India's virtual water trade in rice and sugar and its association with declining groundwater levels

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I hereby declare that the data presented in this Dissertation report entitled, "India's virtual water trade of rice and sugar and its association with declining groundwater levels" is based on the results of investigations carried out by me in the Economics Discipline at Goa Business School, Goa University under the Supervision of Dr/Prof. Pranab Mukhopadhyay and the same has not been submitted elsewhere for the award of a degree or diploma by me. Further, I understand that Goa University or its authorities will not be responsible for the correctness of observations / experimental or other findings given the dissertation.

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Date: 09/05/2024

Place: Goa University

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"Water is the soul of the Earth."

(W. H. Auden)

"If there is magic on this planet, it is contained in water."

(Loren Eiseley)

PREFACE

It is imperative that we try our best to find alternative solutions to the extreme water poverty that India faces today and the vast amount of administrative energy that is lost in negotiations of the long-drawn inter-state water wars, for e.g., the Cauvery water dispute. Cities like Bengaluru are facing an acute water crisis while alarming rates of groundwater decline can be seen in northern states like Punjab and Haryana. Looking at solutions which are only concerned with efforts to increase the physical availability of water will be a myopic approach to this problem. Water, a precious resource, needs to be managed effectively. Virtual water trade is a step towards water resource accounting and must be adopted in policy circles especially in the face of water stress.

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Last but not the least, I'm grateful to Lord Shiva for dwelling within me and giving me the strength to undertake this research, for showering his blessings on me, and for always having my back. Har Har Mahadev.

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ABSTRACT

India is water-stressed. It is imperative that we address this situation before it reaches water scarcity i.e. annual per capita water availability of less than 1000 cubic metres. Adopting an innovative mix of solutions towards better water management is the way forward. Virtual water trade assessment is one such solution to address this problem as it tells us how much water is being used and where. This study is an attempt to quantify the virtual water trade volume of India at the subnational level pertaining to two water-intensive crop products viz. rice and sugar. In the case of sugar, virtual water exports increased from 633 GL in 2012 to 1386 GL in 2021 while for rice virtual water exports increased from 34446 GL in 2012 to 70469 GL in 2021. Negative water savings have been recorded for almost all years in the period under study in respect of both rice and sugar. An annual export of 320 tonnes of rice or 447 tonnes of sugar is associated with a decline in the groundwater level by 1 mm in that year. An increase in annual gross virtual water exports by 1000 GL from a state is associated with an annual decline in groundwater level in that state by about 1.053 metres. Also, 1000 GL increase in virtual water exports is associated with a lower water saving of about 16 GL. These trends indicate that the current pattern of virtual water trade is unsustainable, both at the national and subnational level, and steps must be taken to implement more sustainable cropping patterns in order to utilise our limited water resources more efficiently.

Keywords: Virtual water trade, water savings, groundwater, India, regression analysis

CHAPTER 1: INTRODUCTION:

1.1 BACKGROUND

Access to clean water and water management are at risk as climate disasters increase and several regions face severe water scarcity (United Nations, 2023).

India had an abundant supply of water resources. However, from being a water abundant country, India is gradually progressing towards water scarcity due to increasing population pressure and urbanisation. Existing practices of water resource management are unable to keep up with these pressures. Going by the Water Bodies 1st Census Report by the Ministry of Jal Shakti GoI (2023), with just 4% of global water resources, India sustains 18% of the world population. About two lakh people die every year due to inadequate water, sanitation and hygiene and about 82 crore people of India have per capita water availability close to or lower than 1000 m^3 – the official threshold for water scarcity as per the Falkenmark Index (NITI Aayog, 2019). India ranked 13th amongst the most water-stressed nations in the world in 2019 (K. Kumar et al., 2023). Therefore, management of water resources has assumed great importance (Ministry of Jal Shakti GoI, 2023).

The water that is used in the production process of an agricultural or industrial product is called the 'virtual water' contained in the product, or the ‘water footprint’ of that product (Hoekstra & Hung, 2002). Studies have suggested that India has the largest water footprint in the world (with regard to all three categories i.e. green, blue and grey) of about 1047 Gm^3/yr (cubic gigameter/year), followed by China (967 Gm^3/yr) and the USA (826 Gm^3/yr) (M. M. Mekonnen & Hoekstra, 2011). According to Hoekstra & Hung (2002), considering the period 1995-1999, India ranked 5^{th} among the countries with the largest net virtual water export of 161.1 billion cubic metre (BCM).

The agriculture sector accounts for about 85-90% of global blue water consumption (Graham et al., 2020; M. M. Mekonnen & Hoekstra, 2011) which is significantly higher than the global average of

70% (Katyaini et al., 2021). The global water footprint related to crop production in the period 1996–2005 was 7404 billion cubic metres per year (78% green, 12% blue, 10% grey). (M. M. Mekonnen & Hoekstra, 2011).

Clean fresh water is a scarce good and thus should be treated economically. There is an urgent need to develop appropriate concepts and tools to do so (Hoekstra & Hung, 2002). Virtual water studies aid researchers, policymakers and the general public in looking at the problem of water scarcity from an economic perspective. It helps to lay more emphasis on how much water is being 'traded' between countries, states, provinces etc. in the guise of trade in goods and services, and thus, serving as a tool in the effective management of water resources.

1.2 THE CONCEPT OF VIRTUAL WATER, WATER FOOTPRINT AND WATER SAVINGS

The term "virtual water" was coined in about 1993 by Tony Allan when water scarce-countries like Israel were increasingly concerned about water-intensive export of fruits from their semi-arid basins (Allan et al., 2003) especially in the face of water wars with Arab neighbours. His empirical analysis was intended to investigate whether trade flows are aligned with water resource endowments (Katyaini et al., 2021). Since then, this term has gained currency and has come a long way in applied research relating to hydro-economics. However, the economics of virtual water trade is yet to be explored to a greater extent in developing countries like India and applied to policy-making. As Katyaini & Barua (2017) rightly state, there is a gap at the science-policy interface.

Virtual water is the water needed to produce agricultural commodities. The concept could be expanded to include the water needed to produce non-agricultural commodities as well (Allan et al., 2003). Since agriculture consumes the bulk of available water resources, it makes sense to apply the concept largely to crops as well as their derived products. Hence, most of the studies done until now pertain to the agricultural sector in some or the other way. When products containing water in

’embedded’ or ’virtual’ form are traded across political boundaries, the phenomenon is termed as ’virtual water trade’.

To visualise the relationship between consumption of goods and freshwater use, Hoekstra (2003) introduced the Water Footprint (WF) concept which measures the freshwater appropriated to produce goods or services, expressed as a water volume per unit of product (usually $m^3 ton^{-1}$). It is the sum of the water footprints of the process steps taken to produce a particular product. The water footprint is an indicator of direct and indirect appropriation of freshwater resources. It indicates direct (the green and blue water footprint) and indirect (grey water footprint) appropriation of freshwater resources which (i) evaporates or evapo-transpires, (ii) is incorporated into a product, (iii) is contaminated, or (iv) is not returned to the same area where it was withdrawn. All four uses result in water being unavailable for local, short-term reuse and refer to water loss to the catchment only (Kar et al., 2014). Water Footprint includes three components: green, blue and grey WFs. The green WF is the volume of rainwater consumed during production. The blue WF is an indicator of the consumptive use of fresh surface or groundwater. The grey WF is an indicator of the degree of freshwater pollution and is defined as the amount of freshwater needed to dilute polluted water to accepted water quality standards (Das et al., 2021). Use of nitrogen fertilisers in crop production is a major cause of water pollution and largely reason for estimation of grey water footprint. As stressed in UNDP’s Human Development Report 2006, which was devoted to water, water consumption is not the only factor causing water scarcity; pollution plays an important role as well. Pollution of freshwater resources does not only pose a threat to environmental sustainability and public health but also increases the competition for freshwater (M. M. Mekonnen & Hoekstra, 2011).

The concept of water footprint was subsequently elaborated in 2008 and provided a framework to analyse the link between human consumption and the appropriation of the globe’s freshwater. Consumptive water use in a certain period in a certain river basin refers to water that after use is no longer available for other purposes (M. M. Mekonnen & Hoekstra, 2011). The scope of VW flows concept has been quite large and has been applied to study water availability, food security, water use efficiency, economic diversification, conflict mitigation, and water scarcity management (Katyaini et al., 2021).

Virtual water trade is becoming an important component of water resource management (WRM) on the global as well as regional level, particularly in regions where water is scarce (V. Kumar & Jain, 2007). Sustainable WRM practices include addressing water supply shortages as well as management of water demands. Virtual water import-export has been suggested as a demand management practice to address the issue of water scarcity (Vanham et al., 2011). It conveys to water users how much water is being used and where.

Now let's look at the concept of virtual water when it is traded across political boundaries and its implications. In order virtual water (VW) flows to be sustainable, coordination among trading partners is required. It is needed to make a conscious decision on agricultural production and agricultural exports backed by the awareness as to whether it is using its scarce water resources to meet the food requirements of a relatively water-rich or water-scarce state. This awareness incorporated into policy making is important to give visibility to the virtual or embedded water flows in order to distribute water scarcity. It must be incorporated in national and state water policy decisions (Katyaini & Barua, 2017). Focus on a single crop will aid policymakers in addressing the deep-rooted structural problems of our water and agricultural economy (and thereby water scarcity) via a piecemeal approach. Each agricultural commodity and its associated virtual water scenario needs to be studied individually. In view of the intense long-drawn inter-state water wars that go on in our country, quantification of virtual water assumes even more importance. It is very important to know where exactly water is being used and how much of it is being used, for better water resource accounting. The next step is to assess whether the same water can be used for another purpose i.e. diverting existing water resources towards higher value uses.

Water resource accounting is extremely important for better water resource management. As an example, NITI Aayog (2019) states that 30% of Indian land is degraded or faces desertification, and this outcome is strongly linked to poor water management. Extensive groundwater extraction contributes to loss of vegetation cover, which eventually leads to desertification. Increasing desertification and land degradation diminishes green cover, which again in turn reduces land's capacity to recharge groundwater and water tables (NITI Aayog, 2019). According to the United Nations Convention to Combat Desertification (UNCCD), land degradation can also cause up to 4% losses in Agricultural Domestic Product in the future for India.

Virtual water assessments can play a role in addressing regional water deficits. The net effect of virtual water trade between two states will depend on the actual volume of water used in the exporting state in comparison to the water volume that would have been required to produce a commodity in the importing state. There will be net water saving if the trade is from states with relatively higher water productivity (where the product traded has a lower virtual water content) to states with relatively lower water productivity (where the product traded has a higher virtual water content) (Chapagain et al., 2006). The inverse of the virtual water content is known as the water productivity of a crop or crop product (Kampman, 2007).

Since the basis of water savings calculations is the virtual water content (VWC) of the crop pertaining to a particular state, it makes sense to understand the factors determining/affecting it. For this study, the figures for the state-wise virtual water content of crops/derived crop products are taken from M. M. Mekonnen & Hoekstra (2011), which have based their water footprint calculations Aldaya et al. (2012). They have used a water balance model which uses data on climate, soil, crop characteristics and actual irrigation as inputs to compute the VWC. The green/blue water footprints (m^3/ton) are calculated by dividing the green/blue component in crop water use by the crop yield. The crop water use is calculated using crop evapotranspiration which depends on climate parameters (which determine potential evapotranspiration), crop characteristics and soil water availability. Yields for crops are taken as given. The grey component of the water footprint (m^3/ton) is calculated by multiplying the fraction of nitrogen that leaches or runs off by the nitrogen application rate (kg/ha) and dividing this by the difference between the maximum acceptable concentration of nitrogen (kg/m^3) and the natural concentration of nitrogen in the receiving water body (kg/m^3) and by the actual crop yield (ton/ha). Since fertiliser application rates were not available, they assumed that crops receive the same amount of nitrogen fertiliser per hectare in all grid cells in India. They assumed that on an average, 10 % of the applied nitrogen fertiliser is lost through leaching, following Chapagain et al. (2006). For the maximum acceptable value of nitrate in surface and groundwater they have used the standard of 10 mg per litre of nitrate-nitrogen, again following Chapagain et al. (2006). The grey water footprint quantified is related to nitrogen use only. (Aldaya et al., 2012; M. M. Mekonnen & Hoekstra, 2011).

The water footprints of harvested crops have been used as a basis to calculate the water footprints of derived crop products by M. M. Mekonnen & Hoekstra (2011). For the calculation of the water footprints of derived crop products, they used product and value fractions. The product fraction of a product is defined as the quantity of output product obtained per quantity of the primary input product. The value fraction of a product is the ratio of the market value of the product to the aggregated market value of all the products obtained from the input product (Aldaya et al., 2012; M. M. Mekonnen & Hoekstra, 2011)

With a rapidly growing population and improving living standards in India, the water requirement of the country is increasing and the per capita availability of water resources is reducing day by day. Thus, there is a need for proper planning of water resource utilisation so that the gap between water availability and water requirement may be bridged, or at least be reduced. Virtual water trade is one of the alternatives to reduce water consumption, or, rather optimise water consumption (V. Kumar & Jain, 2007). Such a concept must be incorporated in policy making circles at the earliest.

1.3 THE WATER SCARCITY SCENARIO IN INDIA

The scarcity of water resources has many cascading effects including desertification, risk to biodiversity, industry, energy sector and risk of exceeding the carrying capacity of urban hubs. The increased scarcity of water affects the broad spectrum of economic, social and developmental activities of the nation. It not only affects Gross Domestic Product (GDP) directly in the form of loss of productivity of agriculture, industrial and service sector (including infrastructure) but also decreases the ability of the population to think, invent and produce which indirectly hampers the growth of the nation (NITI Aayog, 2019).

According to Hoekstra & Hung (2002), available water resources can be dealt with in an economically efficient way by increasing 'local water use efficiency', 'water allocation efficiency' and 'global water use efficiency'. Local water use efficiency plays a role at the user level where price and technology play a key role. Local water use efficiency can be increased by creating awareness, charging prices based on full marginal cost and by stimulating water-saving technology. At a higher level we speak of 'water allocation efficiency' where a choice has to be made on how to allocate the available water resources to the different sectors of the economy. People allocate water to serve certain purposes, which generally implies that other, alternative purposes are not served. Choices on the allocation of water can be more or less 'efficient', depending on the value of water in its alternative uses. Water is a public good, so water allocation at the country or catchment level is principally a governmental issue. The question is here how all demands for water can best be met and where – in case of water shortage – supply should be restricted (Hoekstra & Hung, 2002).

Beyond 'local water use efficiency' and 'water allocation efficiency' there is a level at which one could talk about 'global water use efficiency'. It is a fact that some regions are water-scarce and other regions are water-abundant. In some regions there is a low demand for water and in other regions a high demand. Unfortunately, there is no general positive relation between water demand and availability. A water-scarce country can thus aim at importing products that require a lot of water in their production (water-intensive products) and exporting products or services that require less water (water-extensive products). This is called import of virtual water (as opposed to import of real water, which is generally too expensive) and will relieve the pressure on the nation's own water resources. For water-abundant countries an argument can be made for export of virtual water. Import of water-intensive products by some nations and export of these products by others includes what is called ‘virtual water trade’ between nations. (Hoekstra & Hung, 2002)

No doubt India needs to work at improving water use efficiency at all three levels mentioned above, but its trade scenario is completely contradictory to the third principle of global water use efficiency. India is experiencing a very significant water challenge. Approximately, 820 million people of India - living in twelve river basins across the country have per capita water availability close to or lower than 1000 m^3 – the official threshold for water scarcity as per the Falkenmark Index (NITI Aayog, 2019). In such a scenario, where our country is on its way to water scarcity, producing as well as exporting highly water intensive products and crops makes little sense. India, a water-scarce country, is exporting water-intensive products. That’s the irony. This is why water use efficiency when it comes to trade at the national and sub-national level is a major leakage yet to be plugged. This front requires immediate action.

India is among the water-scarce economies experiencing a highly skewed distribution of water availability in space and time, uncertainties in supplies, and frequent and intense occurrence of hydro-meteorological disasters like floods and droughts. In India, 75–80% of the total annual rainfall is concentrated in the three months of the monsoon season. This leads to a heavy reliance on irrigation to optimise crop production. Irrigation is considered as important for increasing the resilience of the agricultural system, but excessive irrigation can have adverse impacts on the crops, the environment, and water security in India, especially when bulk of irrigation is sourced from groundwater (Katyaini et al., 2021).

Ideally, virtual water trade acts as a tool to alleviate stresses in several water stressed regions (Graham et al., 2020). However, unfortunately, this kind of trade is exacerbating the water scenario in India. Verma et al. (2009) show that the existing pattern of inter-state virtual water trade is exacerbating scarcities in already water scarce states and that rather than being dictated by water endowments, virtual water flows are influenced by other factors such as "per capita gross cropped area" and "access to secured markets".

NITI Aayog (2019) states that our international trade in agricultural commodities is contributing to large quantities of virtual water loss through the export of water-intensive crops. India exported more than 10 trillion litres (10 Gm^3) of embedded or virtual water through the export of about 37 lakh tonnes of Basmati rice in 2014-15 alone, which could have been used to grow much larger quantities of other crops, such as wheat or millet, that have smaller water requirements. Punjab, which produces more than 10% of India’s paddy, utilises groundwater for meeting 80% of its paddy irrigation needs, thus depleting its own and the country’s groundwater resources. Production challenges are being felt across agrarian states as regions run out of their primary irrigation sources. Increasing consumer preferences for high-value crops and dairy and meat products, which require significantly higher amounts of water for production, will only further exacerbate the country’s food security challenges. Climate change will also contribute to these challenges as increasing temperature levels, floods, and droughts create unfavourable environmental conditions for cultivation and impact crop productivity (NITI Aayog, 2019).

While much of the water traded globally is green water or renewable blue water, recent studies have found increasing extraction of nonrenewable groundwater from deep aquifers to grow crops that are then traded internationally. Continued depletion and overexploitation of nonrenewable groundwater has significant negative effects both regionally and globally, including, but not limited to, land subsidence, eventual sea-level rise, and water quality degradation (Graham et al., 2020).

Concerns over food security in the 1960s and 1970s had led to the Green Revolution. It helped ensure food security for the starving millions. However, the economics of crop pricing and markets associated with the Green Revolution had damaging and far-reaching consequences on the country's water, energy and land resources (Prajapati, 2018). Food production increased, but at the same time there was an expansion of irrigated area and a rapid rise in the number of electric and diesel pumps. A large part of the rain-fed area was converted to irrigated agriculture leading to growing multiple crops in a year with increased crop yields. While the expansion in groundwater-based irrigation helped meet the rising food demands of a large population of India, it has resulted in several environmental implications. Groundwater depletion in India has now become one of the most prominent challenges for food and water security (Dangar et al., 2021). Back then, we were facing a food crisis. And now we are going to face another one too, albeit due to another reason. That is why it is important to adopt sustainable solutions that will work in the long-term, rather than using government incentives to create a distorted market structure just like we did during the 1960s and 70s.

Graham et al. (2020) in their future virtual water trade projections find out that India will rely heavily on virtual water imports in 2100. On a temporal scale, water scarce regions export nonrenewable groundwater early in the century but cease to do so after mid-century (i.e.around the year 2050) as the demand scenario changes and groundwater depletion worsens. Tracing the virtual nonrenewable groundwater exports over time shows an important evolution as basins in India like the Indus River basin export substantial volumes in 2050, but do not contribute to the global nonrenewable groundwater exports in the year 2100. This is because extraction in the first half of the century from the large underground aquifers in India causes additional pumping to become too expensive to sustain in these regions. Hence, this implies that India, which according to Hoekstra & Hung (2002) had a water dependency of 0% and water self-sufficiency of 100%, would no longer be self-sufficient when it comes to food and water (‘Virtual water import dependency’ or ‘Water dependency’ reflects the level to which a nation relies on foreign water resources (through import of water in virtual form). ‘Water self-sufficiency’ percentage is simply obtained by subtracting the water dependency percentage from 100). At this juncture, it becomes important to speak about the water-food-trade nexus.

1.4 WATER-FOOD TRADE NEXUS

Agriculture is the largest consumer of the world's freshwater resources, and more than one-quarter of the energy used globally is expended on food production and supply. Feeding a global population expected to reach 9 billion people by 2050 will require a 60 per cent increase in food production (EFG, 2022). Among the economic sectors, agriculture has the largest direct water consumption in India; hence water scarcity can have an adverse effect on agriculture production (Katyaini & Barua, 2017). This statement itself shows how food production and adequate supply of water are intricately linked.

About 40 percent of all the water used for irrigation comes from aquifers. Especially in water-scarce countries, the provision of cheap energy for pumping groundwater for irrigated agriculture can lead to groundwater depletion and declining water quality, with potentially severe consequences for those who now depend on groundwater irrigation. Furthermore, the use of fertilisers and pesticides in agriculture is a serious threat to groundwater quality (EFG, 2022).

In order to address concerns of water insecurity, an integrative perspective on the governance of natural resources is required, where the interlinkages between resource use are considered. The nexus approach embodies a close relationship between the security of resources like water, soil, and climate, and economic and political aspects. The water–food nexus is viewed as important for advancing food security in a water-scarce world. It envisions the use of analytical methods to systematically evaluate the interlinkages between resources and inform relevant resource policies. Efforts at this front have been limited and need to be augmented. One of the methodological approaches for nexus assessment, from the interdisciplinary field of environmental management, is footprint-based virtual water (Katyaini et al., 2021).

India is an important case to study the water–food nexus and how it can aid in the transition from water scarcity to security. That's because multiple approaches have classified India as a water-scarce economy (Katyaini et al., 2021). Also, India is a country where the nexus problem is very 'real'. Addressing the scale of the nexus in a large growing economy such as India is a challenge. The water-food-energy and water-food-trade nexus manifests in different forms; such as investment in irrigation technology (when available) is driving a change in crop production to more high value commodities at the expense of staples . Subsidised energy and fuel potentially drive over exploitation of groundwater resources (Gupta et al., n.d.). Integrated assessments accompanying a nexus approach thus come to fore as important tools of natural resource management and policy frameworks necessitating the need to understand these resources and their use embedded in broad political processes, economic structures and governance conundrums (Prajapati, 2018). An approach for assessing trade-offs generated from resource use in various sectors is required to be developed (Gupta et al., n.d.)

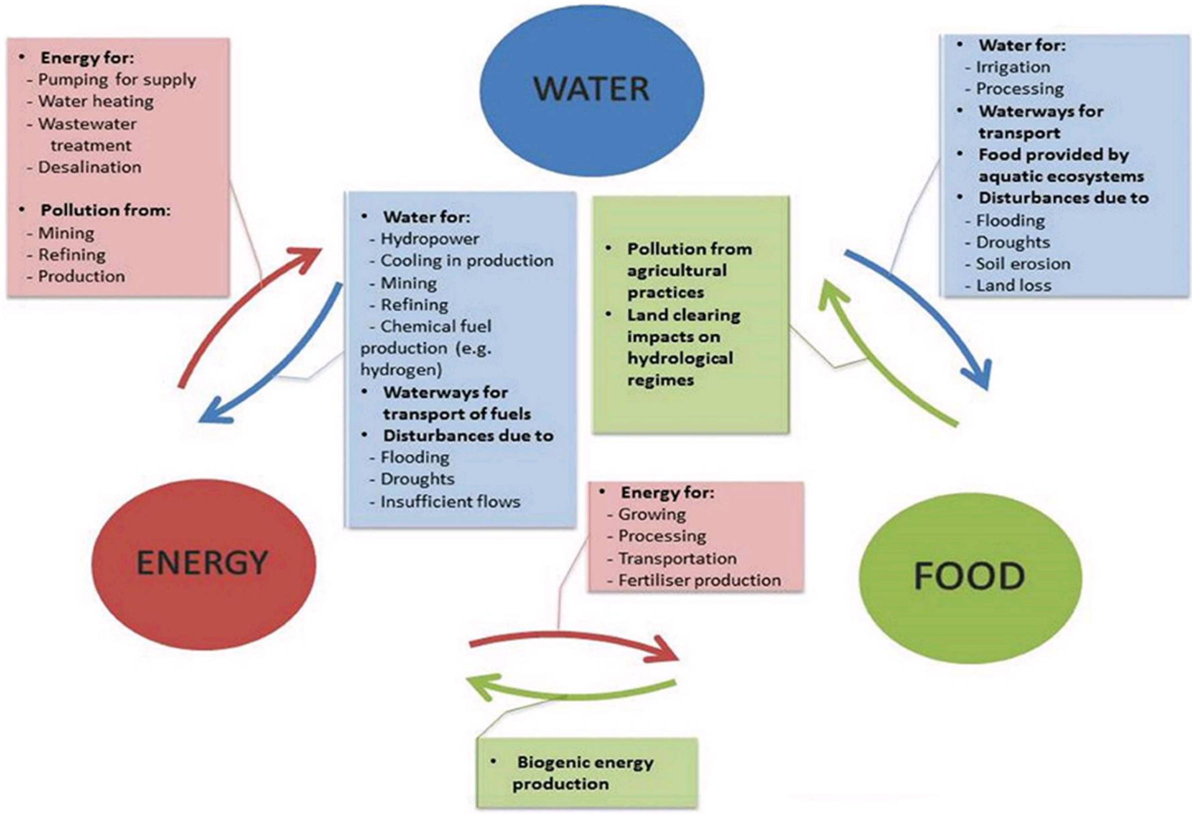

Figure 1.1. The Water-Energy-Food Nexus. Source: Markantonis et al. (2019)

Of all the sectors and human activities, agriculture and food security are most intimately tied to (or dependent on) water, and also affect water the most. Increase in population (to 1.66 billion by 2050) will increase the demand for food. The surge in demand for water-intensive crops will, ceteris paribus, multiply our current agricultural consumption of water. The Ganges has witnessed unprecedentedly low levels of water in several lower reaches in the last few summer seasons, and for the next 30 years, groundwater contribution to the river will continue decreasing. The dwindling of the Ganges river would severely affect water available for surface water irrigation, with potential future decline in food production. Consequently, by 2050, nearly 1/5th (approximately 115 million) of the 500 million inhabitants in the Ganga Basin would not have adequate access to carbohydrate-based food essential for survival (NITI Aayog, 2019).

1.5 THE GROUNDWATER CHALLENGE

Groundwater is water found underground in aquifers, which are geological formations of rocks, sands and gravels that hold substantial quantities of water. Groundwater feeds springs, rivers, lakes and wetlands, and seeps into oceans. Groundwater is recharged mainly from rain and snowfall infiltrating the ground. Groundwater can be extracted to the surface by pumps and wells (EFG, 2022).

In India, groundwater irrigation has observed a marked rise since the 1970s and water tables are depleting rapidly in many parts of the country. Schemes such as Minimum Support Price (MSP) and the Public Distribution System (PDS) have ensured a solid economic preference for rice and wheat based diets. This has led to a shift from traditional millets and the resultant increase in micronutrient deficiency. Studies have found that a favourable shift back to millets could ensure less water usage and thereby lower groundwater extraction, improve public health, and reduce greenhouse gas emissions. However, tweaking the existing preference for rice and wheat using policy has remained elusive. Instead, due to the powerful lobby of large farmers and state irrigation departments, governments have continued to provide free or subsidised power to Indian farmers. (Prajapati, 2018).

As mentioned above, rainfall in India is highly uncertain and consequently, agricultural activities are highly dependent on irrigation. According to Central Groundwater Board (CGWB), the contribution of groundwater is nearly 62% in irrigation, 85% in rural water supply and 45% in urban water supply. The entire green revolution in the country was based on the development of groundwater resources. There are over 20 million wells pumping water with power supply provided by the Government. This has been depleting groundwater, while encouraging wastage of water in many states. A comparison of depth to water level of pre-monsoon 2018 with decadal mean pre-monsoon (2008-2017) reveals that about 52% wells are showing decline in water level (NITI Aayog, 2019).

The patterns of interstate cereal trade in India emphasise the large dependency of agriculture on groundwater irrigation in groundwater-scarce states. Of the cereals traded within India in 2011-12, 41% were produced in states with over-exploited groundwater reserves and a further 21% in states with critically depleting groundwater reserves. 76% of the Indian population relies at least in part on cereals produced in states with over-exploited groundwater (Harris et al., 2020).

Not only does groundwater sustain ecosystems, it is also an important factor in climate change adaptation. With the rise in water scarcity and the decrease in the availability of surface water (due to human activity and climate change), there is increased reliance and pressure on groundwater (UNESCO, 2022). In certain river basins, water scarcity results from a mismatch between freshwater availability and demand. The Ganges basin in India is one of the river basins where blue water consumption is highest during the period of lowest water availability. Blue water refers to the volume of surface and groundwater consumed in the production of goods and services. Rice and wheat have the largest blue water footprint, indicating that they are produced through irrigated agriculture (Katyaini et al., 2021).

Good groundwater management is needed to achieve most of the Sustainable Development Goals (SDGs) of Agenda 2030. Fifty-three of the SDG's 169 targets have a link to groundwater. For instance, SDG target 2.4 on sustainable food production systems and resilient agricultural practices relies on the availability of groundwater. Good groundwater management is needed to achieve SDG target 6.6 to protect and restore water-related ecosystems, and SDG target 15.1 on the conservation of freshwater ecosystems and their services (EFG, 2022).

1.6 RATIONALE BEHIND SELECTION OF RICE AND SUGAR

India accounts for approximately 26 per cent of global rice production, consumes approximately 22 percent of global rice stocks, and contributes around 40 per cent of the world's rice exports (Malik et al., 2023). This study focuses on two agricultural commodities, namely rice and sugar. Rice and sugarcane are two of the most water consuming crops in Indian agriculture, which together consume more than 60 percent irrigation water of the country while occupying about one-fourth of the gross cropped area in the country. Skewed water allocation and inefficient irrigation practices like flood irrigation, are raising flags regarding sustainability of water use in Indian agriculture. Rice and sugarcane are commonly known as "water-guzzler" crops. Hence if sustainable agriculture water-use has to be ensured, economics (productivity and profitability) of at least these two crops needs to be studied thoroughly to see how best higher productivity and profitability can be achieved with lesser amounts of irrigation water. If the Prime Minister's vision of "har khet ko pani" (water to every field), and "per drop, more crop" is to be achieved within a reasonable time frame, one needs to look at the economics of agriculture (its productivity and profitability) with a different lens. It must shift its focus from land productivity and profitability to irrigation water productivity and profitability. This has to be done for at least two crops, rice and sugarcane (Gulati & Mohan, 2018).

1.7 RESEARCH GAP AND OBJECTIVE OF THE STUDY

Attempts have been made to estimate the virtual water content of different crops and crop products for India. These estimates have been mostly at the national level. Sub-national water footprints for India have been calculated by M. M. Mekonnen & Hoekstra (2011) and Kampman (2007). Water requirements vary between crops, and are affected by local agricultural and climatic factors; hence in a country the size of India, estimating the embedded water in food consumption and assessing the associated resilience of the food supply, requires subnational information linking locations of consumption and production (Harris et al., 2020). Studies at the subnational/interstate level in India regarding virtual water trade flows have been few (Chopra & Behera, 2021; Harris et al., 2020; Kampman, 2007; Katyaini & Barua, 2017; Verma et al., 2009) and have not been done for sugar. Sugar being a highly water-intensive agricultural commodity, its virtual water trade is necessary and yet to be quantified. Studies on the status of virtual water trade in conjunction with groundwater levels of Indian states have been limited (Chatterjee et al., 2022; Harris et al., 2020) and the domain is relatively unexplored. Considering the immediacy of this issue, it is necessary that the literature be further augmented.

The quantification of virtual water provides some insights as to its role in redistribution of water resources. It is useful in raising the public awareness of water resources and environmental impacts. It provides an opportunity to enhance water management (Yang & Zehnder, 2007).

Virtual water assessment is important to move towards internalising water as a factor of production (Katyaini & Barua, 2017) because in India right now, water is not being treated as a scarce resource or as a scarce factor of production. According to the Heckscher-Ohlin theory, the scarce factor of production must be available at a relatively higher cost and these cost differences form the basis for trade. However, sometimes, water prices either do not exist or are set so low that they in no way reflect the real value of water. Hence, virtual water trade patterns fail to be governed by comparative cost advantages (Yang & Zehnder, 2007). According to Kapuria & Saha (2021), water is one of the most underpriced factors of production.

There is a need for a virtual water trade strategy so that an economically appropriate value is attached to water or to its supply because trade would regulate itself in accordance with comparative cost advantages. Rather than the food importing side, there is a need to pay adequate attention to the food exporting side as well. This is associated with water endowments, resource use efficiency and environmental impacts associated with the production of goods for export (Yang & Zehnder, 2007). This is where quantification of virtual water flows becomes necessary.

Against the above background, the present study attempts to quantify and analyse the virtual water flows taking place among states of India in the guise of sugar and rice. It is important to know if these virtual water flows benefit India as a whole or not. Therefore, this study also attempts to calculate the corresponding national water savings/losses that have occurred due to inter-state movement of sugar as well as rice. In addition to that, a regression analysis has been done to analyse the link between the groundwater level of the states of India and virtual water exports. This is done in order to determine if virtual water exports from a state have an impact on the groundwater levels of that state. Lastly, the link between virtual water exports and water savings of a state is analysed through a regression analysis as well, to determine if the virtual water trade of a state leads to net water losses or gains.

1.8 SCOPE OF STUDY

The period of this study is 2012-22.

This study covers all states and union territories (UTs) of India except Andaman and Nicobar Islands and Lakshadweep. Andhra Pradesh for the period before its bifurcation into two is assumed to include the trade of Telangana as well. The same assumption holds true for some years even after bifurcation because interstate trade data has not shown separate figures for the two states. The trade of Dadra and Nagar Haveli and Daman and Diu have been considered as one before the reorganisation of union territories. Similarly, Jammu and Kashmir includes the trade of Ladakh as well. Inland movement of commodities i.e. movement within a state/UT has been excluded. Manipur and Mizoram were excluded from virtual water trade calculations of interstate and international trade of sugar due to their negligible role in trade of sugar. Manipur, Mizoram and Sikkim had to be excluded from the regression analysis involving decline in groundwater levels and virtual water exports ground due to lack of groundwater data availability in respect of the three states.

Hereby, ‘union territory’ will be referred to as ‘state’ for the sake of convenience.

CHAPTER 2: REVIEW OF LITERATURE

There have been studies all over the world which have calculated the water footprint or virtual water content of either primary or secondary products either at the national level, sub-national level or at the local/village level. It can even be calculated in the context of a particular river basin. Alternatively, any geographical area can be divided into distinct units according to its unique climate (rainfall, temperature, humidity, albedo etc.) and soil conditions in order to obtain accurate results of the virtual water content of a product grown or produced in that particular region. The water footprint varies across different crops and different production regions as well. The water footprint within a geographically delineated area (e.g. a province, nation, catchment area or river basin) is equal to the sum of the water footprints of all processes taking place in that area (M. M. Mekonnen & Hoekstra, 2011).

Initially, studies used to concentrate only on green and blue water footprint (the green and blue component of virtual water trade) mainly due to lack of data availability. Hoekstra & Hung (2002) limited their definition of water use to blue water use i.e. they considered only blue water footprint when it comes to virtual water trade calculations. Subsequently, studies began to separate blue water consumption from green water. M. M. Mekonnen & Hoekstra (2011) was the first study at the global level to incorporate the grey water footprint in agriculture.

Hoekstra & Hung (2002) quantified the volumes of all virtual water trade flows related to international crop trade between nations in the period 1995-1999 and to put the virtual water trade balances of nations within the context of national water needs and water availability. They were the first to make a global estimate of the consumptive water use for a number of crops per country. M. M. Mekonnen & Hoekstra (2011) quantified the green, blue and grey water footprint of 126 crops as well as more than two hundred derived crop products for the period 1996–2005 in a spatially-explicit way using a grid-based dynamic water balance model i.e. a model that takes into account local climate and soil conditions and nitrogen fertiliser application rates and calculates the crop water requirements, actual crop water use and yields and finally the green, blue and grey water footprint at grid level.

Above were primarily data reports and did not give an in-depth interpretation of the results (Hoekstra & Hung, 2002). These water footprint calculations/estimations have helped in subsequent studies and analyses on water consumption, volume of virtual water trade, etc. .

Kapuria & Saha (2021) analyse the patterns of virtual water trade (VWT) in agricultural products across the globe and the implications for alleviating water scarcity.

Graham et al. (2020) provide an assessment for the first time of changes over the 21st century in the amount of various water types required to meet international agricultural demands. They demonstrate how global agriculture trade and the historical global virtual water trade network will be restructured by 2100 due to potential future socioeconomic and climatic changes leading to alterations in the production of agricultural goods. The study also provides an assessment of the quantities of nonrenewable groundwater extraction from aquifers around the world required to meet the international crop demand.

Above are some of the studies at the global level. One of the first studies at the national level which quantified inter-state virtual water flows in India is by D. Kampman (2007) where the author quantifies and assesses international and interstate virtual water flows from and to the Indian states and tries to address the question as to why water scarce regions have a water deficit. Kumar & Jain (2007) review the virtual water content of various products for India and give the status of virtual water trade taking place from India. Another study is by Verma et al. (2009) where the authors discuss the potential of virtual water trade within the country as an alternative to the National River Linking Programme (NRLP) and explore the factors that influence inter-state virtual water trade in India. Katyaini & Barua (2017) quantify and analyse interstate virtual water flows for the period 1996-2014 pertaining to rice, wheat, maize, millets, gram and pulses and link these domestic flows to the water scarcity scenario in each state. Additionally, they even calculate whether there is a net water saving/loss on account of inter-state food grain trade. Harris et al. (2020) quantify the virtual water trade between Indian states of five major cereals for the year 2011-12 and match cereal exports to the groundwater status of the exporting state . Katyaini et al. (2021) analyse the governance of the water–food nexus in the states with the highest outflows and inflows of virtual water in order to identify the priorities for the states to transition from water scarcity to water security. Chopra & Behera (2021) examine the interstate virtual water trade flows embodied in wheat and rice products across India's different states and union territories during 1994–2017 and link the net virtual water trade flows with water scarcity concentration in Indian states. Chatterjee et al. (2022) quantify the relationship between output subsidies and declining water tables in India via a regression analysis.

CHAPTER 3: METHODOLOGY

The basic approach to calculate virtual water export and import has been to multiply international as well as domestic crop/derived crop product trade flows (ton/yr) by its associated virtual water content (m^3/ton) (Hoekstra & Hung, 2002). A similar approach has been adopted over here.

Inter-state trade data has been taken from the Directorate General of Commercial Intelligence and Statistics (DGCIS). Data on state-wise international exports has been taken from Agricultural and Processed Food Products Export Development Authority (APEDA). However, data on how much sugar and rice have been imported into each state from overseas is unavailable. Hence, when we use the term 'Net Exports' in this study, only imports from other states of India have been accounted for; international imports have not been considered. Correspondingly, virtual water imports from the rest of the world to each state have not been accounted for.

The green, blue and grey water footprints (m^3/ton) for each state of India have been sourced from Mekonnen & Hoekstra (2010) where the authors have calculated the virtual water content (VWC) of primary crops and derived crop products for each state of India. Water productivity differs between states due to different climate and soil conditions.The average water footprint per ton of primary crop differs significantly among crops and across production regions. Crops with a high yield (or large fraction of crop biomass) that is harvested generally have a smaller water footprint per ton than crops with a low yield (or small fraction of crop biomass harvested) (M. M. Mekonnen & Hoekstra, 2011). The yield of the crop is assumed to be constant.

3.1 SUGAR

M. Mekonnen & Hoekstra (2010) classify products according to the Harmonised System of classification of products. Hence, in this study too, trade figures are sourced and classified by the same nomenclature. We are concerned with Chapter 17 (Sugars and Sugar Confectionery) of the Harmonised System (HS) which includes the products mentioned in Table 3.1.

Table 3.1. Classification of sugar products (domestic trade). Source: CBIC, GoI

HS 4-digit code	HS 6-digit code	Product Category
1701		Cane or beet sugar and chemically pure sucrose
	170111	Raw sugar (gur/jaggery)
	170191	Refined sugar
1703	170310	Molasses

Apart from the virtual water content (VWC) of HS Code 170111 (i.e. raw sugar - gur/jaggery) and HS Code 170310 (i.e. molasses) (for each state), the VWC for all other sugar products according to the calculations of M. Mekonnen & Hoekstra (2010) is the same. The VWC for Chapter 17 HS Codes not calculated by (M. Mekonnen & Hoekstra, 2010) (such as HS code 1704) is approximated by the VWC for refined sugar (HS Code 170191). Where VWC data is unavailable for some states, the country-average VWC of India has been taken as a proxy.

For each year, interstate trade data is available for each of the Indian Trade Classification - Harmonised System of Nomenclature (ITC-HS) chapters, as well as separately available for selected commodities. Hence, inland movement among states pertaining to HS Chapter 17 (Sugars and sugar confectionery) is given as a combined figure and separate figures (selected commodities) are available for:

- Sugar
- Gur-Jaggery/Gur-Shakkar
- Molasses

As mentioned above, the VWC of all other sugar products apart from raw sugar (i.e. gur-jaggery/gur-shakkar) (HS Code 170111) and molasses (HS Code 170310) is the same (or is assumed to be the same where VWC values are unavailable) as refined sugar (HS Code 170191). Hence, in this study, when it comes to domestic virtual water trade calculations, the three broad product categories considered are sugar, gur-jaggery/gur-shakkar and molasses. However, 'sugar' is re-defined to include all products of HS Chapter 17 (sugars and sugar confectionery) except gur-jaggery/gur-shakkar and molasses. Hence, trade of 'sugar' is calculated by subtracting the interstate trade volumes of gur-jaggery/gur-shakkar and molasses from the interstate trade of HS Chapter 17. Only for the years 2019, 2020 and 2021 the above adjustment is not made due to unavailability of interstate trade data in terms of product-wise HS classification. Inter-state trade data of gur-jaggery (gur-shakkar) for the year 2021 is unavailable due to a change in format of the data whereby there has been no distinction between the two products. Hence, for the year 2021, the trade of sugar is assumed to include the trade of gur-jaggery (gur-shakkar) as well. This is the classification for trade volume figures used in case of domestic inter-state trade of sugar.

Regarding international trade of sugar, the classification of products used in this study is given in Table 2 below.

Table 3.2. Classification of sugar products (international trade). Source: APEDA, GoI, CBIC, GoI

HS 4-digit code	**HS 8-digit codes**	**Product Category**

1701		**Cane or beet sugar and chemically pure sucrose, in solid form**
	17011110	Cane Jaggery
	17011310	Cane Jaggery
	17011410	Other Cane Sugar: Cane Jaggery
	17019100	Refined Sugar Containing Added Flavouring Or Kg. Colouring Matter
1702		**Other Sugars, including chemically pure lactose, maltose, glucose and fructose, in solid form; sugar syrups not containing added flavouring or colouring matter; artificial honey, whether or not mixed with natural honey; caramel**
	17021110	Lactose And Lactose Syrup Containing 99% Or More Lactose Solid Form
	17021190	Lactose And Lactose Syrup Containing 99% Or More Lactose Solid Form
	17021910	Lactose And Lactose Syrup Other Than Containing 99% Or More Lactose Solid Form
	17021990	Lactose And Lactose Syrup Other Than Containing 99% Or More Lactose Solid Form
	17022010	Maple Sugar And Syrup in Solid Form
	17022090	Maple Sugar And Syrup Other Than Solid Form
	17023010	Glucose And Glucose Syrup, Not Containing Fructose Or Containing In The Dry State Less Than 20% By Weight Of Fructose, Liquid
	17023020	Glucose And Glucose Syrup, Not Containing Fructose Or Containing In The Dry State Less Than 20% By Weight Of Fructose, Solid
	17023031	Dextrose, Not Containing Fructose Or Containing In The Dry State Less Than 20% By Weight Of Fructose, Solid
	17023039	Dextrose, Not Containing Fructose Or Containing In The Dry State Less Than 20% By Weight Of Fructose, Other
	17024010	Glucose And Glucose Syrup, Containing In The Dry State At Least 20% But Less Than 50% By Weight Of Fructose, Liquid

	17024020	Glucose And Glucose Syrup, Containing In The Dry State At Least 20% But Less Than 50% By Weight Of Fructose, Solid
	17024031	Dextrose, Containing In The Dry State At Least 20% But Less Than 50% By Weight Of Fructose, Solid
	17024039	Dextrose, Containing In The Dry State At Least 20% But Less Than 50% By Weight Of Fructose, Other
	17025000	Chemically Pure Fructose
	17026010	Other Fructose And Fructose Syrup, Containing In The Dry State More Than 50% By Weight Of Fructose, Solid
	17026090	Other Fructose And Fructose Syrup, Containing In The Dry State More Than 50% By Weight Of Fructose, Others
	17029010	Palmyra Sugar
	17029020	Chemically Pure Maltose
	17029030	Artificial Honey, Whether Or Not Mixed With Natural Honey
	17029040	Caramel
	17029090	Other, Including Invert Sugar And Other Sugar And Sugar Syrup Blends Containing In The Dry State 50% By Weight Of Fructose
1704		Sugar Confectionery
	17041000	Chewing Gum, Whether Or Not Sugar-Coated
	17049010	Jelly Confectionery
	17049020	Boiled Sweets,Weather Or Not Filled
	17049030	Toffees,Caramels And Similar Sweets
	17049090	Other Sugar Confectionery, Not Containing Cocoa

HS Code for Molasses is excluded from Table 2 as the product has not been exported internationally. The virtual water content (VWC) of HS 4-digit code 1702 and HS 4-digit code 1704 is unavailable, and hence, VWC of HS Code 170191 (Refined sugar) has been taken as a proxy for the same. As mentioned before, data for only international exports is available, not international imports, hence the latter is excluded.

3.2 RICE

To ascertain the volume of rice traded, Principal Commodity trade classification has been used. Domestic inter-state trade data by rail and river available at DGCIS (principal commodity classification) has been divided into:

- Rice in the husk
- Rice not in the husk

The same categorisation has been used in this study in order to calculate the volume of virtual water traded. The following virtual water content figures have been taken for these two categories:

Table 3.3. Classification of rice products. Source: APEDA, GoI

Product	Product Code (HS-6 digit) and Product Description as per Mekonnen & Hoekstra (2010)
Rice in the husk	100620 - Rice, husked (brown)
Rice not in the husk	100630 - Rice, semi-milled or wholly milled, whether or not polished or glazed

Wherever rice was categorised into ‘Rice - Basmati’ and ‘Rice - Other than Basmati’, trade figures were added and combined into one because the virtual water content figures (in m^3/ton) have been assumed to be one and the same for both categories. For the year 2021, rice was categorised as ‘Rice - Basmati’ and ‘Rice - Other than Basmati’, instead of Rice in the husk and Rice not in the husk. Hence the trade figures for both were added up. Virtual water content (VWC) figures are unavailable for Kerala, Mizoram and Telangana and hence the country average VWC of rice has been taken as a proxy for these three states.

3.3 VIRTUAL WATER TRADE CALCULATION

The virtual water exports (VWE) (m^3) of a state are calculated using equation (1):

$$VWE(s_e,p,t) = Green\ (s_e,p,t) + Blue\ (s_e,p,t) + Grey\ (s_e,p,t) \qquad (1)$$

Where variables Green, Blue and Grey are the green, blue and grey water components of exports and are calculated as:

$$Green(s_e,p,t) = T(s_e,p,t) * GreenVWC(p,s_e) \qquad (2)$$

$$Blue(s_e,p,t) = T(s_e,p,t) * BlueVWC(p,s_e) \qquad (3)$$

$$Grey(s_e,p,t) = T(s_e,p,t) * GreyVWC(p,s_e) \qquad (4)$$

Where T is export of product p (or commodity) (in ton) from exporting state s_e in year t GreenVWC is the green virtual water component (in m^3/ton) of product p in the exporting state s_e , BlueVWC is the blue virtual water component (in m^3/ton) of product p in the exporting state s_e and GreyVWC is the grey virtual water component (in m^3/ton) of product p in the exporting state s_e .

Similarly, the virtual water imports (VWM) (m^3) of a state are calculated using equation (5):

$$VWM(s_i,p,t) = Green\ (s_i,p,t) + Blue\ (s_i,p,t) + Grey\ (s_i,p,t) \qquad (5)$$

Where p is the product/commodity imported in year t by importing state s_i ; variables Green, Blue and Grey are the green, blue and grey water components of imports and are calculated as:

$$Green(s_i,p,t) = M(s_i,p,t) * GreenVWC(p,s_e) \qquad (6)$$

$$Blue(s_i,p,t) = M(s_i,p,t) * BlueVWC(p,s_e) \qquad (7)$$

$$Grey(s_i,p,t) = M(s_i,p,t) * GreyVWC(p,s_e) \qquad (8)$$

Where M is the import of product p (or commodity) (in ton) to importing state s_i in year t. GreenVWC is the green virtual water component (in m^3/ton) of product p in the exporting state s_e , BlueVWC is the blue virtual water component (in m^3/ton) of product p in the exporting state s_e and GreyVWC is the grey virtual water component (in m^3/ton) of product p in the exporting state s_e.

The above approach is applied to calculate virtual water flows on account of both domestic as well as international trade.

Net virtual water exports (VW) are calculated as simply the difference between virtual water exports (VWE) and virtual water imports (VWM) of each state s in product p in year t.

$$VW(s,p,t) = VWE(s,p,t) - VWM(s,p,t) \qquad (9)$$

Virtual water flows (VWF) pertaining to a state s in year t are calculated by summing up the net virtual water exports of that state taking into account all products:

$$VWF(s,t) = \sum VW(p) \qquad (10)$$

'All products' means all the individual categories under the Harmonised System (HS) for both rice as well as sugar.

The above methodology is applied to calculate both - virtual water flows on account of international trade (VWF_1) and virtual water flows on account of domestic trade (VWF_2) with respect to a state. Thereafter, domestic and international virtual water flows are added up to obtain the final figure for Total Virtual Water Exports (TVWE) pertaining to a state:

$$TVWE\ (s,t) = VWF_1 + VWF_2 \qquad (11)$$

3.4 WATER SAVINGS CALCULATION

Water Savings (WS) (m^3) generated on account of exports from a state have been calculated using equation (11):

$$WS(s_e,p,t) = [\ VWC(s_i,p) - VWC(s_e,p)\ ] * T(p,s_e,s_i,t) \quad (12)$$

where *T* is the volume of trade of product p between exporting state s_e and importing state s_i in year *t*.

Summing up the water savings (or water losses) for each state for each year t in respect of sugar and rice, we obtain the net water saving/loss (m^3) on account of export of rice/sugar from exporting state s_e:

$$WS(s_e,p) = \sum_{se,p} WS(s_e,p,t) \quad (13)$$

Summing up the water savings (or water losses) of all states in all products for each year, we obtain the net water saving/loss (m^3) for each year:

$$WS(t) = \sum_{t} WS(s_e,p) \quad (14)$$

3.5 RELATION OF GROUNDWATER LEVELS WITH VIRTUAL WATER TRADE

To know if there is an effect of virtual water exports on the groundwater level of each state, a model can be estimated that explains the decline in groundwater level of each state in terms of its virtual water exports, the average annual rainfall received and the average annual temperature. Such a model is adopted in this study which explains the groundwater level in a particular year of a particular state in terms of the state's virtual water exports. This is done at the subnational level in India for the 10-year period of 2012 to 2021. This is the latest period for which data is available. The actual rainfall received in that state and the state's average annual temperature is taken into account as well, in the form of two additional regressors.

The model can be stated in the form of the following regression equations:

$$GW_{st} = \beta_0 + \beta_1 gross_{st} + \beta_2 rain_{st} + \beta_3 temp_{st} \quad (15)$$

$$GW_{st} = \beta_0 + \beta_1 net_{st} + \beta_2 rain_{st} + \beta_3 temp_{st} \quad (16)$$

where variable *GW* is the observed range of average groundwater level measured in metres below ground level (m bgl), *gross* represents the gross virtual water exports (in BCM), *net* represents the net virtual water exports (in BCM), *rain* is the annual rainfall received (in mm) and *temp* is the average annual temperature (in ℃) of state *t* in year *t*. Subscripts s and t denote the state and the year respectively.

Thirty-three states over a period of 10 years are considered, however, due to lack of groundwater data availability with regard to Mizoram, Manipur, Sikkim and no virtual water exports in some years, the number of observations reduces from 330 to 226 and 262 for regression models (15) and (16) respectively. Data on state-wise annual rainfall received is compiled from meteorological sub-division wise annual rainfall statistics (actual rainfall) made available in the Annual Climate Summary published by Climate Research & Services, India Meteorological Department for the years 2012 to 2021. Figures for state-wise and year-wise average annual temperature have been computed from station-wise annual temperature extremes given in the same document. Due to non-availability of temperature figures for Dadra and Nagar Haveli, Nagaland and Puducherry, proxies have been taken as temperature figures of neighbouring states.

The gross as well as net virtual water export figures have been computed in this study. The same figures have been used in the regression models.

Groundwater level is measured in metres below ground level (mbgl). State-wise data for observed range of ground water level for the period 2012 to 2021 has been taken from India Water Resources Information System (WRIS) portal which collects data from the Central Ground Water Board (CGWB), apart from many other national as well as state bodies as well which provide groundwater related data.

3.6 RELATION OF WATER SAVINGS INCURRED WITH VIRTUAL WATER TRADE

Now we try to ascertain the relationship between water savings and virtual water exports. In order to know whether water savings incurred are in sync with the amount of virtual water exports of a state in a particular year, a regression analysis can be done as follows:

$$WS_{st} = \beta_0 + \beta_1 gross_{st} + \beta_2 rprod_{st} + \beta_3 sprod_{st} + \beta_4 ryield_{st} + \beta_5 syield_{st} \quad (17)$$

$$WS_{st} = \beta_0 + \beta_1 net_{st} + \beta_2 rprod_{st} + \beta_3 sprod_{st} + \beta_4 ryield_{st} + \beta_5 syield_{st} \quad (18)$$

WS denotes the water savings (in BCM), *gross* represents the gross virtual water exports (in BCM), *net* represents the net virtual water exports (in BCM) made on account of inter-state trade, *rprod* is the production of rice (in thousand tonnes), *sprod* is the production of sugarcane (in thousand tonnes), *ryield* is the yield of rice (in kg/ha) and *syield* is the yield of sugarcane (in kg/ha). Subscripts s and t denote the state and the year respectively.

Data on the state-wise and year-wise production of rice, production of sugarcane, yield of rice and yield of sugarcane is sourced from the Reserve Bank of India's Handbook of Statistics on Indian Economy. Figures for water savings and virtual water exports are calculated in this study.

In order to compute the regression results, the statistical software package R has been used. The charts and scatter plots in this study have been generated using R as well as Microsoft Excel.

The maps in this study have been generated with the help of India in Pixels Mapmaker - iipmaps.

CHAPTER 4: RESULTS AND DISCUSSION

An important question to ask is why water scarcity exists. Accounting for water consumption via quantification of the water footprint and virtual water trade helps in answering this question in part. This study is a step in that direction.

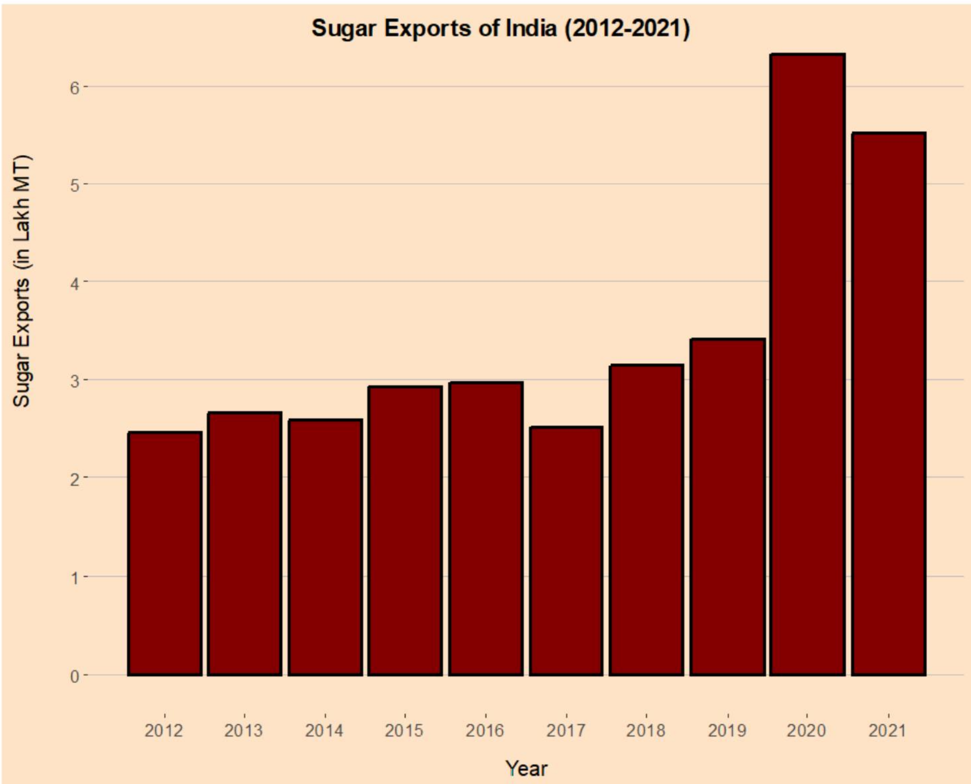

Figure 4.1. Sugar Exports of India (2012-21), Source: Compiled from APEDA database using R software.

Figure 4.1 depicts the exports of sugar (in lakh metric tonne) from India to the rest of the world during the 10-year period of 2012 to 2021. Sugar exports have been steadily increasing in these ten years, from about 2.5 lakh MT in the year 2012 to 6.32 lakh MT in 2020 and 5.52 lakh MT in 2021. Sugar exports of India as a percentage of its sugar production have been increasing as well. It was 0.98 in 2012, 2.04 in 2020 and 1.53 in 2021. The exact figures for all years are given in Appendix II.

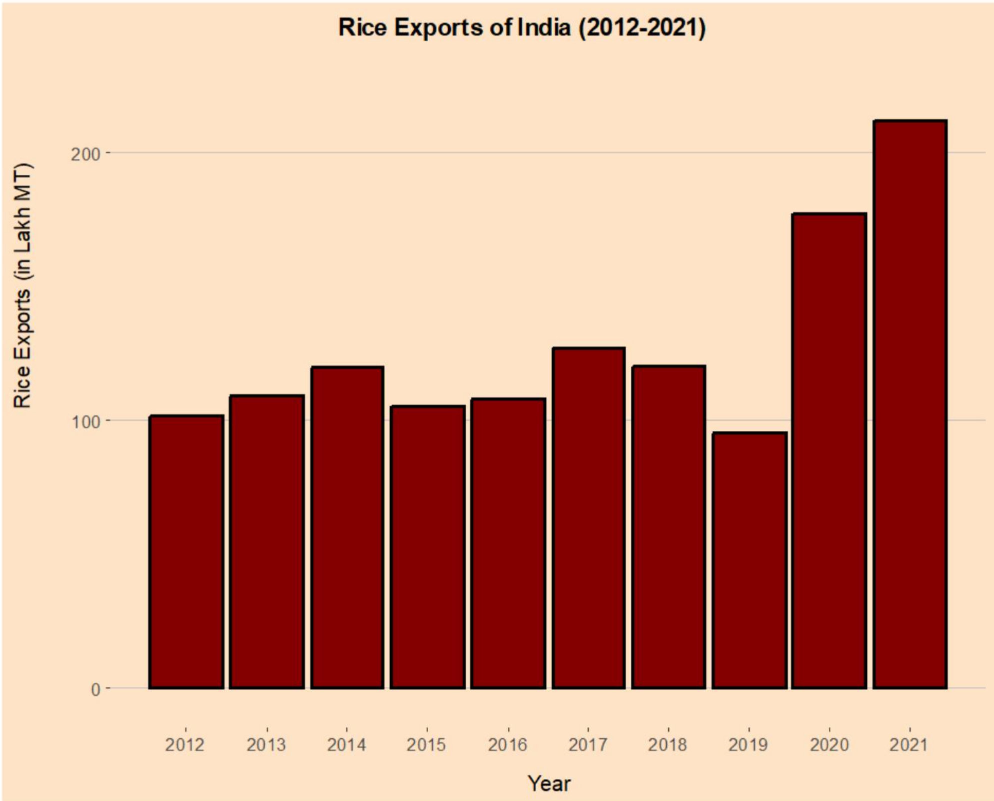

Figure 4.2. Rice Exports of India (2012-2021), Source: Compiled from APEDA database using R software.

Figure 4.2 depicts the exports of rice (in lakh metric tonnes) from India to the rest of the world during the 10-year period of 2012 to 2021. Rice exports have increased manifold in these ten years, from about 101.48 lakh MT in the year 2012 to 177.26 lakh MT in 2020 and 212.10 lakh MT in 2021. Rice exports of India as a percentage of its rice production have increased as well, from 9.64 in 2012 to 14.25 in 2020 and 16.28 in 2021. Details of all figures are given in Appendix II.

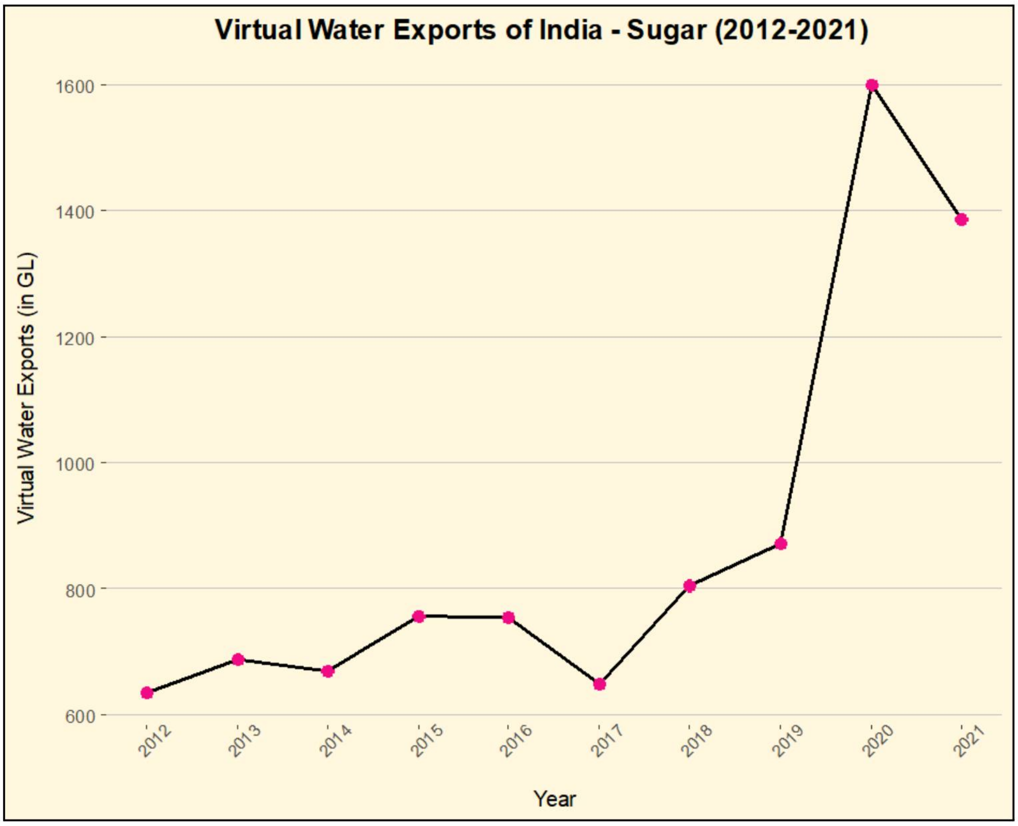

Figure 4.3. Virtual Water Exports of India - Sugar (2012-2021). Souce: Author's calculation, Generated with the help of R software

Figure 4.3 shows the virtual water exported from India as a result of international trade of sugar during 2012-2021. Virtual water exports with respect to sugar have been growing at an average annual growth rate of 11.93% for the period of 2012 to 2021. Virtual water exports increased from 632.86 gigalitre (GL) in 2012 to 1385.60 gigalitre (GL) in 2021, as a result of international trade of sugar.

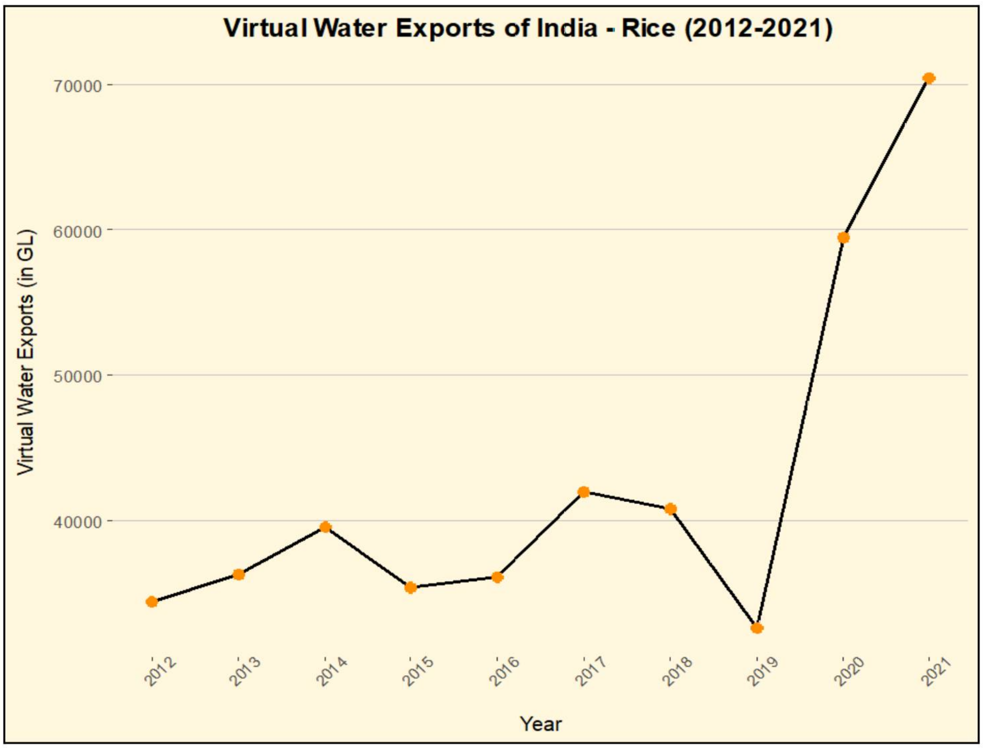

Figure 4.4. Virtual Water Exports of India - Rice (2012-2021). Souce: Author's calculation, Generated with the help of R software

Figure 4.4 shows the virtual water exported from India as a result of international trade of rice during 2012-2021. Virtual water exports in respect of rice exports have been growing at an average annual growth rate of 11.11% for the period of 2012 to 2021. Virtual water exports increased from 34446.44 gigalitre (GL) in 2012 to 70468.65 gigalitre (GL) in 2021 as a result of international trade of rice.

Above was an assessment of virtual water trade (VWT) at the national level. Now, we turn towards the status of VWT at the subnational (state) level.

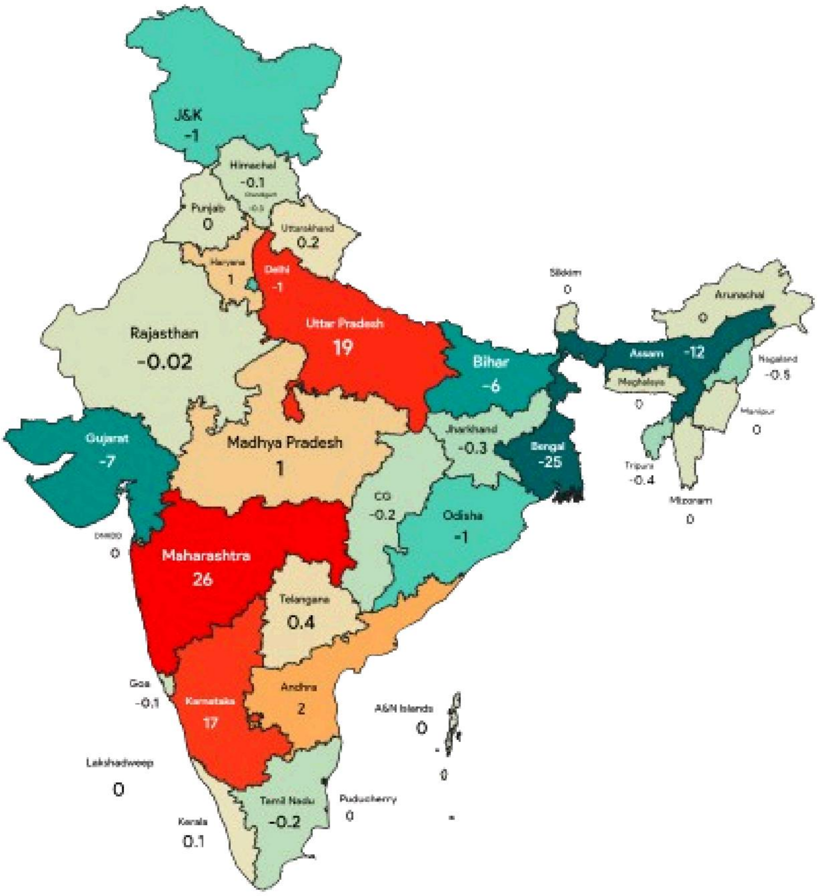

Figure 4.5. Map showing state-wise virtual water flows - Sugar (in BCM). Source: Author's calculation, Generated with the help of IIP Maps (https://iipmaps.com/)

Figure 4.5 above depicts the net virtual water flows (in BCM) to and from each state of India on account of sugar trade. Virtual water outflows are depicted in red and virtual water inflows are depicted in blue. The states with the highest outflow of virtual water are Maharashtra, Uttar Pradesh, Karnataka, Andhra Pradesh and Madhya Pradesh. Maharashtra saw a net outflow of 26115.38 giga litres (GL), Uttar Pradesh 19043.88 GL, Karnataka 17346.44 GL, Andhra Pradesh 1819.55 GL and Madhya Pradesh saw a net outflow of 1155.89 GL on account of both domestic and international sugar trade during the 10 year period of 2012 to 2021. This is in consonance with the states which export the largest quantities of sugar. On the other hand, West Bengal, Assam, Gujarat, Bihar and Odisha are at the bottom of the list where they witnessed a net outflow of virtual water of -25322.60 GL, -11850.33 GL, -6504.60 GL, -6023.81 GL and -1306.20 GL respectively. The negative sign in front of these figures indicates that these states experienced a net inflow of virtual water during this ten year period on the whole on account of domestic and international trade of sugar. The figures for the net virtual water exports on account of sugar trade are given in Appendix IV.

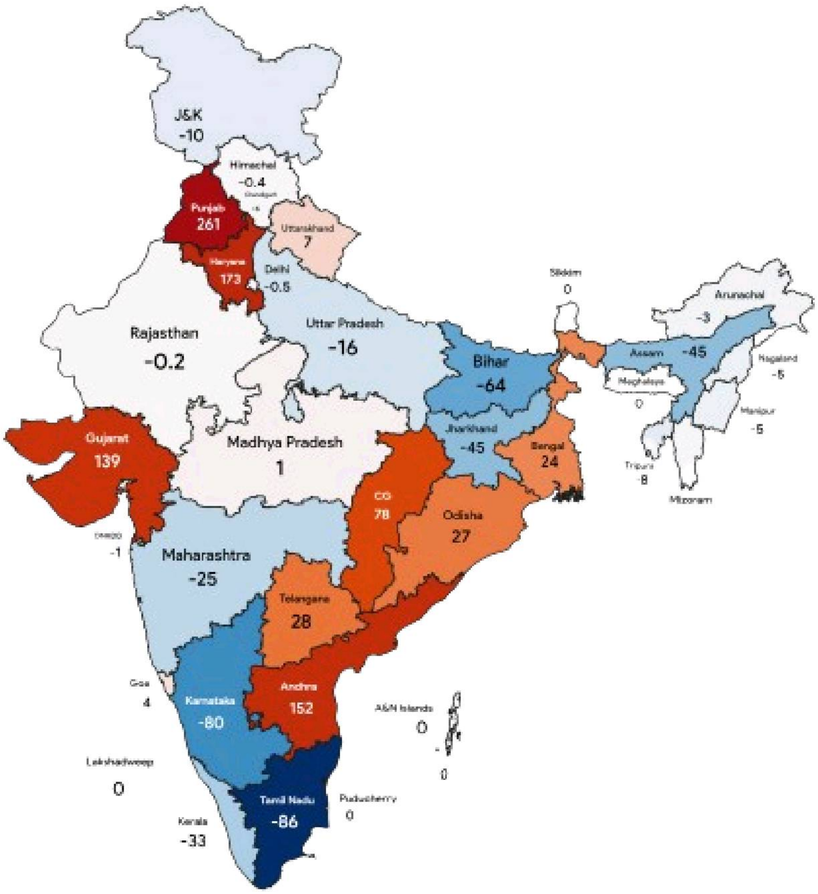

Figure 4.6. Map showing state-wise virtual water flows - Rice (in BCM). Source: Author's calculation, Generated with the help of IIP Maps (https://iipmaps.com/)

Figure 4.6 above depicts the net virtual water flows (in BCM) to and from each state of India on account of trade of rice (both basmati and non-basmati varieties). Virtual water outflows are depicted in red and virtual water inflows are depicted in blue (having a negative sign). The states with the highest outflow of virtual water on account of both domestic and international rice trade during the ten year period of 2012 to 2021 are Punjab, Haryana, Andhra Pradesh, Gujarat and Chhattisgarh with net outflows of 260.71 BCM (billion cubic metres), 173.2 BCM, 152.02 BCM, 139.35 BCM and 78.27 BCM respectively. The figures for the net virtual water exports on account of rice trade of all states are given in Appendix IV. These outflows of virtual water are in consonance with the states which export the largest quantities of rice. On the other hand, Tamil Nadu, Karnataka, Bihar, Assam and Odisha have negative virtual water exports of -86.15 BCM, -80.12 BCM, -63.83 BCM, -44.88, -44.73 BCM respectively. The negative sign in front of these figures indicates that these states experienced a net inflow of virtual water during this ten year period on the whole on account of domestic and international trade of rice.

When we consider both rice and sugar, the states with the highest net outflows of virtual water are Punjab, Haryana, Andhra Pradesh and Gujarat with net outflows (pertaining to rice and sugar both) of 260.68 BCM, 173.72 BCM, 153.84 BCM and 132.85 BCM respectively. The values are presented in Appendix IV. When we consider the total gross virtual water trade, the states with the highest gross outflows of virtual water are the same as mentioned above, viz. Punjab, Andhra Pradesh, Gujarat and Haryana with outflows of 296.8 BCM, 206.1 BCM, 165.4 BCM and 144.4 BCM respectively. The gross virtual water outflows of all states during the period of 2012 to 2021 are graphically presented in Figure 4.7 below and the figures for all states are given in Appendix III.

Katyaini et al. (2021) in their study concluded that Punjab, Haryana, Rajasthan, and Gujarat in the north-west, and Andhra Pradesh and Tamil Nadu in the south, experience high water scarcity. It can be clearly seen that the states in Figure 4.7 that these same states are among those with the highest gross as well as net outflows of virtual water, which is a worrying trend.

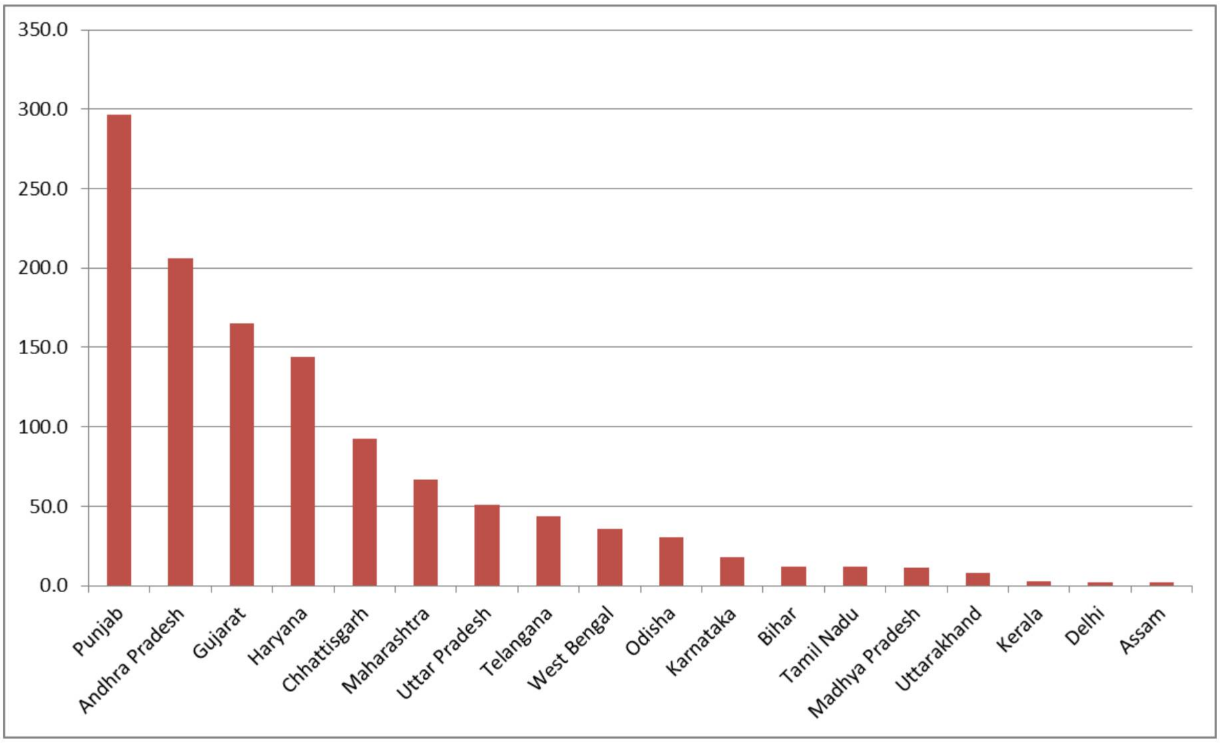

Figure 4.7. Total Gross Virtual Water Outflows (in BCM) of states from 2012-2021, Souce: Author's calculation, Generated with the help of Microsoft Excel

Now we turn towards the analysis of the water savings incurred on account of domestic and international trade of sugar and rice during the period of 2012-2021.

Water Saving is an estimate of the damage being done on account of trade within national boundaries i.e. among the states of India. Appendix V shows the water savings generated due to domestic movement of rice and sugar across the states of India. Figures 4.8 and 4.9 graphically depict the year-wise water savings of India over a 10-year period from 2012 to 2021 on account of inter-state trade of sugar and rice respectively. On the vertical axis there are water-savings/losses and the horizontal axis depicts the year. The figures are given in terms of million cubic metres of water lost or saved. Speaking of domestic sugar trade, for most of the years, India has made net negative water savings i.e. a net loss. In the figures, the red dashed line depicts zero water savings or losses. For the majority of the years, the graph lies below the red dashed line, indicating water losses.

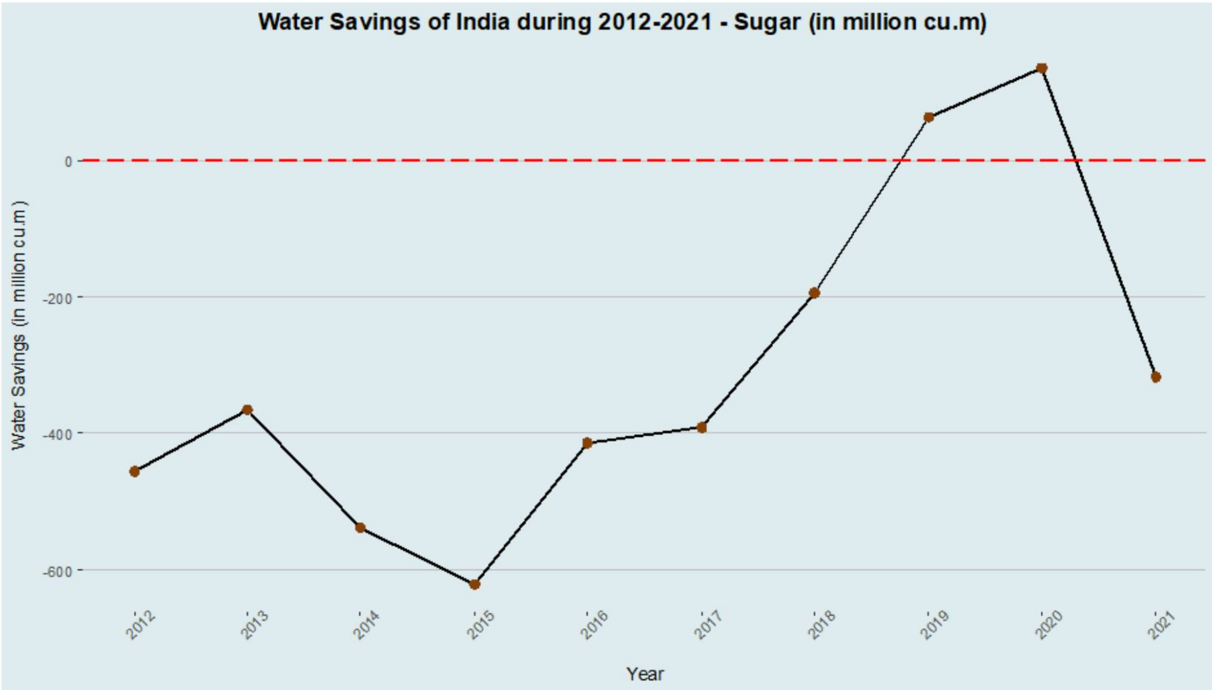

Figure 4.8. Water Savings of India during 2012-2021 on account of inter-state trade of Sugar (in million cu.m), Souce: Author's calculation, Generated with the help of R software

In the case of inter-state trade of sugar, the lowest water savings were made in the year 2015 of -623 million cu.m. 2017 onwards, the water savings scenario regarding interstate trade of sugar started to improve and became positive in 2019 and 2020. In 2019 India made a water saving of 62.2 million cu.m. and of 135.77 million cu.m. in 2020. However, in 2021, the trend reverted back to making a negative water saving, when a water saving of -317.77 million cu.m. was made. The negative sign means that a water loss (water dissaving) was incurred in a particular year.

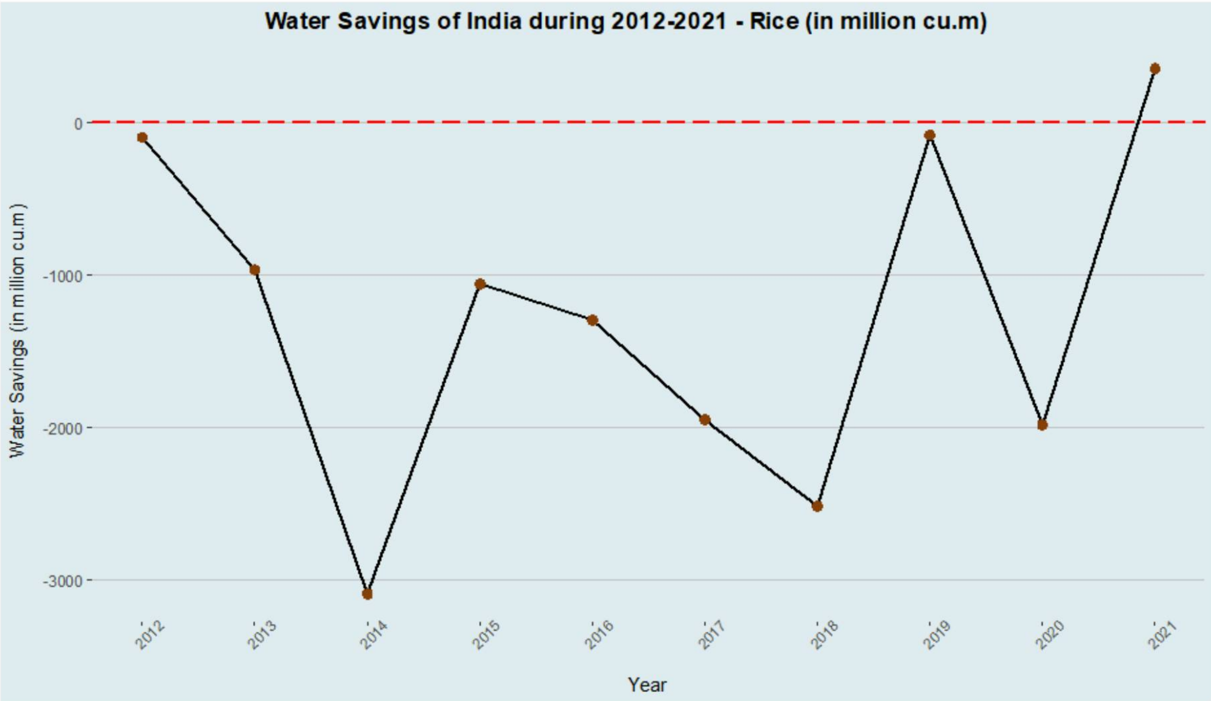

Figure 4.9. Water Savings of India during 2012-2021 on account of inter-state trade of Rice (in million cu.m), Souce: Author's calculation, Generated with the help of R software

Regarding inter-state trade of rice, a negative water saving has been made for all years apart from 2021, when a marginal water saving of 358.73 million cu.m. has been made. In 2012, a water dissaving of -99 million cu.m. was incurred. In 2014 water savings with respect to rice touched a low of -3092.25 million cu.m. . Thereafter, water savings have mostly been in the negative quadrant albeit with fluctuations over time. That is either due to lower exports of rice (due to export controls) in a particular year or lower production of rice due to erratic rainfall. The exact figures pertaining to water savings can be found in Appendix V.

Our results are not directly comparable with Katyaini & Barua (2017) as they consider virtual water flows and water savings with respect to major categories of foodgrains, one of which is rice. Their study does not consider sugarcane or sugar. Nevertheless, our results are broadly the same as them, although with a few dissimilarities. They say that the highest water savings were through VW flows embedded in rice not in the husk in the year 2011-12, and the highest water losses w.r.t. rice was in 2007-08. Our study records water losses for the next 9 years in the context of interstate trade of rice.

Above was an assessment of water savings/dissaving made at the national level. Now, we turn towards the status of water savings at the subnational (state) level.

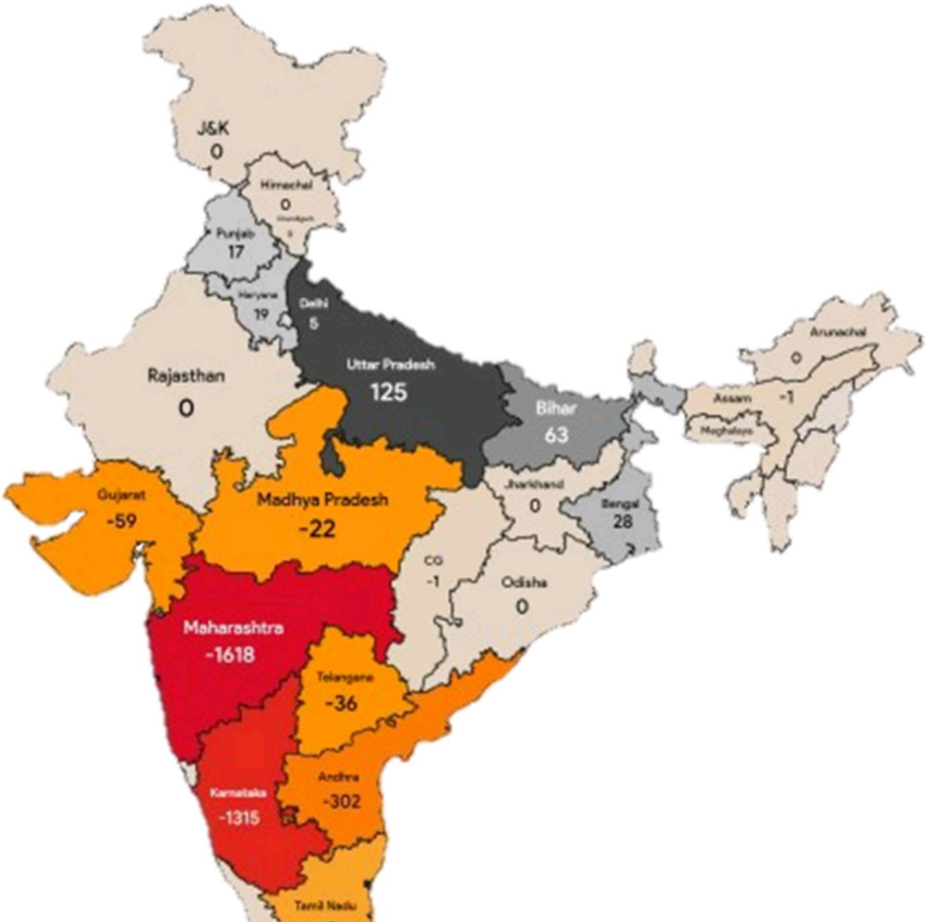

Figure 4.10. Map showing water savings in respect of inter-state sugar trade (2012-2021). Source: Author's calculation,Generated with the help of IIP Maps (https://iipmaps.com/)

The map in Figure 4.10 above shows the total water savings during the period of 2012 to 2021 made on account of interstate trade of sugar. Appendix VI gives the water savings of all states for the same period in respect of both rice and sugar. Regarding domestic trade of sugar, the highest water dissaving has been made by Maharashtra (-1618.33 million cu.m.), Karnataka (-1314.53 million cu.m.), Andhra Pradesh (-302.32 million cu.m.) and Gujarat (-58.72 million cu.m.) (indicated by the shade of deep red) while Uttar Pradesh (124.60 million cu.m.), Bihar (63.41 million cu.m.) and West Bengal (28.44 million cu.m.) have made the highest water savings (indicated by the shade of deep grey).

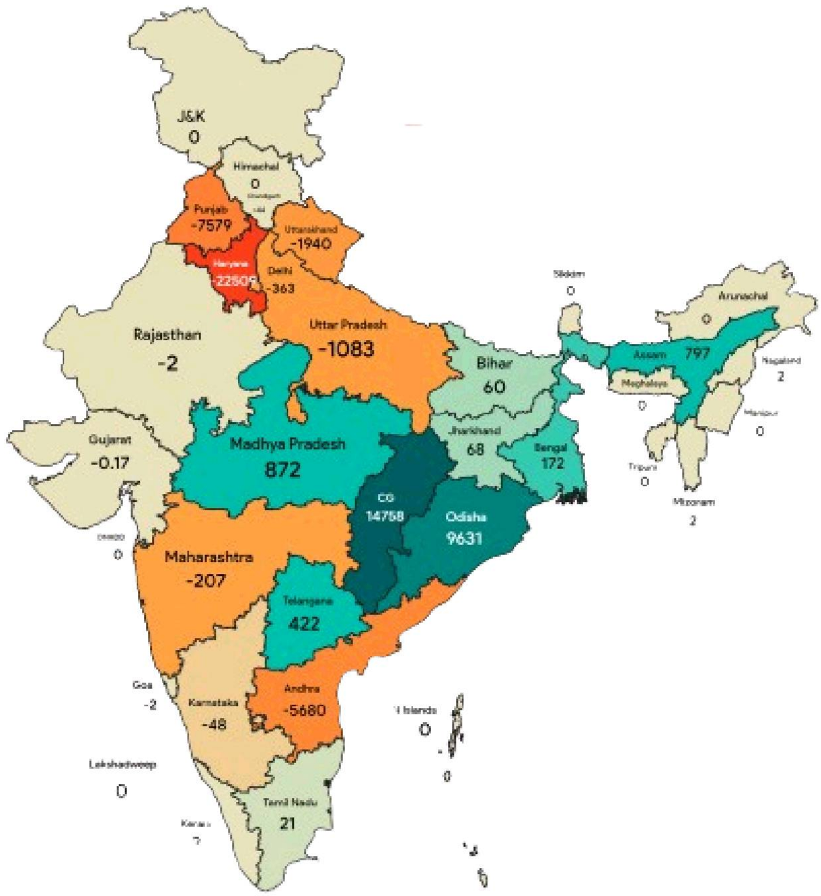

Figure 4.11. Map showing water savings in respect of inter-state rice trade (2012-2021). Source: Author's calculation, Generated with the help of IIP Maps (https://iipmaps.com/)

The map in Figure 4.11 above shows the total water savings during the period of 2012 to 2021 made on account of interstate trade of rice. The highest water dissaving has been made by Haryana (-22.51 BCM), Punjab (-7.58 BCM), Andhra Pradesh (-5.68 BCM) and Uttarakhand (-1.94 BCM) (indicated by the shade of deep red), while Chhattisgarh (14.76 BCM), Odisha (9.63 BCM), Madhya Pradesh (0.87 BCM) and Assam (0.8 BCM) have made the highest water savings (indicated by the shade of deep blue), on account of interstate trade of rice (both basmati as well as non-basmati).

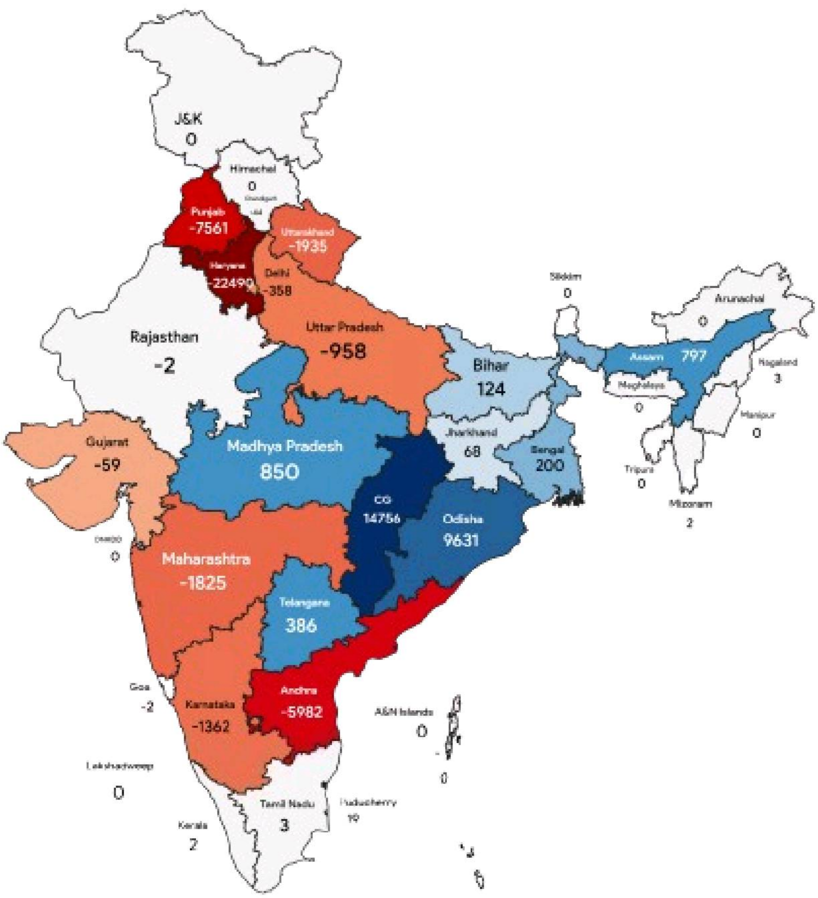

Figure 4.12. Map showing total water savings (2012-2021). Source: Author's calculation, Generated with the help of IIP Maps (https://iipmaps.com/)

The map in Figure 4.12 shows the total water savings during the period of 2012 to 2021 made on account of interstate trade of both rice as well as sugar. When we account for the water savings of both rice as well as sugar, we see that the highest water dissaving has been made by Haryana (-22.49 BCM), Punjab (-7.56 BCM), Andhra Pradesh (-5.98 BCM) and Uttarakhand (-1.93 BCM) while Chhattisgarh (14.76 BCM), Odisha (9.63 BCM), Madhya Pradesh (0.85 BCM) and Assam (0.80 BCM) have made the highest water savings. The negative sign indicates that a water dissaving has been made.

The basis of whether a state has made a water saving or dissaving depends on that particular state's virtual water content with respect to either rice or sugar, and, most importantly, the virtual water content of rice/sugar in the state to which the product is being exported. If the water productivity of the product in the exporting state is lower than the water productivity of the same product in the importing state, then a net water dissaving will be made, i.e., a net water loss. Whether a water saving or water dissaving is made, also depends on the quantity of the product traded. The water productivity/virtual water content of the product depends on a host of factors as mentioned previously, like climatic characteristics of that particular state, soil and water needs of that particular crop, product and value fractions of the derived crop product, etc.. The virtual water content of rice and sugar (categorised according to HS product codes), with respect to each state of India, is given in Appendix I.

These results are broadly in sync with Katyaini & Barua (2017) who suggest that the northern states have the highest water losses from 2005-14. Similarly, in the time period considered in this study i.e. 2012-21, the highest water losses have been made by Haryana and Punjab, followed by Andhra Pradesh, Uttarakhand and Maharashtra which lie in the Southern, Northern and Western zones respectively.

Katyaini & Barua (2017) state that at the national level net water losses were reflected in only 2 years for the period of 1996-2014.. In this study, water losses were seen for all years (2012-2021) except for the year 2021-22, where a marginal water savings was made. Katyaini & Barua (2017) assert that large unsustainable VW-flows are visible at the subnational scale. The present study suggests the same, and this hypothesis will be proved in the following section via regression analysis.

Now, we turn to the question of whether the gross/net virtual water trade is a determinant of the amount of decline of groundwater level in that state. The link between the decline in groundwater level of a state and its virtual water trade is analysed via a regression model, the results of which are presented below.

Table 4.1. Regression analysis results: Regression of groundwater level on virtual water exports. Souce: Author's calculation, Generated with the help of R software

	Dependent variable:	
	GW	
	(1)	(2)
gross	1.053***	
	(0.177)	
net		0.808***
		(0.145)
rain	−0.011***	−0.012***
	(0.002)	(0.002)
temp	2.428***	2.226***
	(0.475)	(0.335)
Constant	−16.717	−7.434
	(11.384)	(8.053)
Observations	226	262
R^2	0.361	0.379
Adjusted R^2	0.353	0.372
Residual Std. Error	20.275 (df = 222)	19.643 (df = 258)
F Statistic	41.895*** (df = 3; 222)	52.572*** (df = 3; 258)
Note:		*p<0.1; **p<0.05; ***p<0.01

Table 4.1 contains the regression results of the models relating the groundwater level in metres below ground level (mbgl) to gross and net virtual water exports of a particular state in a particular year,

the annual rainfall received and the average annual temperature of that state. Rainfall and temperature have been taken into account as two additional control variables in the determination of the groundwater level. Since the groundwater level is measured in mbgl, a higher figure in a particular year compared to a previous year corresponds to a decline in the groundwater level during that year.

The first model shown in Table 4 relates the groundwater level *'GW'* (in mbgl) to the gross virtual water exports '*gross'* (in BCM), rainfall '*rain'* (in mm) and temperature *'temp'* (in ℃). The coefficient on *gross* is statistically significant at the 1% level against the two-sided alternative. It is a positive figure of 1.053 with a standard error of 0.18. This indicates that a higher amount of gross virtual water export is associated with a higher level of groundwater decline in a particular state in a particular year, which is a worrisome trend. On an average, an increase in annual gross virtual water exports by 1 BCM (which is about 10^{12} litres of water) from a state is associated with an annual decline in groundwater level in that state by about 1.053 metres, having the temperature and rainfall of that state fixed. To put this in perspective, about 320 tonnes (or 3.2 lakh kilogramme) of rice exports annually are associated with an annual decline in groundwater level by 1 mm on an average. Similarly, an annual export of about 447 tonnes of sugar is associated with an annual decline in the groundwater level by 1 mm on an average, after controlling for rainfall and temperature in that state.

Considering net virtual water exports (instead of gross), we obtain more or less the same results. An increase in annual net virtual water exports by 1 BCM from a state is associated with a decline in the groundwater level of that state by 0.808 metre, holding the rainfall and temperature of that state constant. This estimate is slightly lesser than the previous one but is still significant at the 1% level, with a standard error of 0.15. The R^2 or the coefficient of determination stands at 36% and 38% for gross and net virtual water exports regression analysis respectively.

These results state that higher virtual water exports are taking place from states that are witnessing a higher decline in groundwater levels. If we plot the decline in groundwater level against the gross virtual water exports of all states in all years (2012-2021), we obtain a scatter plot as shown in Figure 4.13 (a).

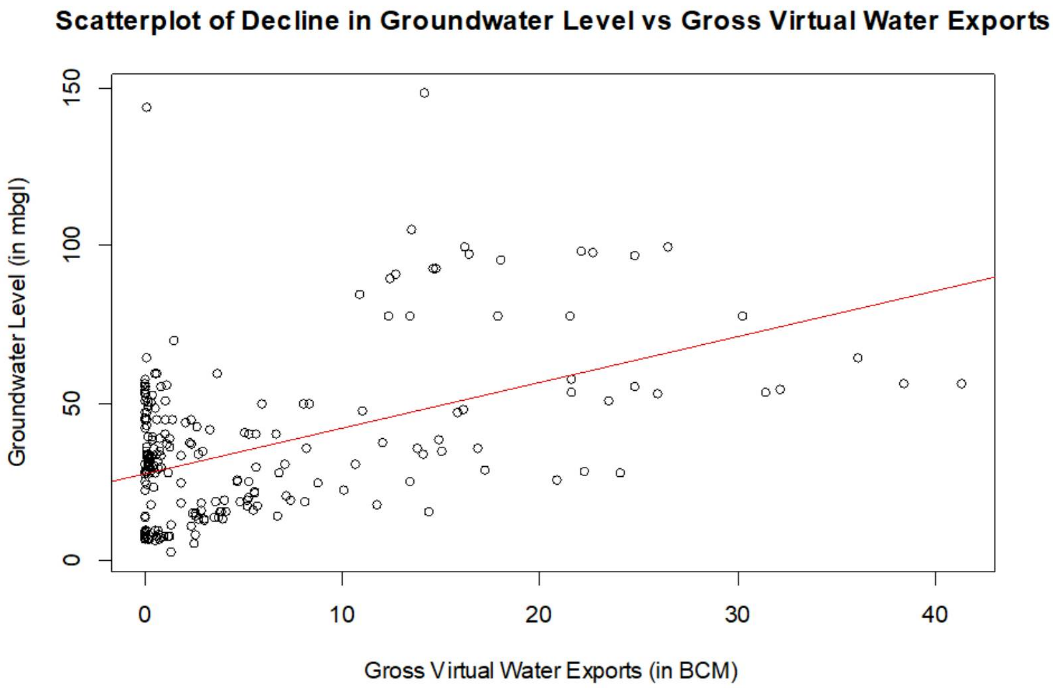

Figure 4.13 (a) . Scatter plot of decline in groundwater vs gross virtual water exports Souce: Author's calculation, Generated with the help of R software

Similarly, if we plot the decline in groundwater level against the net virtual water exports of all states in all years (2012-2021), we obtain a scatter plot as shown in Figure 4.13 (b).

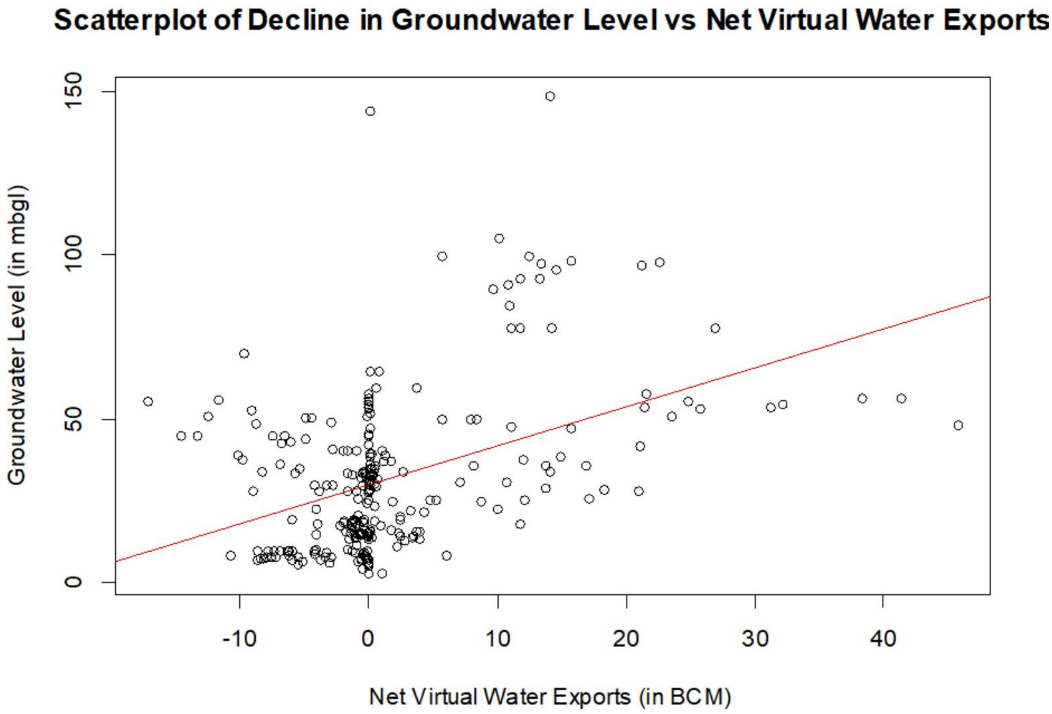

Figure 4.13 (b) . Scatter plot of decline in groundwater vs net virtual water exports. Souce: Author's calculation, Generated with the help of R software

Both the scatter plots indicate a positive correlation between decline in groundwater levels and virtual water exports. The trend line is upward sloping in both cases. Higher the virtual water exports, higher is the depletion of groundwater.

Thus, through this analysis it is concluded that either virtual water exports are contributing to a higher decline in groundwater levels, or, higher virtual water exports are taking place from states which are facing a relatively higher rate of groundwater decline. Either way, it is a cause for concern and must be rectified in the near future. The immediacy of this issue cannot be overstated.

Now, we turn our attention to the relationship between water savings made on account of interstate trade of rice and sugar and the corresponding virtual water trade of a particular state in a particular year. The results of the regression analysis are presented in Table 4.2.

Table 4.2: Regression analysis results: Regression of water savings on virtual water exports. Souce: Author's calculation, Generated with the help of R software

	Dependent variable:	
	WS	
	(1)	(2)
gross	−0.014*	
	(0.007)	
net		−0.016***
		(0.006)
rprod	0.0001***	0.0001***
	(0.00001)	(0.00001)
sprod	−0.00000***	−0.00000***
	(0.00000)	(0.00000)
ryield	−0.001***	−0.001***
	(0.0001)	(0.0001)
syield	−0.00000	−0.00000
	(0.00000)	(0.00000)
Constant	1.533***	1.508***
	(0.221)	(0.214)
Observations	164	164
R^2	0.402	0.417
Adjusted R^2	0.383	0.399
Residual Std. Error (df = 158)	0.637	0.629
F Statistic (df = 5; 158)	21.226***	22.608***
Note:	*p<0.1; **p<0.05; ***p<0.01	

The regression results shown above indicate a negative relationship between the water savings made (in BCM) and the virtual water exports (in BCM) of a state, ceteris paribus .Other factors remaining constant, an increase in the yearly gross virtual water exports '*gross*' by 1 BCM leads to a lower yearly water saving by 0.014 BCM or 14 giga litre (GL) on an average. This estimate increases to 16 gigalitre in the case of net virtual water exports '*net*'. The R^2 or the coefficient of determination stands at 40% and 42% for the two regression models. Variables *gross*, *net*, *rprod*, *sprod* and *ryield* are significant at atleast the 10% level. Sugarcane production '*sprod* ' and yield of sugarcane '*syield'* hardly have any effect on the regressand while rice production '*rprod'* and yield of rice '*ryield* ' have an effect - an increase in yearly rice production '*rprod'* by one thousand tonnes increases the annual water savings of a state by 0.1 GL on an average while an increase in the yield of rice by one kg/ha is associated with a 1 GL lower water saving.

The increase in water savings with an increase in virtual water exports are seen in some states like Chhattisgarh and Odisha which make a positive water saving on account of rice exports. However, if we remove the two states Chhattisgarh and Odisha from the above regression model, the estimate for *gross* decreases to -0.027 from the previous -0.014 and the estimate for *net* decreases to -0.024 from the previous -0.016. This is a huge jump from the previous estimates. Again, these estimates are statistically significant at the 1% level. This means that if we consider all states apart from Chhattisgarh and Odisha, then we find out that other factors remaining constant, an increase in the yearly gross virtual water exports '*gross*' by 1 BCM leads to a lower yearly water saving by 0.027 BCM or 27 giga litre (GL) on an average and a decrease of 24 GL if we consider net virtual water exports. These results are graphically depicted by the scatterplots in Figure 4.14 (a) and (b) below.

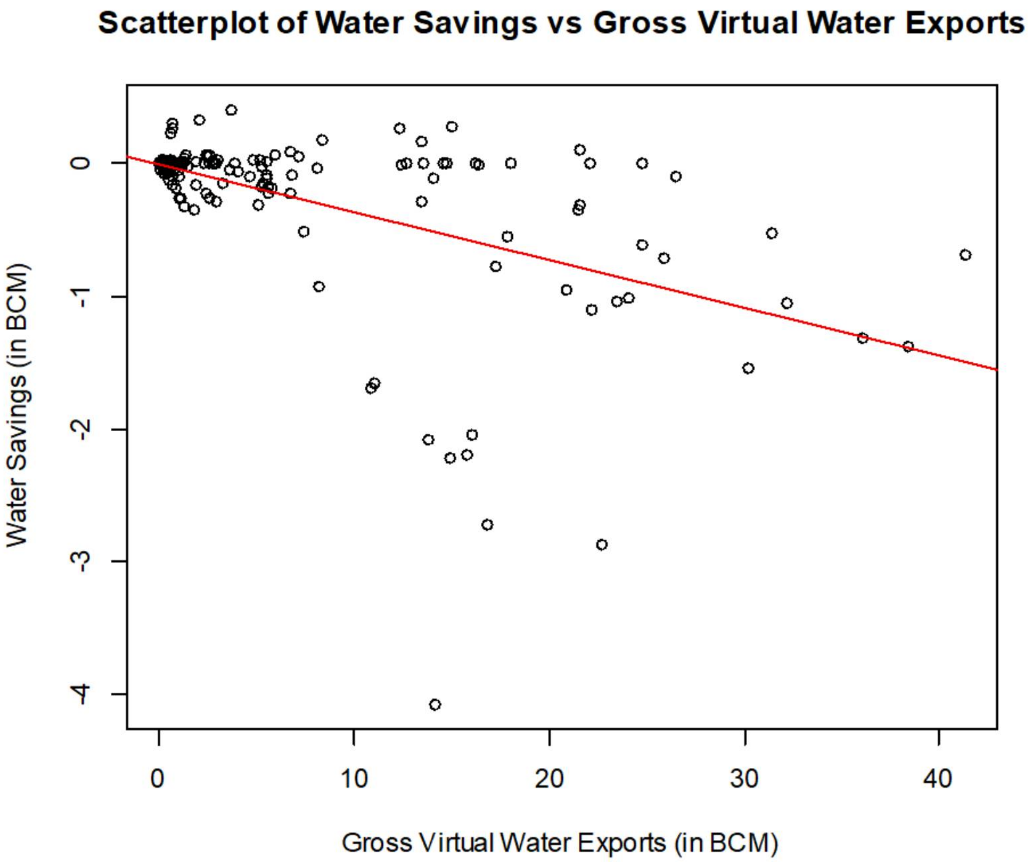

Figure 4.14 (a) Scatter plot of water savings vs gross virtual water exports. Souce: Author's calculation, Generated with the help of R software

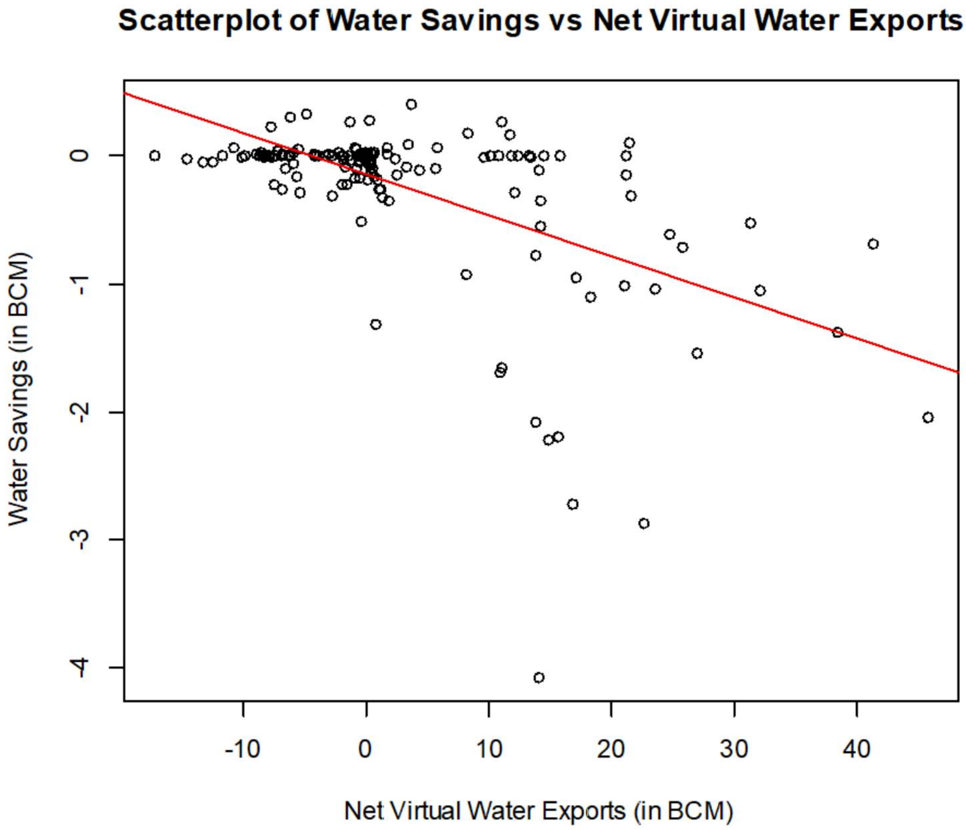

Figure 4.14 (b) . Scatter plot of water savings vs net virtual water exports. Souce: Author's calculation, Generated with the help of R software

The scatter plots indicate a clear negative correlation between water savings and virtual water exports. The trend lines are downward sloping in both cases. It is important to note that the two states of Chhattisgarh and Odisha are not included in the two scatter plots.

This analysis supports the hypothesis that the current pattern of virtual water trade in India is exacerbating its water scarcity scenario. The virtual water trade patterns point towards declining groundwater levels as well as negative water savings when we consider the two highly water-intensive agricultural commodities viz. rice and sugar from the period of 2012 to 2021. This implies that our current trade patterns are unsustainable; they need to be tweaked, otherwise, we would be staring at a water crisis which would inevitably compromise our nation's food security. Virtual water trade which is widely recognised as a tool for achieving regional water scarcity as well as integrated water resource management (V. Kumar & Jain, 2007; Vanham et al., 2011) is falling short of its stated objectives. The analysis in this study of the virtual water trade at the subnational level in India is a realisation that water consumption is not aligned with long-term water endowments, which clearly is not sustainable in the long-run.

The virtual water strategy seeks ways to consciously and efficiently utilise internal and external water resources to alleviate water scarcity in a country or a region (Yang & Zehnder, 2007). However, through the above analysis, it is concluded that virtual water trade is certainly not leading to efficient water usage in India at atleast the national and the sub-national level, except in the case of a few states in the eastern part of the country like Chhattisgarh and Odisha. Virtual water trade, which is widely recognised in the literature as a tool to mitigate water scarcity as well as ease political tensions over shared water resources (Yang & Zehnder, 2007), is not achieving these stated objectives in the context of India. This is mainly due to high exports of (in fact being among the world leaders of) highly water-intensive products as well as moving these products from states with a low water productivity (in production of stated crops) to states with a higher water productivity. This is exacerbating the water scenario of already water-stressed states.

There is a mismatch in existing food grains production patterns and water scarcity at subnational scale in India. States in West, South, and North are among major producers of food grains, despite facing high water scarcity. While the states in East and North-East are not major producers even though they are relatively well endowed with water resources, i.e., less water scarce. VW assessment is intended to reveal the extent of this mismatch through quantification of water loss through interstate movement of food grains (Katyaini & Barua, 2017). In this study, states which are more water-scarce are analogous to those which have higher rates of groundwater depletion and higher water losses in the process of export of virtual water.

Underpricing, or no pricing at all, of precious water resources is a serious concern which needs to be addressed. It is necessary to realise that it is not all about augmenting the physical supply of water but also about enhancing the efficiency of existing water use. Every drop counts. Because water in some places is seriously underpriced, usage of this scarce resource unknowingly leads to its overexploitation. CWC (2017) speaks of the importance of water rates in the country and how irrigation water is priced in the various states in India. It highlights how committees like the Second Irrigation Committee (1972) and the Vaidyanathan Committee (1991) have recommended levying water charges in such a way that they cover operations and maintenance (O&M) costs as well and also evolved a rational water rate structure both surface and groundwater to promote conjunctive use (CWC, 2017; Planning Commission, 2010).

The National Water Policy of 1987 (NWP) states that, "Water rates should be such as to convey the scarcity value of the resource to the users and to foster the motivation for economy in water use. They should be adequate to cover the annual maintenance and operation charges and a part of the fixed costs. Efforts should be made to reach this ideal over a period, while ensuring the assured and timely supplies of irrigation water. The water rates for surface water and ground water should be rationalised with due regard to the interests of small and marginal farmers". Such an approach highlights the importance of appropriate rates of irrigation water use while moving towards the same in a gradual manner so as to not cause any inconvenience to farmers.

According to NWP 1987, water is a prime natural resource, a basic human need and a precious national asset, and planning and development of water resources needs to be governed by national perspectives. The study, assessment and quantification of virtual water trade (VWT) of our country is a part of that planning of the water resources of our country.

Changes in production and interstate trade patterns, in irrigation methods and in the type of cereals consumed appear necessary to improve the resilience of India's food system (Harris et al., 2020). Gulati et al. (2020) rightly state that India needs to address the composition of its agricultural export basket. They say that agricultural exports constitute about 10% of the country's exports, more than 85% of which are low-value, raw or semi-processed, and marketed in bulk. While India should remove any restrictions on agriculture exports, it should also not subsidise scarce inputs such as water to promote exports such as rice (Gulati et al., 2020). This is clearly an unsustainable approach and the excessive emphasis on subsidies is leading to over-exploitation of our country's water resources. Multiple studies (Harris et al., 2020; Katyaini et al., 2021; Saxena et al., 2023) have highlighted that we need to diversify our export basket. Rather than cultivating crops that are in excess of our consumption needs, we must try to move towards cultivating oilseeds, pulses, etc. i.e. crops that we import from the rest of the world. Thus, by doing so, we would also reduce the burden on our foreign exchange reserves and improve the trade deficit of our country.

India has held the title of the world's leading rice exporter since 2012, surpassing the combined rice shipments of the next four largest exporters after it -- Thailand, Vietnam, Pakistan and the United States (Sharma, 2023). Our international trade in agricultural commodities & industrial produce is contributing to large quantities of virtual water loss through the export of water-intensive crops. India exported more than 10 trillion litres of embedded or virtual water through the export of about 37 lakh tonnes Basmati rice in 2014-15, alone, which could have been used to grow much larger quantities of other crops such as wheat or millet that have far less water requirements. Our industrial exports too are not regulated based on the amount of virtual water export they end up causing (NITI Aayog, 2019). This study was an attempt to quantify how much water India as a whole and each state of India is losing through export of water-intensive commodities viz. rice and sugar.

Harris et al. (2020) found that the interstate trade of cereals is associated with slightly more groundwater use than there would be without such trade and it is possible that interstate cereal trade encourages continued production of cereals irrigated alongside groundwater for export. This may discourage agricultural improvements in importing states like adopting water-saving technology like drip irrigation; Eastern states which are safe in their groundwater reserves and net importers, also have the highest yield gaps and therefore the greatest unmet potential to increase production (Harris et al., 2020). However, their exports are not contributing to higher water losses, as found out in this study, and hence their water scenario can be termed as much better compared to the rest of India.

Studies have increasingly highlighted the market-distorting ill-effects of price incentives such as power and fertiliser subsidies and the Minimum Support Price (MSP) system (Chaudhuri & Roy, 2019; Gulati et al., 2020; Parween et al., 2021). Electricity subsidies for agriculture provided by state governments have encouraged farmers to extract groundwater at increasing depths (Harris et al., 2020). According to Chatterjee et al. (2022) these policies have led to a 30% over-production of water intensive crops. It is an irony that the production of essential crops is being substituted by the production of crops that are available in excess. And this is due to the structure of price incentives. In this case, government intervention has been breeding inefficiency in water as well as land usage. Government intervention has led to allocation of resources that is not in sync with the natural forces of demand and supply. Decisions taken in haste in the past are proving to be disastrous today not only in the form of inefficient allocation of resources but also in the form of huge burden on the government exchequer, leading to less-than-optimal use of taxpayer's money. It has become nearly impossible to initiate any withdrawal or tweaking of this deep-rooted incentive structure, because farmers and other stakeholders' vociferously oppose it. Now, the onus lies on the states to take the lead in gradual withdrawal of market-distorting government interventions and promote sustainable farming practices as well as models such as contract farming, so as to provide income security to farmers, especially small and marginal ones. Critics will oppose this argument on grounds of exploitation of farmers and risk to their livelihoods. However, a very important question to ponder is whether farmers and people involved in agriculture have actually become rich and better off until now, with price support initiatives. And whether it has been beneficial to the natural environment and whether our country has moved towards nutritional security and self sufficiency. If not, it's time to pull the plug.

According to Balakrishnan (2000), profitability and growth in agriculture is not only determined by the price support given to farmers. In the absence of private investment, subsidies have been very supportive for farmers and have contributed to high yields, however, the importance of non-price factors like water cannot be overlooked. Non-price factors like water, capex-fuelled infrastructure, research and development and agricultural extension services are major determinants of the profitability in Indian agriculture. Agricultural policy in India has had an excessive price-based focus which is not conducive to growth in the sector (Balakrishnan, 2000).

Nearly 94% of sugarcane area in the country is under irrigation and traditional method of flood-irrigation is leading to suboptimal use of scarce water resources. Adoption of water saving technologies like drip irrigation and skip furrow/alternate furrow irrigation is the need of the hour and can bring down water consumption for sugarcane cultivation up to 30 percent. They also don't compromise on the yield of cane. Looking for, as well as implementation of such solutions is much more applicable to water-stressed states of Maharashtra, Tamil Nadu, Karnataka and Andhra Pradesh. The Pradhan Mantri Krishi Sinchai Yojana (PMKSY) which offers a subsidy on micro-irrigation is an effective step in this direction (CACP, 2022).

A closer look at cropping patterns in the Indian states reveals a frightening inefficiency and sub-optimal planning that is causing most water related problems, including depletion of the ground water tables at an alarming rate. According to an ICRIER study, water guzzling crops like sugarcane and paddy are grown in states like Maharashtra, Uttar Pradesh (UP) and Punjab, using up lakhs of litres of irrigation water per hectare. Despite the intensive water requirement, Maharashtra grows 22% of the total sugarcane output in the country, whereas Bihar grows only 4% of the total sugarcane output. In addition, nearly 100% of the sugarcane crop in Maharashtra is grown through irrigated water, while parts of the state are already facing a severe water crisis. Similarly, Punjab, which is the third largest producer of rice in India, grows paddy using nearly 100% irrigation cover. As a result, while Punjab tops the table in land productivity, it uses more than three times the water than Bihar and more than twice the amount of water than West Bengal, to produce one kg of rice. What is more alarming is that 80% of the water used for irrigating the paddy fields in Punjab is drawn from groundwater sources (NITI Aayog, 2019).

Another aspect of water which needs to be addressed urgently is the management of waste water. The per person disease burden due to unsafe water and sanitation was 40 times higher in India than in

China and 12 times higher than in Sri Lanka in 2016. With a country generating 140 BCM of waste water annually, mismanagement of waste water which also contaminates groundwater, lack of liquid waste management, poor sanitation conditions and poor hygiene habits has contributed to a major portion of the population suffering from water-borne diseases. Water borne diseases are now a common phenomenon in both rural and urban areas. The growing population of Indian cities due to natural growth of population and migration has made our cities unsustainable and mindless urban expansion along with overexploitation of existing water resources has adversely affected the carrying capacity of the cities. According to a study, 5 of the 20 world's largest cities under water stress are in India, with Delhi being 2nd on the list (NITI Aayog, 2019).

Research Institutes have developed a number of production technologies at various sugarcane research stations. However, optimal utilisation of technologies by the end user, i.e. the sugarcane farmer remains poor. Effective dissemination of these advanced technologies at the ground level is the need of the hour. State Governments should encourage sugarcane farmers to adopt the latest production technologies and modern farm practices which will aid in enhancing the cane yield levels (CACP, 2022). Sugar obtained from sugar beet has a smaller water footprint than sugar from sugar cane. Besides, the blue component in the total water footprint of beet sugar (20 %) is smaller than for cane sugar (27%) (M. M. Mekonnen & Hoekstra, 2011).

It is said that a reform in the agricultural policies of MSP and subsidies might threaten food security in India. However, the truth is that without water security, food security cannot be ensured. Katyaini et al. (2021) state that transition from water scarcity to water security is also linked to the security of other resources, specifically food security; and that food security is intricately linked with security with respect to water, soil, climate, energy, climate and economic and political factors. Thus, moving towards food security while compromising on water security is not a good option.

The theme of World Water Day 2022 was "Groundwater – making the invisible visible", which helped to refocus attention on the importance of groundwater. A key message of the campaign was, "Groundwater may be out of sight, but it must not be out of mind" and "Groundwater is invisible, but its impact is visible everywhere". It recognised groundwater as the 'invisible ingredient in food' and a 'resource without borders' having a 'finite supply' (EFG, 2022).

According to the United Nations (2023), a lack of data poses a risk to more than 3 billion people living in areas where the quality of freshwater is unknown. Agriculture and untreated wastewater are major threats to water quality, with nitrogen and phosphorus measurements frequently failing to meet targets. Efforts are needed to improve farming practices and wastewater treatment, especially in regions with high population growth. The policy framework at the state level regarding agriculture, water use, especially subsidies needs to have a re-look. Schemes to use solar energy for pumps and encouraging use of barren land to set up decentralised solar power plants are a welcome step (Prajapati, 2018). Avoiding the problems of groundwater depletion requires coherent policies on energy, land use and irrigation (EFG, 2022).

In big countries there are regions of surplus or deficient water availability (V. Kumar & Jain, 2007). Therefore, further studies must focus on virtual water trade at the district level in India and in respect of different crops and their derived products. This would do good in aligning crop production patterns with the water scenario of that state. The World Water Council states 'showing people the virtual water content of various consumption routes will increase the water awareness of people' (V. Kumar & Jain, 2007). It's necessary that innovative solutions such as these be adopted and, moving ahead, the nexus approach and integrated water resource management practices like virtual water trade studies be incorporated into policy-making. India, which is a 'major producer of agricultural products', may not be able to immediately relinquish that title and certainly should not even do so. However, it can certainly realign its production and trade patterns so as to be in sync with the natural environment as well as climatic conditions.

CHAPTER 5: CONCLUSION:

Water should be considered an economic good. Problems of water scarcity and water quality would be solved if it were properly treated as an economic good. Knowing that economically sound water pricing is poorly developed in many regions of the world, this means that many products are put on the world market at a price that does not properly include the cost of the water contained in the product. This leads to situations in which some regions in fact subsidise export of scarce water (Hoekstra & Hung, 2002).

Underpricing, or rather, no pricing at all, creates an illusion of unlimited supply of water. Water pricing is increasingly being recognised as an important tool in water resource management by both Government of India (CWC, 2017; NITI Aayog, 2019) as well as academia (Chaudhuri & Roy, 2019; Parween et al., 2021). Even though groundwater constitutes the bulk of irrigation water demand, efforts to price it have not been adequate. Instituting a water-pricing framework for irrigation could help to regulate groundwater use and conserve dwindling water reserves (Chaudhuri & Roy, 2019).

Several news articles, reports every other day state that cities like Bengaluru, Chennai, etc. are staring at a severe water crisis. In such a scenario, every possible solution to conserve water resources and better manage them must be explored, before it's too late. According to the United Nations (2023), Integrated Water Resource Management (IWRM) implementation needs acceleration to achieve Sustainable Development Goal (SDG) 6 - ensuring availability and sustainable management of water resources for all.

All is not lost, for we can still shift gears and lift India out of water poverty. If a desert country like Israel can do it, can't we?

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APPENDICES

Appendix I

Virtual Water Content of Products (in cubic m/ton)

	HS Code of Product (p) --->	170191	170111	170310	100620	100630
	Product name --->	Refined sugar	Raw sugar (gur/jaggery)	Molasses	Rice in the husk	Rice not in the husk
Sr. No.	Exporting State (s_e)					
1.	Andhra Pradesh	2255	2109	667	2963	3293
2.	Arunachal Pradesh	2374	2219	702	1850	2056
3.	Assam	2841	2656	839	2113	2347
4.	Bihar	2230	2085	658	2748	3055
5.	Chandigarh	2157	2017	638	2870	3190
6.	Chhattisgarh	2351	2197	695	2437	2707
7.	Dadra and Nagar Haveli	2875	2688	850	3828	4253
8.	Delhi	2454	2294	726	3193	3548
9.	Goa	2657	2484	786	3647	4053
10.	Gujarat	2751	2573	814	3313	3681
11.	Haryana	2351	2198	695	3450	3833
12.	Himachal Pradesh	2059	1925	609	3143	3492
13.	Jammu and Kashmir	2374	2219	702	2715	3018
14.	Jharkhand	2141	2002	633	2653	2949
15.	Karnataka	2478	2317	732	3270	3633
16.	Kerala	2374	2219	702	2688	2986
17.	Madhya Pradesh	2476	2315	732	2622	2913

18.	Maharashtra	2570	2403	760	3017	3352
19.	Manipur	0	0	0	2043	2271
20.	Meghalaya	2374	2219	702	2204	2451
21.	Mizoram	0	0	0	2162	2402
22.	Nagaland	2374	2219	702	2013	2236
23.	Odisha	2273	2125	671	2017	2241
24.	Puducherry	2203	2061	652	3295	3661
25.	Punjab	2124	1986	628	2893	3215
26.	Rajasthan	2566	2400	758	3087	3430
27.	Sikkim	1852	1733	548	3324	3693
28.	Tamil Nadu	2377	2223	703	2689	2987
29.	Telangana	2374	2219	702	2688	2986
30.	Tripura	2840	2655	840	3450	3834
31.	Uttar Pradesh	2347	2195	694	2954	3282
32.	Uttarakhand	2302	2153	681	3240	3601
33.	West Bengal	2068	1934	612	2266	2518

Appendix II

Production, Exports and Virtual Water Exports of India w.r.t. Rice and Sugar (2012-2021)

Year	Virtual Water Exports of India due to Sugar (in GL)	Virtual Water Exports of India due to Rice (in GL)	Sugar Exports of India (in Lakh MT)	Rice Exports of India (in Lakh MT)	Rice Production (in Lakh MT)	Sugar Production (in Lakh MT)	Sugar Exports as a Percent of Sugar Production	Rice Exports as a Percent of Rice Production
2012	632.86	34446.44	2.47	101.48	1052.30	251.80	0.98	9.64
2013	686.50	36318.29	2.66	108.90	1066.50	245.50	1.09	10.21
2014	667.97	39607.75	2.58	119.76	1054.80	284.60	0.91	11.35
2015	756.82	35434.94	2.93	105.10	1044.10	251.20	1.17	10.07
2016	754.50	36211.67	2.98	107.56	1097.00	202.30	1.47	9.80
2017	648.77	42000.15	2.52	127.05	1127.60	322.00	0.78	11.27
2018	803.12	40808.99	3.14	120.14	1164.80	331.30	0.95	10.31
2019	870.98	32622.16	3.41	94.95	1188.70	274.60	1.24	7.99
2020	1601.29	59414.04	6.32	177.26	1243.70	310.01	2.04	14.25
2021	1385.60	70468.65	5.52	212.10	1302.90	359.60	1.53	16.28

Source: APEDA, CACP (2022), MoAFW (2023) and Author's calculations

Appendix III

Statewise (Gross) Virtual Water Flows during 2012-2021

State	Total (Gross) Virtual Water Exports - Sugar (in cu.km) during 2012-21	Total (Gross) Virtual Water Exports - Rice (in cu.km) during 2012-22	Total (Gross) Virtual Water Exports - Sugar and Rice (in cu.km) during 2012-21
Andhra Pradesh	4.0562	202.0692	206.1254
Arunachal Pradesh	0.0000	0.0000	0.0000
Assam	0.0134	1.9484	1.9617
Bihar	0.6482	11.3052	11.9534
Chandigarh	0.0000	0.9441	0.9441
Chhattisgarh	0.0335	92.6298	92.6633
Dadra and Nagar Haveli	0.0000	0.0000	0.0000
Delhi	0.1199	2.0106	2.1305
Goa	0.1218	0.0104	0.1322
Gujarat	3.7665	161.6021	165.3685
Haryana	0.6331	143.7226	144.3557
Himachal Pradesh	0.0000	0.0000	0.0000
Jammu and Kashmir	0.0000	0.0000	0.0000
Jharkhand	0.0017	0.5867	0.5884
Karnataka	17.7056	0.4239	18.1296
Kerala	0.0686	2.8461	2.9147
Madhya Pradesh	2.8608	8.5358	11.3965
Maharashtra	28.8270	38.0377	66.8646
Manipur	0.0000	0.0080	0.0080
Meghalaya	0.0000	0.0000	0.0000

Mizoram	0.0000	0.0504	0.0504
Nagaland	0.0061	0.0339	0.0400
Odisha	0.0049	30.6160	30.6210
Puducherry	0.0005	0.1042	0.1047
Punjab	0.1127	296.6443	296.7571
Rajasthan	0.0148	0.1085	0.1234
Sikkim	0.0000	0.0690	0.0690
Tamil Nadu	1.2326	10.6799	11.9125
Telangana	0.4282	43.0958	43.5240
Tripura	0.0000	0.0189	0.0189
Uttar Pradesh	19.4441	31.7887	51.2329
Uttarakhand	0.3738	7.9071	8.2809
West Bengal	0.4598	35.0284	35.4882

Appendix IV

Statewise (Net) Virtual Water Flows during 2012-2021

State	Total (Net) Virtual Water Exports - Sugar (in cu.km) during 2012-21	Total (Net) Virtual Water Exports - Rice (in cu.km) during 2012-21	Total (Net) Virtual Water Exports - Sugar and Rice (in cu.km) during 2012-21
Andhra Pradesh	1.8195	152.0180	153.8376
Arunachal Pradesh	0.0000	-3.1072	-3.10724
Assam	-11.8503	-44.8772	-56.7276
Bihar	-6.0238	-63.8329	-69.8567
Chandigarh	-0.2725	-5.6833	-5.95578
Chhattisgarh	-0.2151	78.2711	78.05601
Dadra and Nagar Haveli	0.0000	-0.5178	-0.51778
Delhi	-0.8540	-0.4646	-1.31857
Goa	-0.0632	3.8676	3.804436
Gujarat	-6.5046	139.3507	132.8461
Haryana	0.5272	173.1959	173.7231
Himachal Pradesh	-0.0613	-0.4247	-0.486
Jammu and Kashmir	-1.0175	-9.7276	-10.7452
Jharkhand	-0.2779	-44.7257	-45.0037
Karnataka	17.3464	-80.1226	-62.7761
Kerala	0.0625	-32.9850	-32.9225
Madhya Pradesh	1.1559	1.1076	2.263489
Maharashtra	26.1154	-25.2754	0.839966
Manipur	0.0000	-4.8711	-4.87115
Meghalaya	0.0000	-0.0044	-0.00441

Mizoram	0.0000	-1.1430	-1.143
Nagaland	-0.4657	-4.6675	-5.1332
Odisha	-1.3062	27.0754	25.7692
Puducherry	0.0005	-0.1214	-0.12092
Punjab	-0.0274	260.7068	260.6794
Rajasthan	-0.0192	-0.2462	-0.2654
Sikkim	0.0000	0.0410	0.040975
Tamil Nadu	-0.1553	-86.1455	-86.3008
Telangana	0.4155	28.1186	28.5341
Tripura	0.0000	-8.1644	-8.16443
Uttar Pradesh	19.0439	-15.9413	3.10256
Uttarakhand	0.2188	7.1902	7.40901
West Bengal	-25.3226	23.8127	-1.50986

Appendix V

Water Savings of Sugar and Rice during 2012-2021 (in million cu.m.)

Year	Water Savings (in million cu.m.)	
	Sugar	Rice
2012	-456.995	-99.0025
2013	-366.733	-966.024
2014	-539.332	-3092.25
2015	-623.032	-1052.34
2016	-414.421	-1290.72
2017	-390.725	-1949.65
2018	-195.858	-2512.88
2019	62.1983	-82.2593
2020	135.7722	-1980.9
2021	-317.777	358.7346
Total	**-3106.9**	**-12667.3**

Appendix VI

Total Water Savings - Statewise (in million cu.m.

State	Total Water Savings in million cu.m. (2012-2021)		
	Sugar	Rice	Total
Andhra Pradesh	-302.32	-5679.66	-5981.98
Arunachal Pradesh	0.00	0.00	0.00
Assam	-0.62	797.36	796.74
Bihar	63.41	60.35	123.76
Chandigarh	0.00	-44.47	-44.47
Chhattisgarh	-1.37	14757.63	14756.27
Dadra and Nagar Haveli	0.00	0.00	0.00
Delhi	4.71	-362.97	-358.26
Goa	0.00	-1.80	-1.80
Gujarat	-58.72	-0.17	-58.89
Haryana	19.39	-22509.08	-22489.69
Himachal Pradesh	0.00	0.00	0.00
Jammu and Kashmir	0.00	0.00	0.00
Jharkhand	0.10	68.20	68.30
Karnataka	-1314.53	-47.81	-1362.33
Kerala	0.00	2.06	2.06
Madhya Pradesh	-21.76	871.73	849.96
Maharashtra	-1618.33	-206.58	-1824.91
Manipur		0.27	0.27
Meghalaya	0.00	0.00	0.00

Mizoram		2.43	2.43
Nagaland	1.20	1.68	2.89
Odisha	0.00	9631.38	9631.38
Puducherry	0.00	-19.19	-19.19
Punjab	17.20	-7578.56	-7561.36
Rajasthan	0.10	-2.02	-1.93
Sikkim	0.00	0.00	0.00
Tamil Nadu	-18.02	20.76	2.74
Telangana	-35.68	421.74	386.06
Tripura	0.00	0.00	0.00
Uttar Pradesh	124.60	-1082.56	-957.96
Uttarakhand	5.30	-1939.91	-1934.61
West Bengal	28.44	171.90	200.34
TOTAL	**-3106.90**	**-12667.29**	**-15774.19**