respectively. The graph below shows the water footprint breakdown of rice production in India (Water Footprint Network, n.d.).



Source: Water Assessment Tool, Water Footprint Network, 2025

Saudi Arabia receives less than 100mm of rainfall per year. There are no permanent lakes, swamps or rivers in the country dominated by arid regions. The country only has a few wadis (rivervalleys), but they fail to support the country's domestic water needs (Odnoletkova and Patzek, 2023). Saudi Arabia heavily relies on its non-renewable groundwater sources, accounting for about 80-85% of its water supplies. This heavy reliance leads to depletion of aquifers and fall in the groundwater quality (Sallam, 2010). The local production comprises only 33% of the total food available in the country (this includes domestic products and imported products) and only 11% of domestically produced goods are exported (Odnoletkova and Patzek, 2023). As the country lacks rainfall and has a high rate of evapotranspiration (evaporation of water from surface water and plants), the blue water footprint of Saudi Arabia for rice production is higher than the global average blue water footprint. The country also has barely any green water footprint, making its production fully dependent on blue water footprint, i.e, non-renewable aquifers. Trading of water-intensive crops has conserved 1100- 16,000 Mm3/ year of blue water footprint, which may have resulted in losses of green water footprint of exporting countries

(Kashifi, et al., 2022). The Virtual Water Trade (VWT) in India-Saudi rice trade has saved water resources for Saudi Arabia. Thus, Saudi Arabia has ensured food security through this trade, as well as imported 'water security'. According to Alamri and Reed (2019), during the span of 2000-2016, the overall virtual water trade of agricultural products has reduced Saudi Arabia's water deficit by 54%. The trade of virtual water has helped bridge the gap between local water resources and food demand. About 43% of Saudi Arabia's water comes from net virtual water imports from all crops. The virtual water trade also saves Saudi Arabia's energy and reduces its carbon emissions. Saudi Arabia has been able to save about 5.80-8.66 MT of carbon dioxide due to crop imports from 2011-2019. This accounts to about 1.5% of the country's total annual emissions, hence, reducing the CO_2 footprint of the country (Kashifi, et al., 2022).

Sustainability Challenges

Globally, India is one of the five largest virtual water exporters of rice (Gowri and Sivakumar, 2021). India exploits a lot of its domestic water resources for its rice exports which significantly increases the virtual water trade between the two countries. India faces sustainability challenges in its rice production and export, especially with its growing population and only 4% of its water resources left (Satyanarayana,n.d). India has become a water-stressed country as it has an annual per capita water availability of 1,137 m^3 , according to the census of 2001 and 2011 (which is below the water-stressed annual per capita water requirement standard,i.e., 1700m^3). According to the National Water Stressed Rankings, in 2018-19, India exported 12,014.16 metric tons of rice, causing extremely high baseline water stress. Export of virtual water harms the water and food sustainability of the exporting country and thus, extensively exporting water-intensive crops like rice can level-up water scarcity of India's domestic water resources. Since, virtual water is the water available at the end of the product, it is irreversible in the hydrological cycle (Nishad and Kumar, 2021). The price of water is not economically priced, i.e, the cost of water is not included in the price of rice, and thus, the cost of the scarce water used in the production of rice remains unfairly subsidized in global virtual water trade (Gowri and Sivakumar, 2021).

Over extraction of groundwater for irrigation is a major cause of this depletion. India is the highest extractor of groundwater, more than China and the U.S combined (Goomra and Bharti, 2024). The total virtual water embedded in India's rice exports in 2023-24 was 40.87 billion m^3(BCM). This accounts for 17% of India's annual groundwater extraction (Satyanarayana,n.d). The cultivation of rice mandates constant flooding of paddy fields, this accounts to 2,500 litres of water per Kg of cultivated rice. The water table in some regions is falling by 4cm per year (Global Agricultural Productivity Report, 2021).

60% of rice is cultivated through irrigation methods, the rest depends on rainfall. Rice demands about 28% of the gross irrigated area in India and a substantial amount of energy subsidy provided for agriculture is consumed for the irrigation of this crop. Regions with high yields like Punjab, Haryana, Andhra Pradesh and Tamil Nadu consume excessive amounts of irrigation water, aggravating water stress. For instance, Tamil Nadu has 94% of its rice-cultivated area irrigated, similarly, Andhra Pradesh has 95% irrigation coverage. Punjab, Haryana and Uttar Pradesh have been recognised as the "water risk hotspots" globally. This unsustainable irrigation of rice production can also affect the food security of India, as these regions provide 50% of domestic rice. (Sharma, et al., 2018).

The global water footprint benchmark is the standardized measure of the water productivity or the water footprint in the process of producing a product. The global green-water footprint for production of rice is 859 m^3/t. The blue-water footprint of rice in India is 1800m^3/t which is 115% more than the global water footprint benchmark. The Ganga river has a blue water footprint of about 17 ,10^9 m^3/yr. Rice contributes to about 19% of the water footprint in Ganga. The annual average of blue water scarcity is the ratio of blue water footprint to blue water availability. The annual average of blue water scarcity of the Ganga basin is 2.4 which means that the blue water footprint of the Ganga basin is 2.4 times the blue water availability and the water scarcity is at about 240%. Likewise, the Indus river basin has an annual average blue water scarcity of 2.7. Rice contributes to 25% of the total blue water footprint of the Indus river basin (Water Footprint Network, n.d). India's water use also affects rivers like the Indus, Ganges and Brahmaputra that are transboundary (crosses international borders), which makes the overuse of the river in India affect the basin-level river water balance over borders (Mukherjee and Barua, 2025). The production process of rice can also lead to the contamination of local water bodies due to fertilizers and pesticides in the field leading to excessive grey water footprint (Chapagain and Hoekstra, 2011).

Another sustainability challenge regions where rice is produced face is the loss of fertility of the soil. Soil becomes deficient in its micro-nutrients. The stagnation of water in rice fields causes this decline of soil fertility (Shergill, 2007). Rice cultivation also contributes to methane emission (9-11%) and carbon footprint (Bharadwaj, 2022). The inefficient use of fertilizers in the traditional methods of rice farming contributes to Green House Gas (GHG) emissions (Tracextech, 2025).

Saudi Arabia, on the other hand, heavily relies on imported food for the country's food security. Henceforth, making their food security susceptible to global conflicts, wars, power shifts, climate change and disruption in global crop supplies (Odnoletkova and Patzek, 2023). Changes in import-partner relationships or disruption in the supply chain of rice due to climate change can create a risk for Saudi Arabia. Inflation in international prices can affect local prices of food imports. Geo-political tensions with other countries, like for example, rifts with Iran can lead to cut off access to the Straits of Hormuz, which could interrupt rice exports from India and Pakistan (Chatham House, 2013).

Sustainable Measures

To mitigate the sustainability challenges of growing such a water-intensive commodity like rice in India will require adopting water efficient measures of production. According to the Sustainable Rice Platform, rice production uses 30% to 40% of the world's irrigation water. Traditional rice production requires constant flooding of paddy fields which demands excessive water. Such practices have caused much harm to water-producing states like Punjab, Uttar Pradesh and Bihar. Thus few sustainable rice farming practices have been developed to curb the environmental drawbacks of rice production (Tracextech, 2025).

The Direct Seeded Rice (SDR) is an agricultural technique that includes directly sowing the rice seeds into the field instead of transplanting seedlings. This technique is helpful for water conservation because seeds can be sown in dry fields or partially flooded fields, it does not require constant flooding to control weeds. Consequently, the avoidance of constant flooding also reduces methane emissions and carbon footprint. This agricultural technique helps reduce evaporation losses through dry seeding and is a sustainable solution for a water-stressed country like India. DSR saves about 30-50% of water compared to traditional rice production methods. For instance, in India it has brought down the water wastage litres per kg from 1,800 to 1,100 (Tracextech, 2025).

Alternate Wetting and Drying (AWD), rice cultivation, also called controlled irrigation also controls the use of excessive water in the production process by continuous flooding. The AWD technique involves flooding and non-flooding fields alternatively. It monitors the depth of water by allowing the water level in the rice fields to drop to 15cm below soil surface before irrigating again. This level of water is safe since the roots can still take water from the saturated soil, leading to no loss of crop yields. This method also reduces methane emissions by 30-70%. This method also involves Digital Monitoring, Reporting and Verification (DMRV) to use advanced technology into the cultivation of the crop through sensors, satellite imagery, data analytics and real-time data. This helps rice farmers monitor their irrigation schedules, access information about the soil moisture, water levels and prevent both under-irrigation and excessive use of water (Bharadwaj, 2022).

These methods can help reduce carbon dioxide emissions by optimising water productivity in the cultivation of rice. It can also reduce the use of chemicals and pesticides. It can lead to reduction of water by 30-40%, helping to mitigate water scarcity across regions of India (Tracextech, 2025). Other initiatives can be to diversify the regions of production where water availability is highest and most of agriculture is dependent on rainfall rather than groundwater (Satyanarayana, n,d.). The central government can also partner with state governments to formulate policies and mandate initiatives like the Sahi Fasal campaign, launched by National Water Mission to encourage farmers from water-stressed regions to grow crops that are not water-intensive and Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), to improve irrigation efficiency over all fields ("Har Khet ko Pani") (PMKSY, n.d and Government of India, n.d.).

On the global governance level, the bilateral trade can also adopt the Sustainable Rice Platform by the United Nations Environmental Programme (UNEP) established for setting up sustainable production standards in the global rice supply and reducing the environmental implications of rice production. SRP is an alliance of the farmers, consumers, exporters, retailers and researchers. Its main purpose is to improve the livelihood of small rice farmers, mitigate the environmental and climate effects of water footprint included in rice production and secure the global rice market by sustainably meeting the growing needs of populations across the world. The SRP standard is a framework for sustainability norms for the supply chain and a normative set of alternate cultivation practices for farm-level adoption. It includes agro techniques like AWD cultivation. The SRP Performance Indicators for Sustainable Rice Cultivation is a monitoring mechanism that measures and assesses the sustainability impacts of the recommended practices. It is to ensure compliance to the SRP Standards. The SRP Assurance Scheme is a management system which involves third party assessment (assessment done by a group independent from producer), where the producer gets SRP-verified and the claim is earned. The SRP also provides ways to the government to measure and incentivise sustainable farming amongst farmers. It brings together private companies, international donors and governments. The SRP has guaranteed a 10% increment on farmers' net income, reduction of water by 20% and greenhouse gas emission by 50%. In India, the LT Foods, a major rice company is labelled as "SRP-verfied" (Sustainable Rice Platform, n.d.).

Discussion

The findings of this study aligns with and extends the existing literature on virtual water trade and makes it specific to the bilateral rice trade of India and Saudi Arabia. This study is consistent with Hoeksta and Chapagain's study which brings up the foundational aspects of virtual water and formulates an equation to calculate the same. The existing literature on virtual water did not explore the bilateral trade of Saudi Arabia and India. This study thus fills the gap of the existing literature by quantifying the virtual water flow embedded in the bilateral rice trade. It alters the equation mentioned in Hoeksta and Chapagain's research report according to the trade data and the estimate of per unit water footprint caused by rice cultivation It found that the virtual water flow is 2.83 km^3/tonne. This quantification of virtual water flow highlights the charge on the sustainability of India's rice production.

The bilateral trade between India and Saudi Arabia bears sustainability challenges. It aggravates water scarcity in the already water-stressed regions of India. Despite facing these challenges, there is no formal bilateral trade agreement established between India and Saudi Arabia to ensure sustainable farming and facilitate a green transition.

The UN Sustainable Development Goal (SDG) 12 which advocates responsible consumption and production can be applied in the rice trade between India and Saudi Arabia. India can follow the target 12.2 which states, "sustainable management and use of natural resources", which implies sustainable use of India's groundwater and river basins. Target 12.4, Responsible management of chemicals and waste can be achieved by mindful and efficient use of fertilisers to prevent the release of chemicals into soil and water (grey water footprint). Target 12.6, encouraging companies to adopt sustainable practices and sustainability reporting, for instance, LT Foods is helping achieve this target. More large companies and MNCs should take up this initiative to adopt sustainable practices and direct sustainability information into reporting and monitoring agriculture. Saudi Arabia, as a developed country, can take the lead to uphold the target 12.9 of aiding developing countries' (India) scientific and technological capacity for sustainable consumption and production. Upholding the SDG 12 responsibly can help achieve the 2030 Agenda on Sustainable Development. (The Global Goals, n.d.). India can also actively participate in the Sustainable Rice Platform by having more Indian farmers, consumers, exporters, retailers and researchers to comply with the SRP standards. Despite being a dominant rice producer, according to the 2022 annual SRP report, only 4,094 farmers have earned their SRP claim.

On the other hand, Saudi Arabia is heavily reliant on India's rice exports. It also faces insecurity in its national food security, which can be caused by disruptions in Saudi Arabia should diversify its rice import sources. It should thus diversify its import sources to other water-abundant countries like Pakistan, Thailand, China and Pakistan. This solution could benefit both Saudi Arabia and India: Saudi Arabia can gain a support rice supply chain and India could ease its exploitation in its domestic water sources. The Saudi Agricultural and Livestock Investment Company (SALIC) has been investing in farmlands outside the borders of Saudi Arabia, for instance, Sudan, U.S., Egypt, Ukraine, Australia and Argentina for securing its food imports (Alpen Capital,2023). These investments made to supply its wheat needs can be extended to meet its domestic rice needs.

The limitation of this study is the approximate or estimated calculation of the virtual water flow in India-Saudi Arabia's rice trade. The accurate calculation of the virtual water trade (VWT) includes region-specific, i.e., India's recent data on rate of evapotranspiration, irrigation efficiency, water percolation, climate change, crop yield, rainfall patterns, etc. The unit water footprint of rice in India per tonne is derived from Chapagain and A.K. Hoekstra's report of 2010, which makes it inaccurate in today's times, considering the change in the factors that influence the virtual water flows mentioned above. The study limits region-specific solutions for attaining sustainable production.

Conclusion

This research paper explained the concept of virtual water and applied it to the bilateral rice trade between Saudi Arabia and India. The study highlighted that the bilateral trade is not just an economic trade but also revealed the virtual water and its sustainability implications on the exporting country, India. It drew the economic interdependence of the two countries, emphasizing on the “water-for-oil” relation between the two countries. This trade also has sustainability challenges. From the production point of view, India faces groundwater depletion, reduction of its domestic water resources and an increase in greenhouse gases. Whereas, on the consumption side, Saudi Arabia faces over-dependency on its national food security. To mitigate these challenges, this study highlighted sustainable measures like Direct Seeded Rice (DSR) and Alternate Wetting and Drying (AWD) agricultural techniques. The study recommended the mandate of global frameworks like the Sustainable Rice Platform and the UN SDG 12 to make the bilateral trade more sustainable.

The key findings of this paper include the estimated calculations of the virtual water flow in India’s rice exports to Saudi Arabia, which accounts to 2.83 km^3/tonne. The paper also applies the targets of SDG 12 on the case study of India-Saudi Arabia rice trade, highlighting the conservation of India’s domestic groundwater resources and river basins and Saudi Arabia, being developed, to support India to achieve sustainable production and consumption.

The study can be taken forward by examining more on the bilateral trade of India-Saudi Arabia rice trade and its implications on sustainability. The calculation of the virtual water flow can be precise and topography-specific with extensive research on rate of evapotranspiration, irrigation efficiency, water percolation, climate change, crop yield, rainfall patterns, etc, specifically in the regions of Punjab and Haryana where rice cultivation is dominant. Country-specific solutions for achieving sustainable trade can be recommended. A study of elaborated implementation of sustainable global frameworks like the Sustainable Rice Platform and UN SDG 12 can be advocated.

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