

# Virtual Water Trade and Its Implications for India's Water Sustainability in a Globalized World

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## Abstract

*Virtual water is a concept that refers to the amount of water used in the production of goods and services. It is a useful tool for understanding the water footprint of a product or service. Virtual water can be used to support sustainable development in water-scarce regions. The concept of virtual water can help us understand the impact of our consumption patterns on water resources. It can also help us identify ways to reduce our water footprint. For example, we can reduce our consumption of water-intensive products like meat and dairy. We can also support sustainable agriculture practices that use less water. Virtual water is an important concept for understanding the sustainability of our water resources and the impact of our consumption patterns on the environment.*

*In the case of India, it has been shown in the past that we are headed to becoming a water-scarce region, unless we take strong steps in the direction of sustainability. Our study, with the help of pooled regression, found that in the period of 6 years between 2014 to 2019, India's trade in rice and wheat (two most important agricultural products) caused a decline in water sustainability. If trade in virtual water is going from countries with lesser natural water endowment to countries with higher natural water endowment, then contrary to expectations, virtual water trade is indeed causing water scarcity rather than preventing it.*

**Keywords:** *Virtual water trade, Trade and sustainability, Water scarcity.*

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## **I. Introduction**

With a rise in awareness about environmental concerns, considerable focus has fallen on water and water scarcity across the globe. At the same time, a growing global population and decrease in land devoted to agriculture has directly affected food sustainability as well. The globe faces limited and constantly exploited water resources (Nishad and Kumar 2022), and hence maintaining water sustainability is becoming a growing challenge. Virtual water trade is growingly being seen as an option to balance the water inequality among different regions of the world. First conceived by (Allan 1999), virtual water has been defined as the volume of water required for the production of a commodity (Hoekstra and Hung 2005; Hong Yang, Wang, and Zehnder 2007). Thus, virtual water trade is the volume of water embodied in products exchanged internationally.

(Hoekstra and Hung 2005) carried out a detailed study of virtual water trade flows internationally and found that the total flow amounted to a massive 695 billion cubic metres on average (between 1995 and 1999), which in that period was equal to a little less than 15% of all the water used for crop production. This clearly indicates the potential of virtual water flows to compensate for the water endowments of countries, especially the ones trading in crop and livestock across borders.

Countries like India have a definite comparative advantage in the production of agricultural products, while some countries also have a similar comparative advantage in the production of livestock (some examples being China, Canada, Brazil, Australia and New Zealand). For developing and developed countries alike, water scarcity has

turned into a major concern (Duarte, Pinilla, and Serrano 2014), these regions should be monitoring their environmental constraints, since lack of water would hamper primary production. A decline in livestock and agricultural production, coupled with the lack of freshwater would not only affect the exporting countries, but also the entire world, thus mandating a need for a global and holistic water de-stressing strategy. Countries and relevant institutions and stakeholders would need to understand the dynamics of unequal exchange of water resources and the subsequent sustainability problems.

Better methods for managing and using water resources are provided by virtual water. There are certain drawbacks, though (Nishad and Kumar 2022). For instance, exporting virtual water can have a negative impact on a country's water sustainability, and can create irreversible losses in the process (the primary basis of our study). Since there are few effective policies for exporting virtual water, it is necessary to recommend or implement sustainable regulations in this area. Water footprint is a possible tool to aid sustainable management policy planning and governance. The water footprint of a region or a crop provides information about the quantity of total water consumed in the region or by that particular crop. This water footprint method is useful because it accurately measures the volume of water required to produce a specific crop in a given region. The aspect of the geographical conditions is captured because the virtual water for producing the same quantity of a crop would be different in say an arid region compared to a wetter region.

In our study, we consider the virtual water trade between India and the top 15 trade partners of India in a gravity model, considering renewable water resources per capita as our variable of interest, with arable land as a control variable. Within this trade, we focus on two of the most widely traded crops - Rice and Wheat. India is the 2nd largest producer of rice globally, and rice is a major water intensive

crop, with a virtual water content on average equal to 3000 litres per KG. Likewise, wheat's virtual water content (as per global average) is 1350 litres per KG, second only to rice among majorly traded crops. (GDRC)

India is a crucial country to be studied because India has only 3.83% of the world's total fresh water resource to feed the largest population in the world (Nishad and Kumar 2022). Several regions in India have faced persistent water shortage, and India is already one of the water-stressed countries of the world, facing the danger of entering the water scarce zone. We aim to provide specific insights on whether India along with its major trade partners is going to create even more water tensions due to the virtual water trade, and whether this trade is even based on the country's water endowments or not.

The rest of the paper is structured as follows. Section 2 contains a literature review of research on virtual water and virtual water trade. Section 3 contains the data and methodology of the regression analysis. Section 4 contains the results and discussion, followed by conclusion in section 5.

## **II. Literature Review**

Water security, as defined by the UN Water, *“is the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.”*

Virtual water (VW) can be a potential tool to help countries achieve water security (Oki and Kanai 2004). For a country with lesser water resources, virtual water can be a way to relieve the water stress. (Wichelns 2001)

Due to India's large and fast growing population, the per capita water availability has been reducing steadily (Tiwari et al. 2017). Rainfall, the most important source of freshwater in India, shows great variability ranging from 450mm to even 3055mm on the better side (Tiwari et al. 2017). Past research has shown that around 50% of regions in India face Economic water scarcity, with some regions approaching physical water scarcity (which means lack of water to even meet all demands). Thus, a detailed data-based study of how India's agricultural trade is contributing to either accelerating or negating this water scarcity in recent periods is necessary.

Virtual water, essentially the amount of embedded water in products, was a concept coined in the late 90s, but only gained traction after a decade. Its trade makes route for a hidden flow of water across borders, which can potentially help countries with a greater water endowment (hence comparative advantage in water-demanding goods) export virtual water to countries with a lower water endowment, hence aiding global water sustainability. (Oki and Kanae 2004; Tiwari et al. 2017)

"Virtual water" is an amalgamation of agronomic and economic ideas, with an emphasis on water as the primary production component. The economic component considers the opportunity cost of water, which is its worth in other uses such as the cultivation of other crops or use in industrial activities etc. The agronomic component deals with the amount of water used to produce crops. (Wichelns 2001) It is essential to use the ideas of VW commerce to lessen the burden on water resources from agriculture because irrigation uses more than 90% of the total water consumed globally. (Tiwari et al. 2017)

(Wichelns 2001) says that in countries facing water scarcity, the study of virtual water is even more important in analyzing policy and trade patterns. There have been a variety of studies that have studied

VW trade flows and its impact on water scarcity and sustainability.

(Konar et al. 2011) covers the structure of VW trade flows globally, especially in the context of food trade. It tried to address the distribution of trade network connections using complex network theory. They found that while the US is a major exporter of virtual water content, Japan is a major importer, and the sole trade between US and Japan would account for ~5% of global trade flows in virtual water. They found a global hierarchy in which countries with large water resources (and hence more VW flow), cluster with other countries that have large water flows. Countries including the USA, China, Canada, Mexico, Russia, Australia, New Zealand, Japan, Chile and Argentina are few countries within this cluster. A number of these countries are also among India's top trade partners.

Following a more conventional Heckscher-Ohlin model, Reimer (2012) tries to see the relation of VW trade with comparative advantage theory. Contrary to theoretical models, the trade of VW flow is not significantly related to relative water abundance in the exporting countries, and this is what makes our study crucial, because although India is considered a virtual water exporting country, but it is facing water scarcity. Largely, Reimer (2012) found that the HO Model doesn't fit the real-world virtual water trade flow scenario.

However, there is not enough consensus about the flow of virtual water from water-abundant countries to those with a scarcity or vice versa, since (H. Yang et al. 2006) had found very different results in their study, where they claimed that the trade of virtual water was indeed saving water globally due to the flow from countries with high crop water productivity to countries with a corresponding low productivity.

Input-output analysis has been a majorly employed tool while studying VW trade. (Liu et al. 2019) use multiregional input-output analysis to study the flow of VW within China, where a few regions

(just like India), suffer from water scarcity. However, from their analysis they concluded that water is not flowing in a manner to benefit the water-scarce regions in the country, but is rather flowing simply from less developed to more developed regions instead. This pattern is dangerous in the long-run for water sustainability issues in the lesser developed region.

In a similar study for China by (Zhang et al. 2011), it was found that even though the water use efficiency had been improving with time, around 83% of water use was for export purposes. Again, there was no link between water endowments and virtual water flow within regions.

Going back in history, (Duarte, Pinilla, and Serrano 2014) studied the first era of globalisation and its effect on water consumption. They found that it was largely the growth of overall trade that led to more flow of virtual water from one country to another, and very little was contributed by shifting towards more water-intensive trade goods.

There have been plenty of studies covering virtual water trade with respect to a country or a region. (Mohammadi-Kanigolzar, Ameri, and Motee 2014) consider the case of Iran and show that despite being a water-scarce country, it is a net virtual water exporter, which is constantly straining its water resources. They also point out the poor water resource efficiency in Iran as compared to the countries from where it procures its imports. In a similar study by (Faramarzi et al. 2010), it is shown that by adjusting the cropping pattern within the country and by intra-country water trade, Iran can achieve better water utilisation. In the period studied, it was shown that the current trend of trade does not lead to proper water utilisation in the production cycle.

Using graphical analysis on India's rice production and export, (Nishad and Kumar 2022), which acts as a major inspiration for our study's direction, it was concluded that in less than 300 years, India

would lose all the available water in the country with the current export rate of water. Post 1990, India's virtual water trade balance has been positive, rising to 32 billion m<sup>3</sup> between 1990-2018.

(Roson and Sartori 2010) takes a skeptical view at virtual water trade, saying that even though it has potential to curb the negative effect of water scarcity, it can only help marginally. In the middle-east and North Africa, however, the results are more promising. (Antonelli and Tamea 2015) shows that virtual water trade has not only grown, but also that this trade has decreased the impact of water-deficits in Middle East and North Africa (MENA) economies. There is still a lack of consensus however, as even in a recent study (Hekmatnia, Isanezhad, et al. 2023; Hekmatnia, Ardakani, et al. 2023), it was claimed that there was no positive correlation between the water abundance of virtual water exporting countries and the global sustainability of freshwater resources. (Goswami and Nishad 2015) goes as far as issuing a warning in the case of India, predicting acute water shortages from 2022 due to the current trends in virtual water trade.

Overall, we find that there is no fixed consensus on the impact of water abundance on virtual water trade, but there are alarming trends for India. We utilize a gravity-model (Xia et al. 2022; Duarte, Pinilla, and Serrano 2019) in our study, the first of its kind for India's case, to see the driving factors behind this virtual water trade, and hope to comment more strongly on the impact it is having on water sustainability.

### **III. Data and Methodology**

#### ***III.1 Data Sources***

##### **III.1.1 Countries:**

We have covered data from India's top 15 trade partners, over a time

period of 6 years, (2014-2019). Due to the vast differences in national and geopolitical factors among the countries under consideration, the final regression analysis has limited bias from factors affected by diplomatic relations between a trade partner and India, or from bias caused by factor endowments of a particular nation.

USA	China	UAE	Saudi Arabia	Russia
Indonesia	Iraq	Singapore	South Korea	Netherlands
Australia	Germany	Japan	UK	Malaysia

Table 1: Top 15 Trade partners of India

### **III.1.2 Natural and Socioeconomic Factors**

The factors affecting virtual water trade can be classified into two types: natural factors and socioeconomic factors. Given that virtual water trade is based on economic activities, the social and economic conditions of importing and exporting countries invariably affect virtual water flow, while the amount of virtual water in a given region is determined by the amount of water used by crops during their growth period (Xia et al. 2022). For the analysis, only virtual water trade of wheat and rice is considered, both of which are water-intensive crops.

Renewable water resources and arable land are two major factors that invariably affect virtual water trade; Countries rich in water and land would tend to cultivate water-intensive crops and export these crops to countries scarce in water and land resources, in accordance with the Heckscher-Ohlin Theory. Virtual water thus tends to flow out of countries with abundant water and soil resources and flows into countries with poor water and soil resources (Kumar and Singh 2005).

Virtual water trade also requires economic strength of both the

importer and exporter; Citizens of countries with scarce water resources would require sufficient purchasing power to afford products from other countries, while the countries abundant in water resources would need to invest more in production of water-intensive crops to meet international demand. Higher population correlates to higher food and water consumption, thus affecting virtual water trade. Transportation costs also play an important role in determining the volume of virtual water flow, hence geographical distance between exporter and importer is an important factor. Higher transportation costs from geographical separation impedes trade.

We have thus used five indicators influencing virtual water trade to construct the panel data. These indicators are renewable freshwater resources per capita (Water), arable land (Land), geographic distance (DIST), gross domestic product (GDP), and population (POP). The data on renewable freshwater resources per capita and cultivated area were taken from AQUASTAT (<http://www.fao.org/aquastat/en/databases/>). The gross domestic product and population of each country were obtained from World Bank Open Data (<https://data.worldbank.org/>). Geographic distance data between countries were obtained from the Cepii database (<http://www.cepii.fr/anglaisgraph/bdd/distances.htm>).

### **III.1.3 Crops and Virtual Water Content**

We have used annual trade data of wheat and rice, two water-intensive crops, between India and its top fifteen trade partners from Trade Map (<https://trademap.org/>). The values of virtual water content of wheat and rice were obtained from GDRC data on water footprints (<https://www.gdrc.org/uem/footprints/water-footprint.html>). Virtual water content includes all the water used in crop growth and development, from sowing till reaping. These values were then multiplied by the volume of export/import from/to India, to obtain the

virtual water flow in each case, and import values were subtracted from export values and virtual water export of both rice and wheat were added for each country and for every year, to obtain the Net Virtual Water Export data.

### ***III.2 Methods***

#### **III.2.1 Gravity Model using panel data**

The gravity model is derived from the law of universal gravitation. It assumes that the trade flow between two countries mainly depends on their economic strength and the geographical distance between them (Xia et al. 2022). We can also construct a gravity model using the five main trade indicators and level of virtual water trade.

In our study, we use panel data with 15 (denoted by  $i = 1, 2, \dots, 15$ ;  $i$  representing a country) countries and 6 time-series inputs (denoted by  $t = 1, 2, \dots, 6$ , from 2014 to 2019). The logarithmic linear panel model can be set to:

$$\ln y_{i,t} = \alpha_i + \beta_i \ln x_{i,t} + \lambda_t + \mu_{i,t}$$

where  $y_{i,t}$  is the dependent variable of dimension  $N \times 1$ ,  $x_{i,t}$  is the independent variable of  $N \times k$ ,  $\beta_i$  is the parameter to be estimated,  $\alpha_i$  is the individual effect,  $\lambda_t$  is the time effect, and  $\mu_{i,t}$  is the error term.

Before fitting the model, we transformed the variables as well as the trade data in order to remove differences in scale of factors and to standardize the variances in our data. To achieve this, we calculated the ratio between the value for India and the value for the concerned trade partner, for each year. The natural logarithms of these ratios were taken to normalize the dataset.

In certain cases, there was a net import of rice and wheat observed, giving us negative values for net virtual water exports, which could not be log normalized. Instead, the inverse hyperbolic sine function

was used to normalize the net VW export values. At sufficiently high inputs, as present in net export data, the inverse-hyperbolic sine function behaves like the logarithmic function, while being able to handle negative inputs.

Our equation for the model of virtual water flows was hence as follows:

$$\begin{aligned} ASINH(NET\_VW\_EX_{i,t}) = & \beta_1 \ln(Water_{i,t}/Water_{I,t}) \\ & + \beta_2 \ln(Land_{i,t}/Land_{I,t}) + \beta_3 \ln(DIST_{i,t}) + \\ & \beta_4 \ln(GDP_{i,t}/GDP_{I,t}) + \beta_5 \ln(POP_{i,t}/POP_{I,t}) + c + \mu \end{aligned}$$

where  $i = 1, 2, \dots, 15$ ;  $t = 1, 2, \dots, 6$ ;  $c$  is the intercept term;  $\mu$  is the error term; 'I' represents corresponding time-series data for India. All variables except distance were proportional to the value of the variables of India in the model.

### ***III.2.2 Model verification and estimation***

We used the F-test to test our model's overall fit, at a significance level of 5%. The p-test was used to test the significance of  $\ln(Water_{i,t}/Water_{I,t})$  in our model, to determine the effect a country's renewable water resources (per-capita) has on the country's virtual water exports, allowing us to determine whether virtual water trade has actually improved India's environmental sustainability.

## **IV. Results**

Our study is primarily concerned with the virtual water trade of India, specifically regarding rice and wheat. This research involved a meticulous analysis of various data sources and a comprehensive exploration of the subject. The data utilized in our investigation

encompassed multiple variables, which were subjected to log normalization, or transformation using the Inverse Hyperbolic Sine Function for the net export values. The data was collected for the years 2014-2019 and subsequently utilized in a pooled OLS regression.

The following variables emerged as statistically significant in our final regression model:

- 1 Renewable Water Resources per capita
- 2 Arable Land Area
- 3 Distance between the involved nations
- 4 The GDP of the two nations
- 5 The population of both nations

These findings are grounded in data and statistical analysis. Specifically, our results indicate that India's net virtual water trade is negatively influenced by the availability of renewable fresh water resources. Our analysis shows that this virtual water trade is negatively correlated with the GDP of both nations and the currency exchange rate between them. While as per expectations the relationship with population is positive, it seems that even distance has a positive relationship with virtual water net exports from India. This intriguing paradox warrants a more detailed discussion, which will be elaborated upon in the conclusion section.

The following table 2 presented in a structured and objective manner, provides a concise summary of our regression results:

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. xi: regress TNetEx_it lnWater_itWater_Indiat lnLand_itLand_Indiat lnDISTi lnGDP_itGDP_Indiat lnPOP_itPOP_Indiat
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Source	SS	df	MS	Number of obs =	90
Model	1831.182	5	366.2364	F( 5, 84) =	4.54
Residual	6771.70315	84	80.6155137	Prob > F =	0.0010
				R-squared =	0.2129
				Adj R-squared =	0.1660
Total	8602.88515	89	96.6616309	Root MSE =	8.9786

TNetEx_it	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]
lnWater_itWater_Indiat	2.233579	.7350206	3.04	0.003	.7719096 3.695248
lnLand_itLand_Indiat	1.599808	.6724847	2.38	0.020	.2624989 2.937118
lnDISTi	11.09943	4.570824	2.43	0.017	2.009847 20.18901
lnGDP_itGDP_Indiat	-6.119532	1.980731	-3.09	0.003	-10.05843 -2.18063
lnPOP_itPOP_Indiat	8.095638	2.159915	3.75	0.000	3.80041 12.39087
_cons	-53.22093	35.71834	-1.49	0.140	-124.2508 17.80891

Table 2: regression results

The statistical significance of these variables underscores their influence on India's net virtual water trade. These objective findings reveal that certain factors, such as renewable water resources and arable land, play a pivotal role in this trade, while economic factors (GDP) and currency exchange rates also have significant impacts. The significance of these variables is based on rigorous statistical analysis of the data.

Our dataset, spanning from 2014 to 2019, yielded several key observations:

1. Water availability was identified as a crucial determinant of virtual water trade. This is the primary analysis for our comment on sustainability of India’s virtual water trade. India, being a massive exporter of wheat and rice can look at its export patterns to countries with varying natural water endowments to judge its own sustainability of virtual water trade. Our results show that the countries with a more water endowment than India are the ones we are exporting a larger amount of virtual water to, and this directly indicates that for India (and the countries tied to India via global agricultural trade), this is unsustainable.

2. Economic factors, particularly GDP, emerged as influential determinants of trade volume, not necessarily following the gravity model's expectations. Countries with higher GDPs, such as the United States, China, Japan, the UK, Germany, and Russia, engaged in less extensive virtual water trade compared to India. Conversely, the UAE and Malaysia, with lower GDP figures compared to India, exhibited a relatively larger virtual water trading pattern.
3. The size of the population also consistently correlates with the extent of virtual water trade. Countries which had a larger population have again imported more virtual water (by the means of wheat and rice imports) than their lower population counterparts globally. This is also fairly intuitive and supports expectations of the authors.
4. Geographical distance shows a positive correlation with virtual water trade, which can indicate that India's trade with countries farther makes the tendency of virtual water exports from India higher.

## **V. Conclusion and Remarks**

The comprehensive analysis of several critical factors, including water availability, land resources, geographical proximity, economic indicators, and population offers profound insights into the dynamics of virtual water trade centering India. These findings present an all-encompassing perspective on the challenges and opportunities associated with the concept of Virtual Water Trade on the international trade of major agricultural products to-and-fro India.

Primarily, when examining the availability of water resources and land endowments, a stark contrast emerges among countries. Countries such as the USA, Russia, and Australia, among others,

exhibit significantly higher water availability than India, despite a net virtual water outflow observed from India to these countries. Although this can be explained by India's comparative advantage in production of Wheat and Rice owing to higher labour abundance and targeted advancements in technology and human capital, it exerts a strain on India's already overburdened food production and distribution system. As these nations engage in virtual water trade, it places additional strain on their already limited water supplies, ultimately leading to the unequitable distribution of this resource. Here, we observe a pressing need for enhanced water management and judicious resource allocation to sustain virtual water trade while preserving the delicate equilibrium of the environment.

Furthermore, economic factors, particularly the Gross Domestic Product, exert significant influence over the volume of virtual water trade. Notably, countries with robust GDP figures, such as the United States, China, Japan, the UK, Germany, and Russia, engage in extensive virtual water trade with India. This reveals the pivotal role that economic strength and market capacity play in determining the scale of virtual water exchanged. However, a noteworthy aspect lies in the variances shaped by economic disparities, as evident in the trading patterns of the UAE and Malaysia, characterized by lower GDP figures compared to India. These disparities emphasize the multi-faceted dimensions of virtual water trade and underscore the complexities inherent in international trade relationships.

In our analysis, distance appears to exert a positive influence on the trade volume. The positive coefficient for geographical distance in India's virtual water trade is a departure from the conventional gravity model of trade. Typically, this model proposes that trade between two countries should diminish as the distance between trading partners increases. However, in our analysis, distance appears to exert a positive influence on trade volume. This phenomenon can be understood in the context of a highly interconnected world. Modern

transportation networks, efficient communication and improvement in logistics have, to a large extent, reduced the impact of geographical distance on trade, especially in case of Virtual Water Trade, wherein perishable goods like rice or wheat can now be swiftly transported across long distances. In this light, the positive distance coefficient reflects the evolving dynamics of international trade.

A closer examination of the data reveals an apparent trend: nations with more populations tended to have higher net virtual water exports from India over the period of our study. This not only underscores the positive relationship between population size and virtual water trade but also establishes that this relationship is statistically significant. For instance, consider the case of China, a nation with one of the world's largest populations. Our analysis of virtual water trade data clearly shows that China's sizable population correlates with its significant virtual water exports from India. This alignment between population size and virtual water trade is further exemplified by the United States, another country with a substantial population. Our data illustrates that the United States, with its large population, maintains a notable presence in India's virtual water trade.

In conclusion, the intricate dynamics of virtual water trade are shaped by a multifaceted interplay of factors, which encompasses water and land availability, economic strength, and resource management. Nevertheless, it is crucial to underscore and address the adverse consequences of virtual water trade on the natural endowment of water resources. Such an understanding is indispensable for policymakers and trade stakeholders as they strive to optimize resource utilization and foster sustainable trade relationships. In a world where water resources are progressively becoming more precious and essential for global food security, addressing these challenges is of paramount significance. The most important relationship discovered is that India is substantially exporting virtual water (on a net basis) to countries which have a larger freshwater

endowment through agricultural trade, and this does not help the cause of sustainability for either India or any of its major trade partners, and hence the belief that Virtual Water may help create more water equality among nations is not being supported by our study. Policymakers need to take necessary steps to counter this loss of water from one of the most vulnerable countries when it comes to water scarcity (also the most populous country in the world), and ensure that virtual water trade is utilised for a sustainable distribution of water globally and not otherwise.

## **VI. Limitations and future directions**

Although our results have strong statistical significance and implications for policy, our study is not without limitations. Firstly, although rice and wheat are the most important crops for India's agricultural trade especially when it comes to virtual water content, there are a significant number of other crops that compose India's agricultural trade bidirectionally, and can have a significant cumulative impact on India's virtual water trade. Contemporary promotion and popularisation of crops considered 'superfoods', also has a significant impact on the trade and economic welfare of exporting nations. In this regard, the effect of growing trends in consumption of crops such as barley and millets, and their effect on India's trade pattern can be looked into. Future studies can also look to give a stronger explanation for the positive coefficient of the distance variable, which is behaving contrary to the expectations in the gravity model. Moreover, we have considered the total value of virtual water content in wheat and rice to calculate virtual water outflows and inflows, but for a more accurate representation of these flows, future studies can consider the values of virtual water in per unit weight of rice and wheat respectively, when grown in a particular country.

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