LUND UNIVERSITY
School of Economics and Management

Master's Program in Economic Development and Growth

# *More crop for every drop*

## A holistic analysis of Indian water stress through Virtual Water Trade and Policy

by

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India ranges among the countries experiencing most water stress in recent years, while being a major virtual water net exporter. The country's position relative to its water sources exacerbated since its trade liberalization in the early 1990's, which calls for a future national water crisis. To comprehend India's water stress, this study aims to examine the country's agricultural water use at three levels: Indian agricultural water use in the past and factors steering the sectors water use and economic activity; a meta-analysis on its international and interstate virtual water trade; and a review of policy interventions aiming to alleviate Indian water stress. Results suggest rebalancing trade in water-intensive goods and economic restructuring away from cereal-centralism, promotion of coherent national and state water policy to raise awareness for water scarcities, investments in R&D and irrigation technology to enhance efficiency and productivity, and considering water pricing and quotas on water use to avoid overexploitation.

Keywords: *India, water scarcity, virtual water trade, policy*

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*"The earth, the land and the water are not an inheritance from our forefathers but on loan from our children. So, we have to handover to them at least as it was handed over to us."*

*Mahatama Gandhi*

*"As I travel around the world, people think the only place where there is potential conflict over water is the Middle East, but they are completely wrong. We have the problem all over the world."*

*Koffi Annan*

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| | |
|---|---|
| **ASEAN** | Association of Southeast Asian Nations |
| **ICWE** | International Conference on Water and the Environment |
| **FYP** | Five Year Plan |
| **GVA** | Gross Value Added |
| **MSP** | Minimum Supporting Price |
| **NWP** | National Water Policy |
| **NRLP** | National River Linking Program |
| **R&D** | Research and Development |
| **SWP** | State Water Policy |
| **SDG** | Sustainable Development Goal |
| **VW** | Virtual Water |
| **VWT** | Virtual Water Trade |
| **WF** | Water Footprint |
| **WS** | Water Savings |
| **WUE** | Water Use Efficiency |

# 1 Introduction

The city of Chennai in the Southern Indian state Tamil Nadu has declared ”day zero” in June 2019, which basically means that the seven-million metropole has virtually run out of water. This is yet a mere snapshot of the extent of water stress a large and populous country like India has to endure, because an increasing number of countries suffer from water scarcity. With two-thirds of the world population having to endure severe water scarcity at least one month of the year (Mekkonen and Hoekstra, 2016), this compares to two-fifths well before the turn of the millennium (Hinrichsen, 1997), which implies a looming, global water crisis.

With a third of the world's biggest groundwater systems being already in distress (Richey et al., 2015), all continents are already affected and an increasing number of regions are reaching the limit at which water services can be sustainably delivered. Particularly in light of a constantly growing world population, global water demand will put further pressure on already stressed regions (Lenzen et al., 2013).

Unsurprisingly, water scarcity entails multidimensional conflicts at social, economic and political level over water resources, given the available stock determines whether countries are able to provide food security, which ultimately is also closely linked to economic prosperity (Schewe et al., 2014). At the centre of all economic dynamics related to water use is its associated so-called shadow price – the scarcity of the resource relative to its marginal benefit of use (Aucamp and Steinberg, 1982; Shi et al., 2014), or in other words, the resource's chronically underestimated social and economic value.

Therefore, many scholars advocate it should be considered an economic good and being stipulated in international treaties as promoted by the International Conference on Water and the Environment (ICWE) in Dublin, Ireland in 1992 and also by the United Nations in 2015 formulated sustainable development goals (SDG). They acknowledge the significance of sustainable use of freshwater pertaining to SDG 12, aiming to ‘‘(…) *ensure sustainable consumption and production patterns,*’’ for use of freshwater in agricultural production in developing countries to achieve economic growth and sustainable development (United Nations, 2015). The primary sector is essentially the main sink for water use for food production, accounting for approximately 70 per cent of global total freshwater use.

With climate change, a substantial impact can be observed for conditions of agricultural production and water use (Mimi and Jamous, 2010), as it propels an intensification of extremes of the global hydrological cycles through rising atmospheric temperatures and intensifying frequency and magnitude of precipitation and droughts (WWAP, 2019).

With a global uneven distribution of water reserves, those countries being naturally well-endowed with freshwater logically have the edge over water-scarce nations in terms of water and food security, but also in regards to economic prospects. Hence, a pivotal role to safeguard global water security can be assigned to virtual water (VW) – the water embodied in goods and services through their production, and virtual water trade (VWT) – VW being traded, as it bears the potential for water-stressed countries to efficiently redistribute the global use of water (Hoekstra and Hung, 2002).

In recent years, studies emerged making the case of VWT to assess water flows at global (Hoekstra and Hung, 2002; Chapagain and Hoekstra, 2003a, Distefano et al, 2014) as well as national levels (Zhi et al, 2013 on China; Cazcarro et al., 2013 on Spain; Dang et al., 2015 on the USA; Katyaini and Barua, 2017 on India). All findings have in common that particularly water-scarce economies willing to sustain their economic growth need to improve water-use efficiencies (WUE) in their agricultural activities.

With the push of developing countries integrating the world economy in the last decades, goods' production and consumption location are more than ever geographically apart (Los et al., 2015). Thus, countries participating in international trade ought to decide whether the export of water-intensive goods is worthwhile to pursuit, if the own region already experiences freshwater shortages and to what extent the import of such goods from other water-stressed countries is acceptable (Brindha, 2017; Cazcarro et al., 2013; Dietzenbacher and Velazquez, 2007). Hence, this begs the question what drives the consumption of agricultural VW and how water scarce countries position themselves regarding the trade in water-intensive goods.

Being among the world's largest water exporting countries measured by net VW exports, India faces serious implications for trade in food products (Hoekstra and Hung, 2002, Gupta, 2008; Kampman, 2007; Goswami and Nishad, 2015; Katyaini and Barua, 2017) as well as its long-run economic prospects (Mekonnen and Hoekstra, 2016). The country is the world's largest user of agricultural water, being the most water-intensive sector (Tukker et al., 2016), and has one of the biggest populations affected by water scarcity (Mekonnen and Hoekstra, 2016). The country's trade liberalisation and global trade integration since the early 1990's has essentially contributed India's upsurge as the world's largest water exporter. Since the country ranks among the most water-stressed countries in the world, projections for its future water security are more than uncertain. Being projected with the world's biggest population by 2027 will put further stress on its water sources (United Nations, 2019b). Unless measures are taken to address sustainable Indian freshwater use and distribution to avoid another "day zero" as recently in Chennai, it will have bigger problems than sustaining its recent outstanding growth trajectory that was supposed to herald the country's new era of prosperity.

## 1.1 Problem statement and contribution

The world reaches its limits in effectively using its global water resources to provide the circumstances under which all regions and countries may prosper. An apparent conflict over water not only will, but already ignited at social, economic, and political level (Hofstedt, 2010, Richey et al., 2015), particularly in times where globalization and international trade reshape the world economy. Given India is one of the rising world players in terms of economic activity , having a projected world GDP share that will lift the country to the world's second biggest economy by 2050 (Hawksworth, Audino, and Clarry, 2017), the country will crucially depend on how much water the economy disposes of and where it is allocated in the agricultural sector. This being said, the "how" plays a pivotal role as to sustain Indian economic growth since it took off in the early-mid 1990's after its trade liberalisation in 1991. Examining governmental actions taken at national and state-level show what measures are taken to secure water supply and alleviate regional shortages through a multitude of measures e.g. adequate infrastructure, etc. As a result, the guiding research question of this study can be derived:

*"What is the role of Indian Virtual Water Trade (VWT) in agricultural goods to alleviate the country's regional water stress ?"*

To assess the effectiveness of measures taken on national and state scale to alleviate regional water stress levels since the country's trade liberalisation, the following sub-question will be answered:

*"What measures were taken by the Indian government and state authorities to mitigate regional water stress since the country's trade liberalization in 1991?"*

The study contributes to prior knowledge regarding Indian regional wates shortages by making a holistic and comprehensive assessment factors affecting water use in the agricultural sector, and how Indian VWT at international and interstate level impacts its water use pattern. By conducting a meta-analysis of existing studies that dealt with Indian VWT, this study helps to link and understand the impact of being a net VW exporter and how this relates to a country's water reserves. Previous studies consider international and interstate VWT separately, which is why this study unifies these levels, and emphasises their joint significance in assessing Indian water stress. Examining targeted national and state-level policy measures aiming to alleviate water stress since India's international trade integration furthers and completes the whole discourse on the link between economic growth and environmental impacts. Bringing these three analytical levels together, is to the author's best knowledge the first time that someone conducts such a comprehensive analysis for the Indian case, particularly in light of all further challenges that the country faces in sustaining its water resources in its economic growth trajectory.

## 1.2 Scope and Outline of the Thesis

The scope of the study at hand is delimited by the economic take-off of the Indian economy in 1991 as well as the first emergence of the concept of VWT for the agricultural sector. Consequently, other Indian sectors are neglected. The timespan considered covers VWT data derived from the studies of the meta-analysis, covering at national level the period 1960-2013, and at state-level between 1996-2014. For policy study-purposes, the study covers major ratifications since 1991 until 2019 that aim to address the issue of national and regional water distress.

The thesis is structured as follows: The second section sets out to provide an overview of the factors influencing Indian water scarcity through the lens of agricultural water use. Therefore, India's water use position relative to the rest of the world, its past use of water in the agricultural sector and the country's potential future economic hardships, as well as global climate impact on India are examined, before moving on inefficient use and productivity issues of the agricultural sector. Section 3 makes a brief review regarding the state of knowledge on VW and VWT and thereafter brings quantitative measures into play by using the meta-analysis to evaluate how VWT in agricultural goods, with results being essentially distinguished into international and interstate-level. It is also here, that the main research question is answered. Finally, insights from section 2 and 3 are merged to Indian policy interventions in section 4 that also enters into a discussion of the measures themselves and thereby answers the sub-research question. Conclusions and a suggestion of possible future research are given in the fifth and last section.

# 2 Indian agricultural sector – past and future of water use

## 2.1 Water scarcity – India’s position in global water trade

Slowly but steady, water scarcity occurred in the last decades as a global issue with high stakes in case of failure, that urges to find suitable solutions at global, regional, national as well as community levels. Given the geographic disparity of water resources, some regions are naturally more water stressed with Australia taking an unconsoling first and Africa the second place (Hameeteman, 2013). Figure 2.1 gives a broad overview of the development of increasing global water stress due to rising water depletion rates – the water taken from existing renewable surface and groundwater. The United States, Mexico, Saudi Arabia, Pakistan, India and China are found to have the largest depletion rates, with regional water stress occurring particularly in large countries, which will become a widespread chronic issue (Hinrichsen et al., 1998). Other countries located in the Arab Gulf already have to resort to e.g. cost-intensive oceanic water desalination processes to meet their very basic water demand.

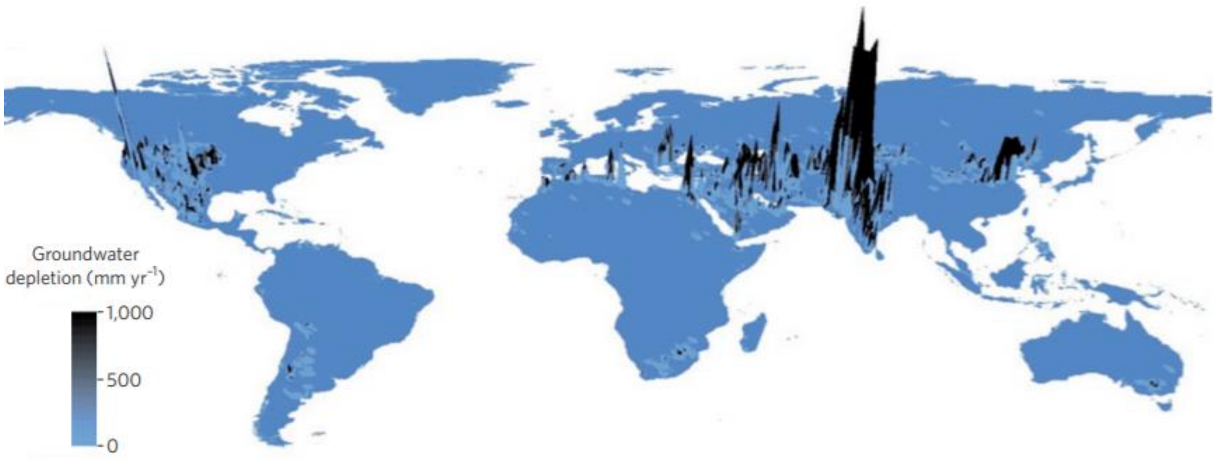


*Figure 2-1 Global groundwater depletion estimates 2012*

Source: Aeschbach-Hertig, et al, 2012.
Note: Colour scale based on the concept of blue water (renewable surface water and groundwater) and dark blue water (non-renewable groundwater)

But what does water scarcity in fact mean and how can it be measured? Under EU definition, it describes the situation where long-run average water needs cannot be satisfied due to insufficient availability (EU, 2007); or, to term it differently, the overexploitation of water resources due to a disequilibrium of water demand and supply (Van Lon and Lanen, 2013). Turning from theory of definition to scarcity quantification, one can distinguish between three main approaches (Rijsherman, 2006): First, per capita water availability (Falkenmark, 1989); second, a consumption and availability approach by simply taking their difference or as a ratio of both. Finally, the third approach encompasses an assessment of socio-economic and physical factors having an impact on stress (Sullivan et al., 2003). Regarding e.g. water per capita, India fares much worse than other agricultural powerhouses like China and Brazil (Dhawan, 2017), indicating India has to use its water available more efficiently.

Particularly groundwater levels underly human management unlike unalterable precipitation and thus put pressure on the world's biggest aquifer systems particularly in recent years (see figure 2). Therefore, Richey et al., (2015) elaborate Renewable Groundwater stress ratios and find for the Indian case, both the Indus Basin (number 23) and the Ganges-Brahmaputra Basin (number 24) figure among the aquifers with the highest global withdrawal rates, whereas the latter being the most overstressed aquifer. This underlines the fact that high levels of irrigation demand, rising population density and urbanisation in the North result unsustainable consumption patterns with the potential to impede not only economic growth and development, but essentially water security.

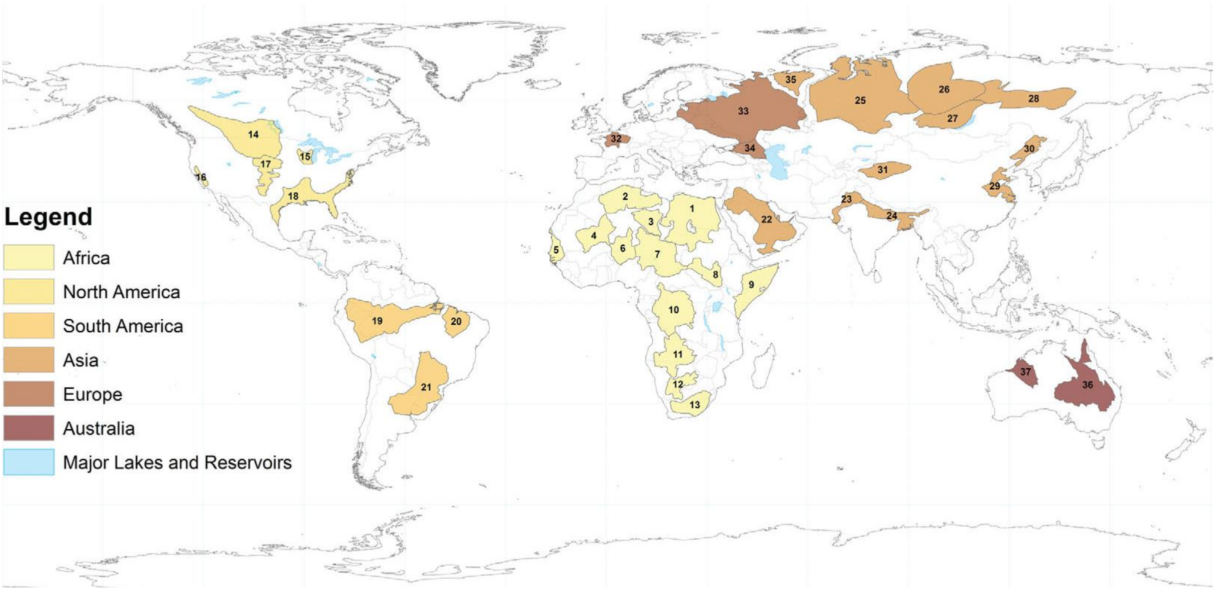


*Figure 2-2 The largest global groundwater aquifer systems.*

Source: Richey et al., (2015).

Therefore, numerous studies emerged in recent years that set out to analyse water flows from different perspectives to understand consumption of water resources. As mentioned before, VW is a term defining the volume of water necessary for the production of a specific good (e.g. food) (Allan, 1993). The international trade in VW can be seen as a continuous flow of nations' water resources, being also called "embedded water" (Hoekstra, 2003) or "exogenous water" (Haddadin, 2003). They emerged alongside the concept of water footprint (WF) pioneered by Hoekstra and Hung (2002), which describes the aggregate VW content in goods and services consumed by individuals or entire economies. Altogether, these approaches in terming and quantifying water use help in comprehending direct and indirect flows of water resources, which can be used for further analysis such as e.g. impact analysis of trade on water availability.

From this point, the role of international trade and its impact on national water resources deserves a more intensive discussion. This is because water scarcity gained much more attention with a booming world economy in the last decades and is increasingly perceived as a global systemic risk chiefly revolving around water use in the agriculture sector. Out of roughly 4 billion people enduring severe and continuous water scarcity, nearly half of those are living in China and India (Mekonnen and Hoekstra, 2016). Various studies on VW flows in China tried to quantify inter and intra-regional water flows being subject to trade (Zhang and Anadon, 2014; Zhi et al., 2013; Guan and Hubacek, 2007). The outcomes go into both directions: VWT can alleviate or exacerbate regional shortages. They do, however, imply that other factors than water availability alone drive VWT, which will be properly addressed in section 3 and 4.

In the global economy, especially the geographical separation of production and consumption of water-intensive products is identified as the main culprit in the looming global water crisis. While Chinese VW embodied in domestic trade being about twice as large as its VW embodied in its international exports (Zhang and Anadon, 2014), its waters-stressed neighbour India is the biggest net exporter of VW (Brindha, 2017; Katyaini and Barua, 2017). Likewise, the Indian national WF has increased 1.3 times between 1986 to 2013, which calls for investigation of water flows and the underlying rationale for water-stressed India.

## 2.2 Historical revision of the Indian agricultural sector

What probably describes best India's development path was captured by its own Indian Ministry of Finance (2016a, p.1) in stating that "*Indian agriculture, is in a way, a victim of its own past success—especially the green revolution.*" The economy is nowadays coined by cereal-centric production varying immensely by region while requiring a continuously increasing amount of vital inputs to agricultural production activities such as land, water and fertiliser. With an employment share of more than 40 per cent, it is still the heart of the Indian economy. Yet, forces such as rapid industrialization and climate change magnify use of land and water, ultimately rendering them scarce goods and posing issues for growth prospects.

As the quote above implies, lies the source to today's Indian economic and development hardships in its past and is closely tied to the county's agrarian development. Figure 3 illustrates the sector's gross value added (GVA) evolution over 63 years of the country's development, which is separated into four periods of average agricultural growth rates. Today, the sector is still loomed by the "ghost of Malthus" (Indian Ministry of Finance, 2018b), who was the predominant force preventing Indian agriculture from graduation to high productivity activity for a long period. In the mid-last century, farmers were regarded as country-feeding heroes, who struggled meeting their food demand themselves. Food security concerns, following two food crises due to a back-to back drought in the mid-1960s urged back-then farm minister Subramanium to search for a solution to international food dependence to divert most resources to high-yield irrigated areas, such as the Punjabs (Sims, 1993) to stop the recurring famines of previous years. previous decades. As a result, massive input subsidies for fertiliser, credit, power and irrigation inputs as well as better grains provided by India's National Agricultural Research System were granted to small and medium scale farmers, who compensated in turn with an immediate and dramatic boost in yields (Murgai, 2001) – the dawn of the green revolution.

If the green revolution was such a success, why all those fluctuations in figure 3 during this golden period? Subsidies became entrenched, because Indian Punjabs were majorly politically represented by aforesaid farmers, who objected any abolition of subsidies. This ultimately manifested in forcing out expenditures that aimed to enhance productivity, growing inefficiency in farm inputs as well as a prioritization of water- and fertiliser-intensive crops in agricultural production (Murgai, 2001). In the long-run, these distortions entailed soil degradation, over-exploitation of groundwater as well as salinity problems (Vaidyanathan, 2000), although within years of the revolution, success showed and India became self-sufficient in food grains.

Particularly the virtual absence of water and electricity prices along with an additional subsidy on tube well drilling for groundwater without any regulation of the number tube wells per land, has led the country to a state of water inefficiency (Johnson, 1989). The combination of yield-boosting inputs and environmental degradation might explain in part the big slumps and peaks during the whole period, which overall still make up for a bright period of Indian agricultural development. However, toward the end of the 1980s, diminishing returns manifested as a consequence of fading effects of green revolution. It turned out the governmental policy framework of subsidies entailed a distortion of the revolution's beneficiaries, a trend to use input-intensive crops as well a regional concentration of agricultural activity. A pathological lack of investment completes the doomed policy set, which has resulted in declining incomes coming out of agriculture for an Indian population relying on it that has not declined, though.

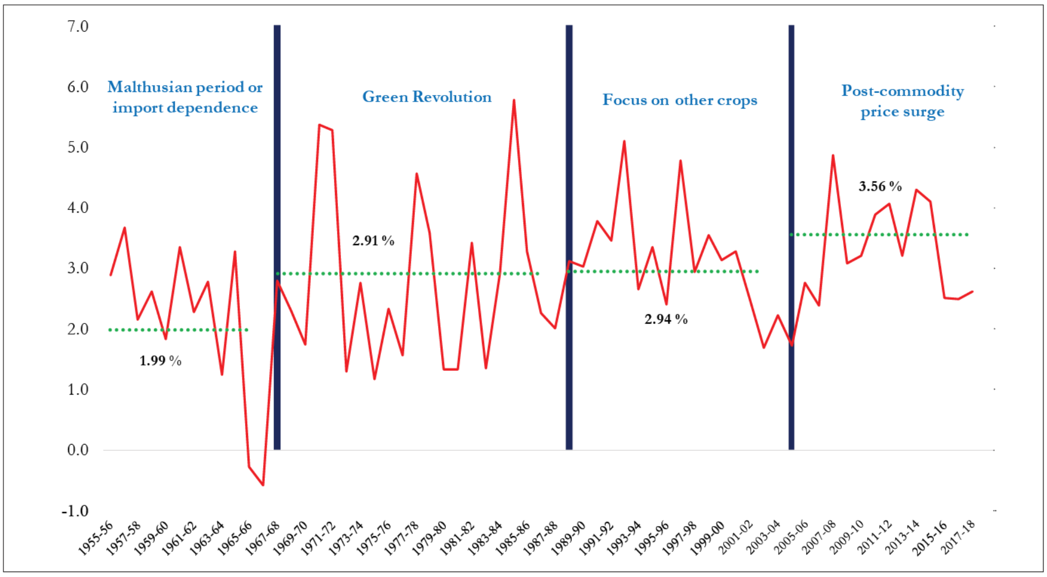


*Figure 2-3 Real Agricultural GVA Growth in India between 1955-2018*

Source: Indian Ministry of Finance, 2018b
Note: Numbers represent average agricultural growth rates for each year in percent with 5 year moving average in green dotted line.

The post-green revolution period (1986-94) eventually set off the wrong-doings of the previous period when input use levelled off (Byerlee, 1992). Plummeting average agricultural growth between the mid to late 1990s was, however, a partial reflection of soaring real prices of staples, which also followed the curve of Minimum Support Prices (MSP) for staples like wheat and rice (World Bank, 2014) and ultimately prompted an increase in domestic prices for cereals (Bathla 2011; Acharya et al., 2012). Usually, rising real prices benefit farmers directly, but MSP may disguise inefficiencies, inhibit productivity growth as well as increase overall cost for food production, entailing a vicious rise in MSP (Rao and Dev, 2010).

The last period can be assessed as the best productivity growth period, taking the five-year average green dotted line. The country is considered the world's largest producer of fresh fruits and vegetables, milk, major spices, various crops, etc. Prices seemed to be the main source of growth in the 1990s and became it again in the 2000's. Yields and land rebounded right after the turn of the millennium, but plummeted again ever since 2007 due to sluggish land expansion together with yields' contribution to growth (World Bank, 2014).

Moderate diversification, modest change in diets as well as rising commodity prices prove unapt to offset the sector's several hardships, which seem to revolve around sluggish productivity growth rates, taking into account the country's development stage. Dhawan (2017) presented during the Global Forum for Food and Agriculture 2017 the Indian case and its use of critical agriculture inputs – land and water. He compares India to other leading countries of the world in agriculture, China and Brazil and gives a bleak picture: cultivable land per person land experienced a much sharper decline than other countries (see figure 4) with prospects for the next 20 years being even worse. The second big challenge is illustrated by figure 5, depicting water per capita available, where the country fares even worse than the other leading agricultural powerhouses. This constraint has yet another magnitude for the Indian economy, which showcases the pressing problem this study intends to shed light on – Indian water use and consumption. While Brazil and China use roughly 60 per cent of their renewable freshwater deposits, India uses more than 90 per cent (Dhawan, 2017).

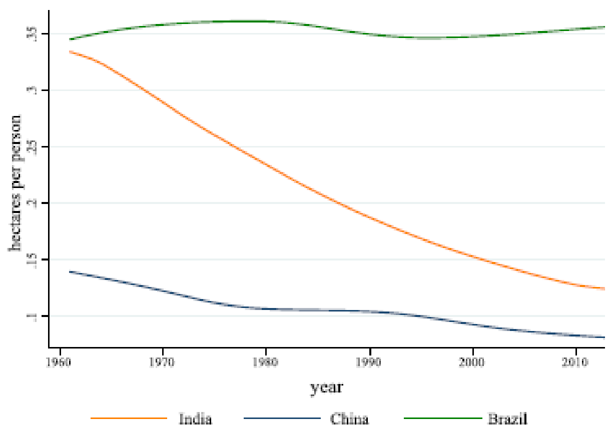


*Figure 2-4 Per capita availability of arable land in India, China, and Brazil*

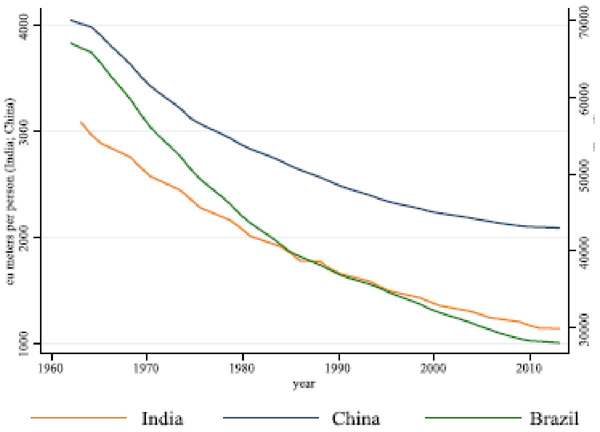


*Figure 2-5 Per capita availability of renewable freshwater resources in India, China, and Brazil*

Source: Dhawan, 2017.
Note: Read India, China off left y-axis and Brazil off right y-axis

The crux of the matter is here: although freshwater is one of India's most scarce resources, the country uses 2 to 4 times more of it to generate a unit output of its major food crops compared to Brazil and China (Chapagain and Hoekstra, 2008).

Such development of depleting water reserves follows a global trend for use of natural resources, particularly groundwater – the input usually used when a region lacks precipitation. Moran et al. (2013) posit annual groundwater withdrawals exceed the rate of natural recharge, resulting in rising global water stress in a world of growing global demand for agricultural output.

To bridge economic growth, development and environmental protection, one needs to ensure economic activity can continue without compromising sustainability of a country's resources. Therefore, the next section outlines what potential headwinds lie ahead of Indian growth.

## 2.3 Challenges of Indian economic growth – the four horsemen of the apocalypse

India's economic development was marked by a rapid catching up performance ever since the 1980's with average per capita GDP growth rates of 4.5 per cent, ranging among the top at the growth frontier and the highest for continuous democracies (Indian Ministry of Finance, 2018b). Some scholar might even say, India's economic catch-up likened "convergence with a vengeance" (Subramanian, 2011). To put its growth performance into perspective: India was classified low-income country with PPP per capita income of $1,033 in 1960, totalling 6 per cent of U.S. per capita income, proxying the development "frontier country". Since then, the country attained lower middle-income status in 2008 and could double its GDP in PPP relative to the U.S. In the long-run, the country is set to reach upper-middle income status by mid-to-late 2020s, given its per capita growth rate of 6.5 per cent (Indian Ministry of Finance, 2018b).

These figures do, however, cast a shadow over the actual development hardships the country needs to master nowadays. A so-called "Late Convergence Stall" seemingly is what India faces fearfully after its economic upsurge of the past 30 years. The Indian Ministry of Finance cynically expressed this concern of potential headwinds in a post-global financial crisis era in form of the *four horsemen of the apocalypse* in its economic survey 2017-2018. These four horsemen go by the names

1. Hyper-globalization repudiation,
2. Impeded structural transformation,
3. Human capital regression induced by technological backwardness,
4. and climate change-induced agricultural stress.

To describe all horsemen in a brief manner, the first comes with winds drying out the trading opportunities that spurred growth for early convergers, especially when those followed the East-Asian pattern of export-led growth (O'Sullivan, 2019) totalling double digit rates for three to four decades. The second comes in form of uncompleted or thwarted structural change. To recap, successful structural change requires 1) a shift of production factors from low to high productivity sectors, and 2) a bigger allocation of resources to sectors striving to favour rapid productivity growth. In the Indian case, low agricultural productivity and high employment shares are emblematic for its uncompleted structural transition (see appendix A). Third, human capital regression weighs heavily on countries that lack in essential fundamentals for sustained growth like widespread education (Mc Millan et al., 2017). India might see itself confronted by a widening gap between capabilities of its labour force and opportunities available for its future labour force (Indian Ministry of Finance, 2018b). At last, horseman number four is of particularly importance, which manifests in form of climate-induced agricultural stress being discussed in detail in the next section given its significance for water use in the agricultural sector.

## 2.4 Effect of global climate change on India

Climate change is a prime example for the necessity of all nations to pull into the same direction and ranges among those issues considered among the biggest global challenges according to the World Economic Forum (2016).

Extreme weather events are predicted to increase in their likelihoods (Hoegh-Guldberg et al., 2018; Bogra et al., 2016). Future outlooks for agricultural productivity and yields are highly dependent on how climatic shifts arise in differing regions. Production areas may become warmer and drier while others experience greater annual precipitation, but in unfavourable timing from the viewpoint of seasonal crop production (Roudier et al., 2011). As a result, agricultural output will be less predictable, particularly in arid regions where water is already a scarce resource (FAO and WWC, 2015). In stark contrast, other areas may benefit from higher temperatures and longer growing seasons bringing about higher yields (Kang et al., 2009; Gerardeaux et al., 2012; Zhou and Turvey, 2014). Notably countries and regions renown for crops requiring higher ozone concentrations such as wheat, rice, barley, sugar beet, and cotton will increase yields, while others will experience heavy yield losses (Jaggard et al., 2010). Especially large countries stretching over various climate zones like China and India will be challenged by varying impacts that will require region-specific socio-economic solutions (Chauhan et al., 2014; Wei et al., 2014; Xiong et al., 2010; Zhou and Turvey, 2014).

The FAO World Water Council 2015 makes projections for the year 2050 and finds that especially poor lower-income residents are the most prone to experience food insecurity given their limited means to adapt production and consumption patterns according to changing weather patterns (HLPE, 2012). Primarily arid and semi-arid regions would be most negatively affected if rainfed, because precipitated areas account for 80 per cent of global cropland and 60 per cent of global food yields (Turral et al., 2011) compared to a 40 per cent for irrigation (Siebert, et al., 2013).

Many precipitation-poor regions resort to groundwater irrigation for fuelling their agricultural activities, threatening the state of many river basins shared by multiple countries, drawn into potential water conflicts (Just and Netanyahu, 1998; Spulber and Sabbaghi, 1994). A force like global climate change is likely to put additional pressure on groundwater resources since water supply variability is a highly subjective matter to it and its rates of recharge and discharge (Kløve et al., 2014; Kurylyk et al., 2014).

Kumar and Jain (2011) confirm that large variations in agricultural practices, climate and land productivity result in large variations in agricultural productivity between Indian states. India is likely to experience further stress due to the negative impact of climate change apart from enormous water wastage owing to poor management (see section 2.4) along with distorted water pricing policies. The Indian Ministry of Finance (2018a) estimate for temperature increases prompting to slump farmers' revenue by 20 to 25 per cent in non-irrigated land, in the wake of climate change

Further, the country is also plagued by regional weather hardships such as droughts and floods, where the former caused millions of deaths in the 18th, 19th, and 20th century. Major drought-prone regions are such as Southern and Eastern Maharashtra (Western India), Northern Karnataka (South-Western India), Andhra Pradesh (South-eastern coast of India), Odisha (Eastern coast of India), Telangana (South-eastern coast of India) and Rajasthan (Western India) (see figure 2.6). When adding agricultural activity to the picture, it is striking that out of 140 million hectares of arable land, 42 per cent lie in drought-exposed regions (Dhawan, 2017). Population growth projections and accompanied demand in some of those states (Census 2011) reiterate that solely intensified groundwater use seems to help overcome such critical periods. Yet, the resulting groundwater overuse and quality deterioration also entail less availability for agriculture than in the past, thereby causing even more pressure on agricultural production.

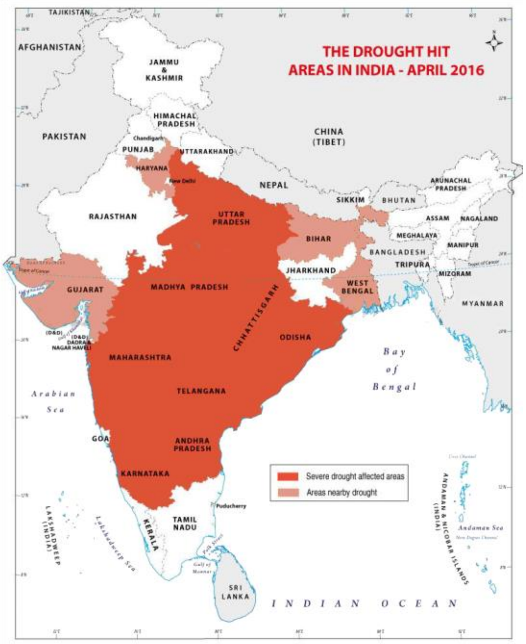


*Figure 2-6 Drought-exposed regions of India in 2016*

Source: Dhawan, 2017

Another important feature of the country's weather topology are floods that affect 12 per cent of the country's total area with Bihar in the Northeast being the worst hit state where hardly a year goes by without a major flood incident (FAO, 2015). With the start of the monsoon season in June, rivers come down from the Himalayan hills in Nepal with enormous force, to rise above the dangerous shore levels in the North and East (see figure 2.7). Consequently, regions such as North Bihar, with the Kosi river popularly known as "the sorrow of Bihar" crossing it, where the unsteady river course resulted in 15 changes in its course with 2.8 million people having to live with the aftermath, which primarily is land degradation totalling a staggering 22.5 million hectare, caused by floods, water and wind erosion (FAO, 2015).


*Figure 2-7 Major rivers of India and main flood-prone region.*

Source: Own representation, based on Maps of India (2020).

Climate change models by the IPCC, predict Indian temperatures to rise by 3-4 degree Celsius by the end of the 21st century (Pathak, Aggarwal and Singh, 2012), implying that in the absence of any adaptation by farmers or in policy terms (such as irrigation), farm incomes will dwarf on average by 12 percent (Indian Ministry of Finance, 2018a). This begs the question why irrigation practices are seemingly as detrimental to the Indian agriculture as thus-far found. Figures 2.8 showcases the spread of irrigation for Indian regions between 1966-2011. Less than 20 percent of agriculture was irrigated in 1966 compared to staggering mid 40 percent in 2011. Best irrigated parts are the Indo-Gangetic plain, and parts of Gujarat and Madhya Pradesh, which compare to the Western and central regions.

If India fares so badly in regards to its groundwater reserves, what does the picture look like when one examines precipitation and temperature changes? Exclusively rainfed areas will be the most severely affected by climate change, mainly due to the intensification of extreme weather conditions resulting in more hot, dry and warm days against a decreasing number of cold days reported by the Indian Meteorological Department (IMD) between 1970-2015. Such development will logically also have an impact on average temperatures and rainfall during both Indian cropping seasons Kharif – the monsoon crop season (June to October), and Rabi, covering the months November to April (Kumar and Jain, 2011).

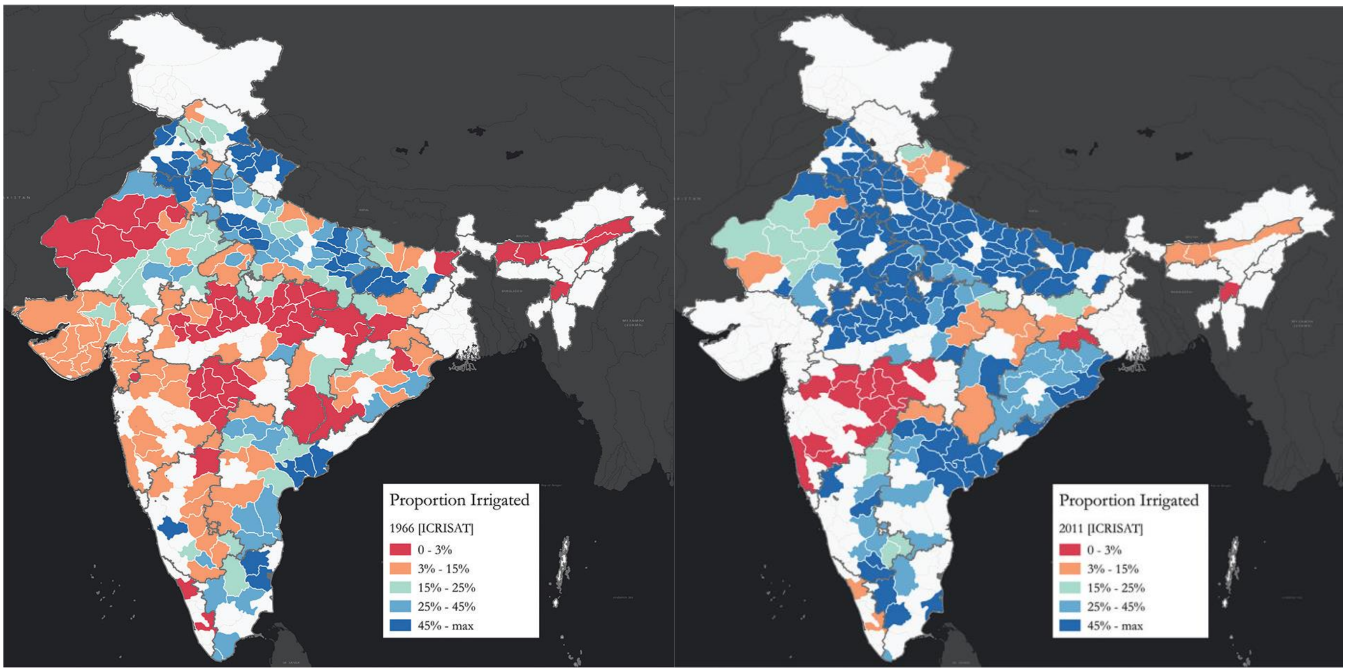


*Figure 2-8 Spread of irrigation in Indian regions between 1966-2011*

Source: Indian Ministry of Finance, 2018a
Note: Survey calculations from ICRISAT data where white areas indicate missing data

In sum, the analysis above supports three main channels through which climate change may affect economic prospects for agriculture and farmers.

1. An increase in average temperatures,
2. A decline in average precipitation,
3. And a higher annual number of dry-days.

It is noteworthy, however, that all three factors are correlated, rendering the total impact of climate change no simple sum game: Region-specific changes and dynamics, given India's geo-climatic diversity, do not allow to apply one standard to all (Zhang and Cai, 2011). Last but not least, the "how" water is paramount in coping with future climatic hardships, leading to the subsequent section.

## 2.5 Lack of water use efficiency and productivity

The previous chapters have thus far shown how the Indian economy chiefly relies on the agricultural sector and how its historical shortcomings in effectively managing the country's water resources can impede sustained growth. This chapter sets out to investigate India's use practices including withdrawal and consumption cycles, lacking knowledge and technology investments, water infrastructure as well as pollution further exacerbating water stress.

The FAO World Water council (2015) stresses that water shortages will intensify in most regions where use of ground- and surface water is not sustainable like the North China Plain as well as Central and South Asia. Food and water security – SDGs 2 and 6 can be achieved even with a world population reaching between 9 and 10 billion, provided water management and allocation are done wisely while increasing agricultural productivity (de Fraiture et al., 2010; de Fraiture and Wichelns, 2010; Springer and Duchin, 2014).

Agricultural water allocation in form of withdrawal accounts for more than 70 per cent of all withdrawals from rivers, lakes and aquifers, with urban areas showing an increasing demand, which will entail a decrease in availability for agriculture (FAO and WWC, 2015). In contrast, global agricultural water volume will need to increase to serve soaring demand between now and 2050, prompting many farmers to adopt more efficient practices, especially using "*less water for more crop*". That call for productivity will only be heard, provided innovative technologies and investment for education and training in irrigated and rainfed management practices are warranted.

It is important, however, to discern different water withdrawal types, blue, green, and grey water, as proven important and discussed in detail at a later stage of this section. Blue water is mobile, can be abstracted, pumped, stored, treated, distributed, collected, and recycled. Conversely, green water comes from precipitation, is limited in arid areas, is highly immobile and generally not much valued by users (Distefano et al., 2014). The last type, grey water is initially polluted water that requires dilution with other water sources to make contained pollutants harmless. Hence, it can be used to show the degree of pollution of water reserves and may indicate a propensity of industrial water intensity.

Using a Water-Withdrawal Input−Output Model of the Indian economy, Bogra et al., 2016 find for the direct and indirect use of green, blue and, a third and very important distinction in this study's setting, scarce groundwater for agriculture, considered for 13 major crops including water intensive crops of paddy, wheat and sugarcane. Figure 2.9 gives a through overview with top 10 states representing 603 billion $M^3$ of blue water use in agriculture of which 407 billion $M^3$ is groundwater and 223 billion $M^3$ is scarce groundwater, thus, letting the authors conclude their consumption represents 98 per cent of domestic scarce groundwater use. This yields a pattern of its regional distribution with high dependence of cereal-specialized Northern states and states of Gujarat, Rajasthan, Madhya Pradesh and Karnataka for other crops.

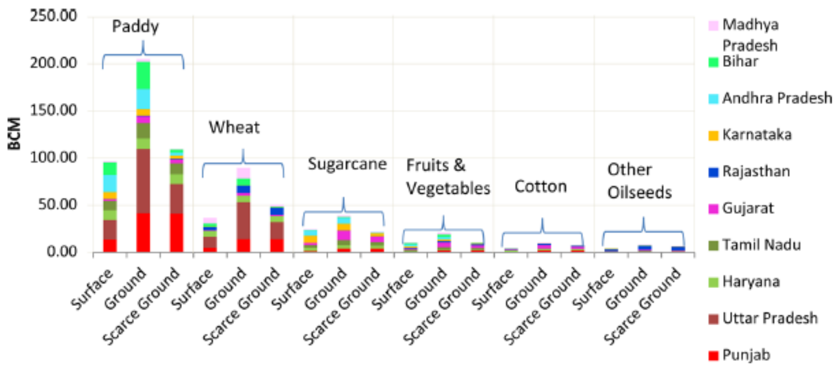


*Figure 2-9 Surface, Ground, and Scarce-water flows of cereals with contributing states*

Source: Bogra et al., 2016.
Note: Data for states of Maharashtra and West Bengal not available

Water withdrawal alone is but one lens through which one may assess the state of water use of nations. Consumption itself is one central driver for withdrawal given water use is mainly explained by two variables: population size and infrastructure (Distefano et al., 2014). Reducing demand could for instance call for a major shift in cropping patterns, with chance to reduce irrigated areas (Balwinder-Singh et al., 2015).

At last, recharge levels of groundwater are most decisive as India's aforesaid renewable groundwater use is the largest in the world. A partial explanation of this issue is that farmers in main states obtain subsidized energy to pump groundwater. Consequently, farmers withdraw large groundwater quantities, which insulate them from forces like monsoons and droughts (see previous section) and does not make water a constraint to agricultural gains (Kumar and Jain, 2011). Such practices, yet, compromise excessive groundwater states in their ability to recharge their water depot since withdrawal exceeds the natural recharge rates. For all states, the Central Ground Water Board found in 2011, that out of 6,607 assessment units in the country, 1,071 units (in 15 states and 2 union territories) have been categorized as "over exploited" based on long term decline in groundwater levels.

Thus-far, it appears that the true value of a vital resource like water usually does not take part in discourses of its distribution, allocation and, most importantly, its price. Hoekstra and Hung (2002) suggested that problems of water scarcity, water excess and deterioration of water quality would be solved if the resource 'water' were properly treated as an economic good, as to prevent its global shortages. This begs, however, the question whether the broad public is aware of its scarcity and, hence, its value.

The FAO (2015) recognises that lack of awareness of global water scarcity and stresses the function of water institutions to communicate shortages to final users. In the same vein, the spread of agricultural know-how as well as efficient use of resources such as water is crucial in the Indian case, as the system seemingly shows three deeply rooted weaknesses.

First, targeted education focusing on agriculture, measured by students enrolled in agricultural universities falls particularly short in states where the share of agriculture to GDP is high, which primarily applies to states in the Northern (except Punjab and Haryana) and Eastern regions. Hence, diffusion of new agricultural innovations and practices are plagued by institutional and academic shortcomings (Tamboli and Nene, 2013; Niti Aayog, 2015), or even dissemination of information about public programs such as MSP, are unable to achieve their intended objectives.

Second, investment in public agricultural research is poor, being substantially below that of China, and measured by a share of agriculture GDP even less than that of Bangladesh and Indonesia (see figure 2.10). The country started under-spending on R&D even relative to its level of development (Indian Ministry of Finance, 2018c).

Last but not least, an ostensible big lack in research productivity to augment resource efficiency, like water and land, is required as scientists in public agriculture research institute, assessed by instituting performance indicators have majorly (63.5 per cent) "low to very low level of productivity" (Paul et al., 2015).

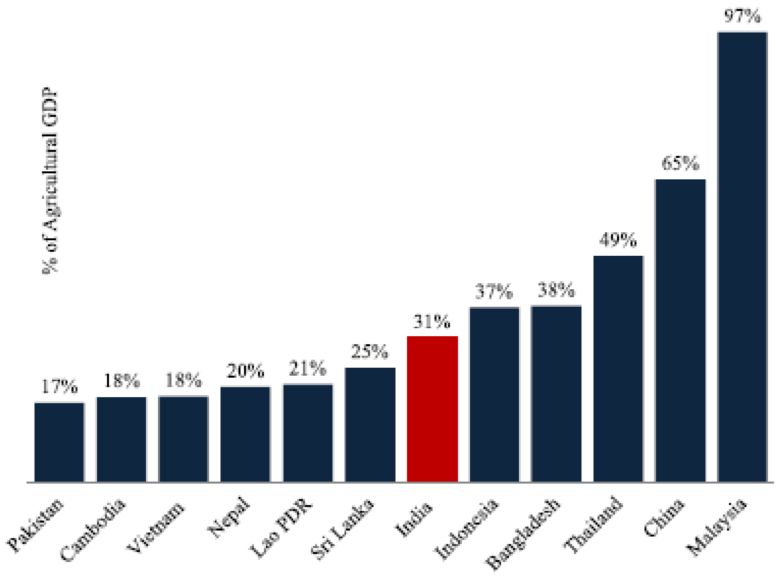


*Figure 2-10 Agriculture Research and Development Spending in 2010*

Source: Stads, G.J. 2015. "A snapshot of agricultural research investment and capacity in Asia." ASTI Resource Paper for the Asia Pacific Association of Agricultural Research Institutions' High-Level Policy Dialogue, Bangkok. December 2015. Washington, DC: International Food Policy Research Institute.

The previous sections have already pointed to a chronic issue of insufficient productivity in the agricultural sector, halting a full unfolding of structural transformation, which would improve lots of Indian livelihoods. Despite the country's looming water crisis, India's irrigation remains highly inefficient from a technical point of view. India's third Minor Irrigation Census has shown that in 2001, a meagre 3 per cent of roughly 8.5 million tube well owners used drip or sprinkler irrigation – a commonly renown efficient irrigation practice, compared to 88 per cent using flooding through open channels for cultivation (Dhawan, 2017). Unsurprisingly, this is also the least efficient practice, which points to the country's widespread lack of adequate agricultural technology.

The national water infrastructure is another reason why the country will have to affront a turbulent future (Briscoe, 2005), unless its government continues to expand its infrastructure uniformly for all states. It is, however, wrongly believed that the infrastructure network is insufficient, given the country has reached 81 per cent of its ultimate irrigation potential, which is why further extension on a large scale is limited. In point of fact, it is the inefficiencies, that was and still is fairly high. As suggested above, lacking information and technical skills of poor farmers (Ali and Byerlee, 1991) are a major product of discontinuous investments in agricultural R&D and education.

As mentioned at an earlier stage, the use of grey water in combination with water pollution also have a major stake in ensuring nations' water security. Behrens et al., (2017) state for instance that economic activity has a big impact on water pollution and acidification and salination of groundwater. Salinization (Kazmi et al., 2012) can impair agricultural productivity over time, and degrade water quality in rivers and shallow aquifers, making them unfit for human consumption (FAO and WWC, 2015). Constant pumping of deep groundwater can expedite the movement of saline shallow groundwater into deeper aquifers, thus contaminating important sources of water for drinking and irrigation (Chaudhuri and Ale, 2014).

In sum, this section showed how India's withdrawal and consumption cycles, the country's lack of R&D, knowledge and investment as well as deficiencies in its water infrastructure and management can further accelerate the depletion of the country's water reserves, particularly if pollution is also considered. Thus, they showcase how socio-economic changes and regional water allocation disputes are no far-fetched reality (Bogra et al., 2016). It is for this reason, that insights gained will help in assessing whether redistribution of global water via national and international virtual water trade can improve India's water stress.

# 3 Indian Virtual Water Trade and water stress – A meta-analysis

Previous sections briefly described how virtual transfers via global trade from water-abundant regions of production to far away located, water-scarce areas of consumption can be termed as the globalization of water (Distefano et al., 2014). A vital role plays the price of water, since it is theoretically cheap where abundant, but the opposite is not necessarily true: price distortions may prompt incorrect, mostly low pricing through among others general absence or a lack of well-defined water rights, as is the case in India. Through uneven global, geological distribution of water resources (World Bank, 2010b), some countries thus not only have economic advantages considering water use in the primary sector, but also environmentally the edge over others. Given VWT is identified important means to balance local, national, and global water budgets (Chen and Chen, 2011; Duarte et al., 2002; Guan and Hubacek, 2007; Hubacek et al., 2009; Velázquez, 2006; Yang et al., 2006; Yu et al., 2010; Zhao et al., 2009, 2010), the subsequent sections are concerned with, first, showing the state of knowledge regarding previous research in the field of VWT. That section will take the approach to broaden the topic at global scale, before zooming into VWT applied to the case of Indian agricultural goods and the underlying reasons to trade at all. The second subsection is dedicated to present the actual meta-analysis results of Indian international and national VWT, and how these flows aid in alleviating its water stress.

## 3.1 Previous literature on Virtual Water and Virtual Water Trade

Alongside the VW concept, introduced by Allan (1993) and defined as water being "contained" in a certain product along its production process, emerged the water footprint, proposed by Hoekstra and Hung (2002). The latter follows the analogy of the ecological footprint (Wackernagel and Rees, 1996) and Odums embodiment perspective in systems ecology (1971). As stated before, the concept is particularly relevant in relation with trade (Lenzen and Foran, 2001), as areas can save water by replacing some of their domestic production of water-intensive goods by imports from relatively water-abundant regions. This evokes the Heckscher-Ohlin (HO) theory (Wichelns, 2001; Hakimian, 2003; Sayan, 2003), predicting relatively water-abundant regions to export goods and services that are produced in a relatively water-intensive way, as also found MacDonald et al., (2015) and Wichelns (2004). Such relation calls into memory the rationale behind international trade, that drives the increasing process of trade globalization.

Suranvic (2007) makes a summary by stating five reasons why two regions engage in trade:

1. The Ricardian comparative advantage model explaining trade driven by differing technological differences;
2. Differences in resource endowments explained by HO;
3. Demand disparities according to the Linder effect explaining trade between surplus entities;
4. The new trade theory positing the relevance of economies of scale;
5. and government policies creating trade environments different from natural advantages and disadvantages.

In the Indian case, the 1991 trade liberalization package allowed the country to undergo a structural shift consisting of internal and external components with the former lowering domestic barriers and embracing industrial competition, whereas the latter, entailed among others a free import regime for exporters (Das, 2012). These structural changes also sparked early debate about the environmental impacts of trade liberalisation and regulations, since the cost of environmental degradation (and conversely the benefits of environmental preservation) are not reflected in the price of goods and services (UNEP, 1999), nor in the price of some inputs such as water. This discussion will, however, take place in detail in section 4 for it is a policy-related debate. It brings, yet, another term into play being central to trade in goods: unequal ecological exchange.

Although scholars advocate VWT bearing the potential to redistribute uneven endowments of water in the world (Allan, 1997; Chapagain et al., 2006; Yang et al., 2006; Lenzen et al., 2013a), it could allow wealthy consumers to purchase precious scarce water from lower-income countries (Lenzen et al., 2013a), which is also termed unequal ecological exchange (Moran et al., 2013; Emmanuel, 1972; Hornborg et al., 2007; Martinez-Alier, 2007). Such exchange is illustrated by figure 17 for the world regions in terms of financial balance of trade in US dollars as well as embodied water. A second dimension demonstrates the flows relative to countries' income levels. It is striking that in a number of cases (e.g. Africa to W. Europe) the balance of trade in embodied water opposes the one in financial terms.

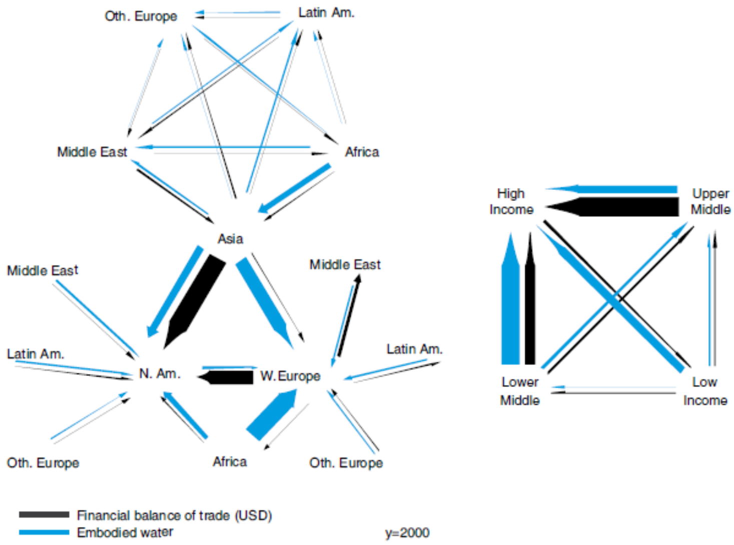


*Figure 3-1 Inter-regional balance of trade in term of financial flows and embodied water in 2000*

Source: Moran et al., (2013)

Hoekstra and Mekonnen's (2012) find that not all trade structures enhance global water availability, as water-scarce countries may also import water-intensive goods from other water stressed regions, which ultimately just shifts the environmental burden of irrigation demand abroad. Knowing that roughly one-fifth of global cropland and agricultural water is allocated to the production that is consumed abroad (Hoekstra and Mekonnen 2012, Kastner et al. 2014)., the whole trade in water-intensive goods debate ostensibly is much more intricate than HO factor endowments' trade theory is able to explain.

When looking into the ASEAN (Association of Southeast Asian Nations) region and how India fares relatively, Chen et al., (2017) assess global freshwater use embodied in worldwide supply chains via a Multi-Regional Input-Output model and find India and ASEAN to be the world's largest outflow economies for agricultural freshwater. This finding underlines the most concerning feature of Indian water trade: the country has been a net water exporter for many decades, although it suffers water shortages. The Indian Ministry of Finance (2016a) states that India used to be a net water importer until around 1980s, which shifted with a changing trade paradigm to exports of mostly grains. When comparing to its neighbour China, the ratio of export to import of VW is about 4 for India and 0.1 for China. Thus, China clearly remains a net importer of water, being also evident from its trade patterns coined by water-intensive imports. In contrast, India exports water-intensive goods, which begs the question how its VWT pattern developed over time relative to the country's rising water stress.

Table 3.1 enlists all relevant sources that conducted Indian VWT analysis, the timespan covered, the agricultural goods assessed as well as the VW import-export balances as long-term, annual averages for timespans covered. These sources will serve as cornerstones for the first part of meta-analysis aiming to reveal how Indian water shortages might be explained through international VWT in agricultural goods.

*Table 3-1 Sources consulted for meta-analysis of Indian international VWT*

| No. | Reference | Study period | Products (number indicated, if available) | VW import ($Bm^3/y$) | VW export ($Bm^3/y$) | Net VW ($Bm^3/y$)[a] |
|---|---|---|---|---|---|---|
| **Country-level analysis** | | | | | | |
| 1 | Hoekstra and Hung (2002) | 1995-1999 | 38 crop products | 2.4 | 34.6 | -32.2 |
| 2 | Chapagain and Hoekstra (2003a) | 1995-1999 | 146 livestock products | Not available | Not available | -2.2 |
| 3 | Chapagain and Hoekstra (2003a) | 1995-1999 | Crop and livestock products | 3.9 | 38.4 | -34.5 |
| 4 | Zimmer and Renault (2003) | 1999 | Crop and livestock products | 31 | 8 | 23 |
| 5 | Chapagain and Hoekstra (2004b) | 1997-2001 | 285 crop and 123 livestock products | 17 | 42.6 | -25 |
| 6 | Kumar and Jain (2007) | 2001-2005 | 106 crop and livestock products | 71.7 | 45.7 | 26 |
| 7 | Gupta (2008) | 2001-2006 | 283 crop products | 41.2 | 51.6 | -10.4 |
| 8 | Goswami and Nishad (2015) | 1961-2010 | 75 crop products | 5.9 | 44 | -38.1 |
| 9 | Brindha (2017) | 1986-2013 | 329 Crop and livestock products | 32.6 | 59 | -26.4 |

[a] Positive value indicates net virtual water import and negative value describes net virtual water export
Note: values displayed depict annual averages for each respective timespan covered by the author(s).

Looking at the table above, it becomes evident that a comparative analysis is not simple, since not only time periods covered are hardly similar, but metrics differ substantially, like number and classification of products, if at all indicated, indicators used, etc. There are three studies using crop products only, ranging between 38-28; one study investigating a total of 146 livestock products only; and five studies using both, crops and livestock products. Given this great heterogeneity in agricultural content, a comparison of results across studies is hardly advisable, if one is concerned with consistence. Therefore, results of the meta-analysis will be grouped by product classification used by studies– crops, livestock, crops and livestock, whereby the last group will be divided into studies finding India as a net VW exporter and importer.

Likewise, table 3.2 below enlists the studies consulted for the Indian interstate VWT analysis. Unlike the last table, these studies count total VW flow resulting from interstate agricultural trade. Although such view might seem simplistic, it proxies the occurrence and development of interstate trade volumes. It is also accompanied by the indicator net VW savings via interstate VWT, which suggests interstate VWT does indeed lead to VW savings (if investigated by study). The results reported for interstate VWT are based on a comparative analysis, following a chronological order, due to the limited number of studies and their crop trade focus, and differing time periods covered. Solely Katyaini and Barua (2017) will a comparative analysis to some extent.

*Table 3-2 Overview of meta-analysis sources of Indian interstate VWT*

| No. | Reference | Study period | Products (number indicated, if available) | Total virtual water flow as a result of inter-state trade ($Bm^3/y$) | Net VW savings via interstate VWT (if indicated in $Bm^3/y$) |
|---|---|---|---|---|---|
| **Inter-state analysis** | | | | | |
| 1 | Kampman et al., (2007) | 1997-2001 | 80 crops | 106 | 41 (at global level) |
| 2 | Kumar and Jain (2011) | 2003-2006 | Wheat and Rice | 148 | |
| 3 | Katyaini and Barua (2017) | 1996-2005 and 2005-2014 | 9 crop categories | 9.96 and 23050 | 11.2 and 25932 |

Note: Positive value indicates net virtual water import and negative value describes net virtual water export.
For Katyaini and Barua (2017) results, also please consult appendix I.

## 3.2 Results of meta-analysis

### 3.2.1 Indian international Virtual Water Trade

The pioneers in the field of VWT analysis were Hoekstra and Hung (2002) who ascertained a lack in knowledge over the actual volumes of virtual water flows between countries, more specifically related to international crop trade. Therefore, they studied VWT in the period 1995-1999, using a simple method of multiplying international crop trade (38 products) flows (ton/yr) by their associated VW content ($m^3$/ton) (see table 3.2). They retrieved trade data from the UN Statistics Division and VW content data from various FAO databases, which proved to be the data backbone of most studies' analysis of VW flows. Further, they introduced the term "water footprint", equalling the sum of the domestic water use and net virtual water import, which can be understood as a measure of a nation's actual appropriation of the global water resources, rather than looking at domestic use alone. They further introduced indicators measuring a nation's 'water self-sufficiency' and a nation's 'water dependency' levels as well as a water scarcity indicator measured as ratio of total water use to water availability.

Further, they provide an overview of several water indicators as can be observed in table 3.3, which depict how India fares in year 1995 relative to China and the USA, being chosen for their comparison as they share many relevant characteristics, including population and country size, large quantum of VW flows, display of some degree of regional water scarcity, etc. It becomes apparent that India withdraws much more water, while having less water available than China or the USA. It also has the highest water footprint as well as the highest water scarcity level being 10 per cent higher. In terms of net water imports, India proves to be a net exporter indicated by the negative sign, yet being substantially outmatched by the American water exports that are almost 7 times larger. At last, all three countries display high water self-sufficiency levels, which means their water imports and exports are in balance, whereas China already seemed to depend more on water imports, reflected by its higher dependence level.

*Table 3-3 Gross virtual water imports into and export from India between 1995-1999*

| INDIA | 1995 | 1996 | 1997 | 1998 | 1999 | Total |
|---|---|---|---|---|---|---|
| **Gross VW import** ($10^6 m^3$) | 595.7 | 1,517 | 4,084.9 | 4,449.0 | 1,418.6 | 12,065.2 |
| **Gross VW export** ($10^6 m^3$) | 25,203.5 | 85,625.4 | 28,994.7 | 29,101.4 | 4,136.6 | 173,061.6 |
| **NET VW import** ($10^6 m^3$) | -24,607.8 | -84,108.3 | -24,909.9 | -24,652.4 | -2,718.0 | -160,996.4 |

Source: Hoekstra and Hung, 2002.

*Table 3-4 Water footprints, water scarcity, water self-sufficiency and water dependency of nations in 1995.*

| Country | Water withdrawal ($10^6 m^3$) | Water availability ($10^6 m^3$) | Net virtual water import ($10^6 m^3$) | Water footprint ($10^6 m^3$) | Water scarcity (%) | Water self-sufficiency (%) | Water dependency (%) |
|---|---|---|---|---|---|---|---|
| **China** | 504,315 | 2,800,000 | 42,189 | 546,504 | 18.0 | 92.3 | 7.7 |
| **USA** | 492,259 | 2,478,000 | -168,000 | 324,259 | 19.9 | 100.0 | 0.0 |
| **India** | 607,227 | 2,085,000 | -24,610 | 582,617 | 29.1 | 100.0 | 0.0 |

Source: Hoekstra and Hung, 2002

Gupta (2008) encompasses a total of 283 crop products to comprehend Indian VW export surplus and examines these relative to WF provided by Chapagain and Hoekstra (2004b). His approach is to look at contributions of various agricultural products to global and Indian volume of virtual water. He found that 20 products contribute to a total of 92 per cent of the export of VW (see table 3.5) for periods 2000-2001 and 2005-2006. Milled rice figures with 30.21 per cent at the top for average VW exports. The percentage share of oil-cake, castor oil, non-durum wheat and meslin, cotton, non-roasted coffee and sesame seeds in virtual water export through crop products were 18.17, 9.14, 7.50, 6.49, 3.71 and 2.92 respectively.

*Table 3-5 Important crop products contributing to export of VW from India*

| *Product Details* | *Virtual Water Content ($m^3$/ton)* | *Average Percentage of Virtual Water Exported through Crop Products (2001–02 to 2005–06)* |
|---|---|---|
| Milled rice | 4,113 | 30.21 |
| Oil-cake and other solid residues | 3,431 | 18.17 |
| Castor oil and its fractions | 24,518 | 9.14 |
| Other wheat and meslin | 1,654 | 7.50 |
| Cotton, not carded or combed | 19,678 | 6.49 |
| Coffee, neither roasted nor decaffeinated | 12,180 | 3.71 |
| Sesame seeds | 8,415 | 2.92 |
| Fruits of the genus capsicum | 11,126 | 2.14 |
| Sugar refined | 1,391 | 1.85 |
| Lentils | 6,652 | 1.81 |
| Other black tea/other partly fermented tea | 7,002 | 1.71 |
| Other maize | 1,937 | 1.28 |
| Wheat or meslin flour | 1,860 | 1.09 |
| Durum wheat | 1,654 | 0.95 |
| Shelled groundnuts | 4,886 | 0.93 |
| Broken rice | 4,254 | 0.70 |
| Black tea packets not exceeding 3 kg | 7,002 | 0.64 |
| Raw cane sugar | 1,301 | 0.50 |
| Other oil seeds and oleaginous fruits w/n broken | 8,023 | 0.43 |
| Oil-cake and other solid residues | 1,981 | 0.42 |
| Other crop products | n.a. | 7.43 |

Source: Gupta (2008), derived from CMIE India TRADES Database and Chapagain and Hoekstra (2004b)

In the same fashion, he creates table 3.6, which depicts imports, with palm oil (crude and refined), soya bean oil (crude and refined), cotton, dried peas and other beans being the major items that comprise more than 83 per cent. A comparison of the top ten exports and imports demonstrates that the bundles differ in their composition by mainly cereal-centric exports and pulses imports. Both, exports and imports figure oils, seeds and cotton, suggesting India is a big market for these products.

*Table 3-6 Important crop products contributing to import of VW from India*

| *Product Details* | *Virtual Water Content ($m^3$/ton)* | *Average Percentage of Virtual Water Imported through Crop Products in India (2001–02 to 2005–06)* |
|---|---|---|
| Crude palm oil and its fractions | 5,169 | 27.08 |
| Soya bean crude oil | 7,852 | 21.07 |
| Refined palm oil and its fractions | 5,274 | 12.76 |
| Cotton, not carded or combed | 19,678 | 10.66 |
| Peas, dried and shelled | 3,040 | 5.73 |
| Other beans, dried and shelled | 8,335 | 3.41 |
| Other soyabean oil and its fractions | 8,012 | 2.99 |
| Chickpeas, dried and shelled | 2,712 | 1.86 |
| Dates, fresh or dried | 3,030 | 1.62 |
| Cloves | 61,304 | 1.38 |
| Crude oil of sunflower and safflower seed | 8,541 | 1.32 |
| Raw cane sugar | 1,301 | 0.99 |
| Lentils, dried and shelled | 6,652 | 0.82 |
| Kidney beans including white pea beans, dried and shelled | 8,335 | 0.68 |
| Beans, dried and shelled | 3,078 | 0.65 |
| Other nuts, fresh or dried | 7,692 | 0.59 |
| Jute and other textile fibres, raw or retted | 2,823 | 0.57 |
| Almonds, fresh or dried in shell | 9,769 | 0.52 |
| Cinnamon and cinnamon tree lowers | 18,083 | 0.49 |
| Coffee, neither roasted nor decaffeinated | 12,180 | 0.45 |
| Other crop products | n.a. | 4.37 |

Source: Gupta (2008), derived from CMIE India TRADES Database and Chapagain and Hoekstra (2004b)

Last but not least, Goswami and Nishad (2015) made a comparative regional analysis between India and China and exemplify sustainable and non-sustainable VWT in long-term perspective. Their time-period covered is the longest so far in the meta-analysis with 50 years coverage (1961-2010), and takes numerous indicators for their analysis into account such as rainfall, arable land, population, water demand type, import and export indicators as well as trade ratios (see table 3.7). Their VW export and import data figure in the meta-analysis overview table 3.7.

When comparing some key indicators for both countries between 1961-2010, it becomes evident that although India has roughly a third more area-average annual rainfall than China, the latter has much more total surface and groundwater available. Consulting indicators such as water demand for consumption for food grains and all crops as well as Total water exports and imports show that India consumes on average more water and its net water exports are larger than China's. The export/ import ratios sum up the substantial differences in their VWT pattern as the Indian ratio for all crops is 3.9, compared to 0.36 for China and for food grains 25.2 and 0.17, respectively, being also consistent with previous findings.

*Table 3-7 Water and land data for India and China based on averages between 1961-2010*

| Parameters (units) | Symbol | Current value (2009/2010) India | China | Data period |
|---|---|---|---|---|
| Area-average annual rainfall (mm) | R(t) | 1148 | 755 | 1961–2010* |
| Total land ($10^{10}$ m²) | Area | 297 | 932.7 | 1961–2010* |
| Arable land ($10^{10}$ m²) | $A_g$ | 157.8 | 111.3 | 1961–2010* |
| Population ($10^6$) | $P_T$ | 1210 | 1320 | 1961–2010* |
| Total export of food products ($10^9$ Kg) | $F_{ET}$ | 12.5 | 28.65 | 1961–2010* |
| Total import of food products ($10^9$ Kg) | $F_{IT}$ | 13.83 | 109 | 1961–2010* |
| Per capita consumption of all crops (Kg) | $F_{CP}$ | 350 | 650 | 1961–2010* |
| Per capita consumption of food grains (Kg) | $F_{CP}$ | 150 | 146 | 1961–2010* |
| Total food consumption ($10^9$ Kg) | $F_D$ | 413 | 911 | 1961–2010* |
| Water footprint (m³/kg) | $W_{FP}$ | --- | -- | 1996–2005 |
| Total water available (surface and ground water) ($10^9$ m³/year) | $W_A$ | 1911 | 2840 | 1961–2010* |
| Total water demand for production for food grains ($10^9$ m³/year) | $W_P$ | 579.6 | 593 | 1961–2010* |
| Total water demand for production for all crops ($10^9$ m³/year) | $W_P$ | 1139.6 | 1133 | 1961–2010* |
| Total water demand for consumption for food grains ($10^9$ m³/year) | $W_D$ | 536.9 | 227 | 1961–2010* |
| Total water demand for consumption for all crops ($10^9$ m³/year) | $W_D$ | 1111.8 | 876 | 1961–2010* |
| Total water Export ($10^9$ m³/year) | $W_{ET}$ | 44 | 10.1 | 1961–2010* |
| Total water Import ($10^9$ m³/year) | $W_{IT}$ | 5.9 | 27.5 | 1961–2010* |
| Cumulative water import ($10^9$ m³/year) | -- | 290 | 1042.3 | 1961–2010* |
| Cumulative water export($10^9$ m³/year) | -- | 263 | 339.8 | 1961–2010* |
| Ratio of export/import (all crops) | -- | 3.9 | 0.36 | 1961–2010* |
| Ratio of export/import (food grains) | -- | 25.2 | 0.17 | 1961–2010* |

Source: Goswami and Nishad (2015), using FAOSTA, AQUATSTAT an NCEP data.

The second contribution of their paper concerns water loss sustainability water through virtual net exports in terms of water involved in production of various crop categories. For average, maximum and current export scenarios, relative water availability, production requirement and surplus (table 3.7) vary between 1500 years to a few decades. In sum, the findings imply that Indian water sustainability measured by the selected 75 crop products, is highly dependent on future decisions to be taken regarding the international trade composition of agricultural goods to sustain its water demand.

The next meta-analysis group looks into livestock products, with Chapagain and Hoekstra (2003a) pioneer an analysis of VW flows between nations in relation to trade in livestock products between 1995-1999. They separate their paper into a section dedicated to a comprehensive livestock analysis, which is why it is treated separately from the remainder of the paper, which combines both, crop and livestock VWT. The latter figures, however, in the third meta-analysis category.

The authors determine VW content ($m^3$/ton) of live animals and took into account feed, drinking volumes, service water consumed during their lifespan and VW embodiments for each livestock product. They study a total of 146 livestock products that are not provide discernible VWT content apart from eight live animal and their finding that India is a net exporter of livestock products' VW (see table 3.1). Since livestock products are more water intensive (5 to 20 times more VW per kg than crop products) (Chapagain and Hoekstra, 2003a), the general conclusion can be yet drawn that VWT in livestock products must be considered to provide a complete picture of Indian VWT.

The last and most important meta-analysis group consists of five studies using both, crop and livestock products, whereas three find India to be a net VW exporter and two the opposite. Since Chapagain and Hoekstra (2003) find that VWT in livestock products constitute approximately 33 per cent of the total virtual water flows, it makes sense to examine these studies apart from the two preceding groups.

To complete the analysis of the Chapagain and Hoekstra paper (2003a), VW flows between nations were computed analogically to the Hoekstra and Hung (2002) approach and appended with livestock products data, with global, regional results available at appendix B.

For India, Table 3.8 extends the previous two papers on population data, per capita WF, and diversifies net VW import into crop and livestock. Results vary due to averages taken for the period 1995-1999 contrasting with stationary values for the year 1995 in Hoekstra and Hung (2002), although most other data input is held constant. The extensions only on livestock reveal that some countries are better or worse off given their high volumes of livestock trade (see appendix B). Looking at table 3.8 below, livestock trade seems to lower net VW imports for all three countries having a minor stake in China (2.4 per cent) and India (10.5 per cent), compared to a striking (absolute) US share of 16.8 per cent. Per capita WF also reveals that footprints are highest in the USA and more than twice as high as the Chinese, with India ranging in-between.

*Table 3-8 National water footprints, water scarcity, water self-sufficiency and water dependency*

| Country | Population[1] | Water withdrawal[2] ($10^6$ $m^3$/yr) | Water availability[2] ($10^6$ $m^3$/yr) | Net virtual water import ($10^6$ $m^3$/yr) | | Water footprint ($m^3$/cap/yr) | Water scarcity (%) | Water self-sufficiency (%) | Water dependency (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Crop | Livestock | | | | |
| **China** | 1,249,245,200 | 532,476 | 2,896,570 | 20,436 | -499 | 442 | 18.4 | 96 | 4 |
| **USA** | 274,602,600 | 480,488 | 3,069,400 | -151,660 | -30,623 | 1,086 | 15.7 | 100.0 | 0.0 |
| **India** | 959,940,000 | 620,808 | 1,896,660 | -321,99 | -3,762 | 609 | 32.7 | 100.0 | 0.0 |

1: Average for the period 1995-99, from FAOSTAT (FAO, 2003)
2: Source AQUASTAT2000 (FAO, 2003).

Comparing these results to Hoekstra and Hung (2002), increases in trade volumes can be attributed to the inclusion of livestock products, but do not change India's position as net VW exporter.

Chapagain and Hoekstra (2004b) continue using the methodologies of their previous study by covering the period 1997-2001, while introducing concepts of internal and external water footprints. It is yet the incorporation of both effective rainfall and irrigation water that sets this study apart from the previous ones, also comprising industrial and domestic sectors' water use. Therefore, their table and illustration are very comprehensive in the sense that it also distinguishes between use of domestic and foreign water resources as well as water footprints by consumption category in detail (appendix C).

Analysis of India's water footprint between 1997-2001 reveals that it has the largest in the world, but it also displays a very high national water self-sufficiency level (98%) (see table 3.9). Again, compared to China and the USA, India has yet the lowest total renewable water resources volume (the measure taken for water availability by FAO and AQUASTAT), which is striking considering the internal water footprint being highest among the countries. In contrast, the external footprint is the lowest with the USA having the largest. Finally, water scarcity, measured as the ratio of the nations' water footprint to its water availability, shows that the country takes fares much worse than the others in regards to water security as the value exceeds 50 per cent. Therefore, the authors conclude, that India and, to a lesser extent, China will not be able to sustain their high levels of water self-sufficiency, if they develop consumption patterns like the USA or some Western European countries.

*Table 3-9 Water scarcity and import dependency for China, the USA and India between 1997-2001*

| Country | Total renewable water resources ($Gm^3$/year) | Internal water footprint[1] ($Gm^3$/year) | External water footprint[2] ($Gm^3$/year) | Total water footprint ($Gm^3$/year) | Water scarcity (%) | National water self-sufficiency (%) | Water import dependency (%) |
|---|---|---|---|---|---|---|---|
| **China** | 2,896.6 | 825.9 | 57.4 | 883.4 | 30 | 93 | 7 |
| **USA** | 3,069.4 | 565.8 | 130.2 | 696 | 23 | 81 | 19 |
| **India** | 1,896.7 | 971.4 | 16 | 987.4 | 52 | 98 | 2 |

Source: Chapagain and Hoekstra, 2004b.
Note: Averages for the period

The last paper that analyses India's net VW exporting pattern is authored by Brindha (2017) and is the most comprehensive in assessing Indian VWT in crops and livestock products between 1986-2013; and grounds on similar metrics as Chapagain and Hoekstra (2004b).

Figure 21 is a distinction of Indian VW exports and imports based on different water types as has also been carried out by Hoekstra and Hung (2002). At first glance, both curves look very similar, but differ for volume scales are almost twice as high for exports compared to imports. It is conspicuous that both curves follow largely similar trendlines and not only VW exports were always higher than imports, but they also took off at a much greater pace ever since the early 1990s, which can be overlooked if one does not take into account the scale effect.

Brindha's findings regarding long-term averages of VW exports from crop, livestock and industrial products equal 46.4 $Bm^3$/y, 0.6 $Bm^3$/y and 12 $Bm^3$/y, respectively. Crop and livestock products experienced a 15 times surge in VW exports in 28 years. Food categories' contribution to VW exports is in the order of oil > cereals > Industrial products > semi-luxury goods > nuts = sugar > cereal products = fruits = animal products = pulses = vegetables > live animals.

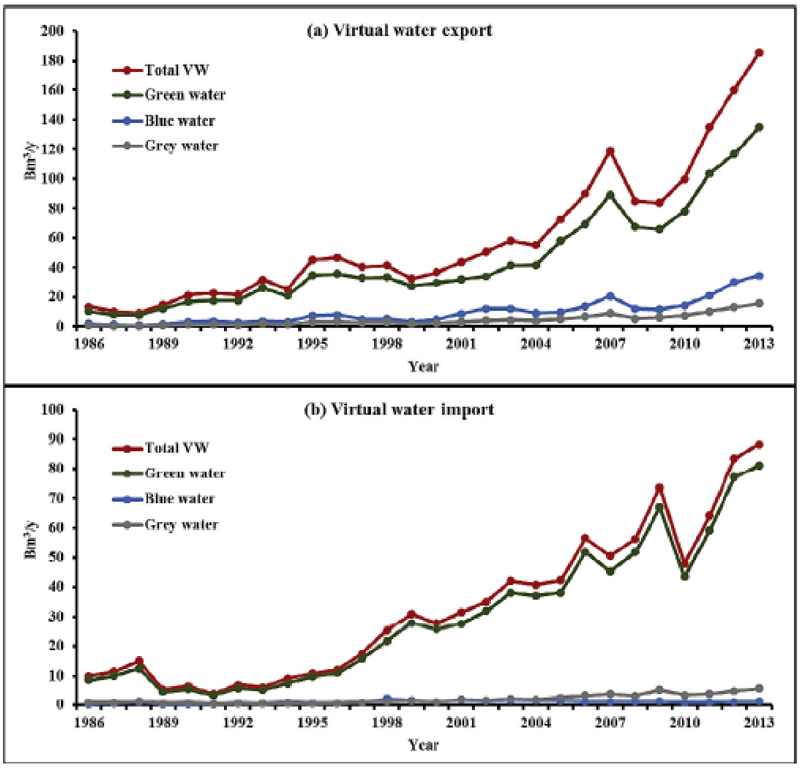


*Figure 3-2 Total Indian VW exports and imports relative to water types.*

Source: Brindha, 2017.

He also draws a clear picture of India's inter-regional VWT patterns that are illustrated by figure 22. Most VWT took place between India and Asia with 43.7 $Bm^3$/y in exports and 19.2 in imports. In total volume terms, Africa is the second most important VWT partner followed by Europe, North America, South America and Oceania.

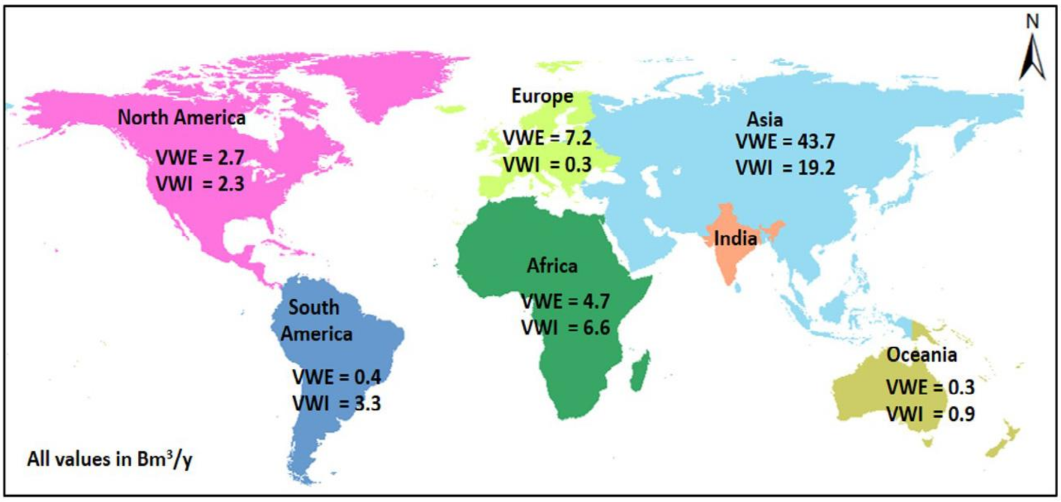


*Figure 3-3 Regional VWT of India between 1986-2013*

Source: Brindha, 2017
Note: VWE = Virtual Water Export; VWI = Virtual Water Import

Brindha's last contribution consists in a classification of Indian trading partners, based on their net trade and total internal renewable freshwater, in other words, available freshwater resources per capita. The trade partner classification in terms of VWT relation regimes was suggested by Zhang et al., (2016). The results can be seen in appendix G with the top-ten countries that import from India and the top eleven countries that export to India, of which nine are water-stressed, too.

At last, two papers oppose the general findings of India being a net VW exporter. Zimmer and Renault (2003) provide an extension on the Hoekstra and Hung study (2002) for 1999, that categorises global food products with regards to processes and their VW value into primary, processed, transformed, multiple-, by-, and low or non-water consumptive products. They partition the global VW budget in 2000, with meat and animal products representing about 45 %, cereals for 24%, fish and sea food account for 8% and oil for 8%. Overall findings stand in contrast with Hoekstra and Hung (2002), who use actual crop yields per country obtained in the FAO data base in 1999 combined with country estimations of crop water requirements. Their values are therefore country-specific and likely more precise, but they do not include VW linked to transformed and processed products (Zimmer and Renault, 2003). They did therefore expect differences particularly for those countries, that export considerable amounts of transformed products, like the USA.

Comparing again India with China and the USA for 1999, it is striking that the VW balances differ substantially (see table 3.10). The USA are a big net VW exporter and China imports a great proportion more than it exports. India, in turn, becomes in a net importer. Such change is yet to consider with shortcomings such as data availability and discrepancies, since Zimmer and Renault use FAO and TS data from USDA (used in case FAO data was missing) that differ substantially particularly for Asian countries. Therefore, observing very different results for India should be taken with caution as the result of being a net VW importer in 1999 must be seen through the lens of data divergence.

*Table 3-10 Water consumed for crop production and virtual water traded for China, USA and India 1999*

| Country | Water use for crop production | VW imported | VW exported | Net VW balance |
|---|---|---|---|---|
| **China** | 624 | 75 | 19 | 56 |
| **USA** | 502 | 65 | 234 | -169 |
| **India** | 423 | 31 | 8 | 23 |

Source: Zimmer and Renault, 2003. Note: Values in $km^3$/year.
Note: Authors assume an annual increase of 1 per cent in water productivity.

The study conducted by Kumar and Jain (2007) presents a review of VW content and flows of various products estimated for India between 2001-2005. A detailed overview of Indian crop and livestock products for the period 1997-2001 is available at appendix D. Besides that, their study consolidates a brief overview of VWT provided by trade data of FAOSTAT with export, import and net import accounts (see table 3.11).

Obviously, their findings, labelling India as a clear net VW importer for the period, stand in stark contrast with previous studies. Kumar and Jain note, however, that the crop and livestock product import and export data also include the crop and livestock products received as food aid during these years.

*Table 3-11 Virtual water trade related to crop and livestock products from India 2001-2005*

| Year | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|
| **Export ($Gm^3/yr$)** | 34.62 | 47.72 | 47.32 | 51.63 | 47.32 | 45.72 |
| **Import ($Gm^3/yr$)** | 68.85 | 69.02 | 68.43 | 67.53 | 84.44 | 71.65 |
| **Net import ($Gm^3/yr$)** | 34.22 | 21.30 | 21.11 | 15.91 | 37.12 | 25.93 |

Source: Kumar and Jain, 2007.

Taking a closer look at the peak of the three-year average development of undernourished people between 2003-2005 in appendix E, it immediately becomes apparent that food aids must have had a substantial impact on the food and livestock import-export balance given the 34 per cent increase in malnourished Indians in mere three years. Therefore, any inferences based on Kumar and Jain's findings should be taken with a pinch of salt.

The section has examined how the topic of international VWT in agricultural goods from and into India has been so far treated in the literature with a broad spectrum of findings, which usually depended on time-periods covered, traded goods and databases used for their retrieval as well as methods applied. Authors used a big variety of indicators to illuminate how VW flows can be assessed, which include: water withdrawal, water availability/ renewable freshwater availability, net imports and exports of VW, several water footprint indicators like population adjusted WF of various goods, water scarcity measurements, self-sufficiency and dependency levels, internal and external water footprints, etc. With a range of 38 crops only to 329 crop and livestock products in total, the results of each study are hardly comparable with each other, also in light of heterogeneity in timespans covered ranging from one-year analysis to annual averages for more than 50 years. The most complete studies ostensibly are also the most recent with Goswami and Nishad (2015) as well as Brindha (2017), since their time periods as well as VWT analysis in agricultural goods are the most comprehensive. Nonetheless, it should be stressed that the general trend of findings corroborates the expectations for the whole meta-analysis, leaving aside the studies by Zimmer and Renault (2003) and Kumar and Jain (2007): India is a major VW exporter since the 1980's and the pattern ostensibly has intensified with the country's trade liberalisation in the early 1990's.

With primary goods such as oils, cereals, cotton and non-roasted coffee, India exports products with a VW content ($m^3$/ton) and also in relation to its trade volumes for those products, that embody most of the country's water (see Gupta, 2008; Kumar and Jain, 2007, appendix D). Cotton and non-roasted coffee range among the country's cash crops, explaining their great export volumes (Jain et al., 2007, p. 822). Therefore, the answer of the first part of the leading research question must be answered by saying that Indian international VWT exacerbates the country's water shortages by exporting higher water volumes embodied in its agricultural goods, which are also water intensive in terms of their water requirements in production as well as their trade volumes for a time period covering almost 40 years. Imports play a minor role in counteracting the country's VW outflows due to insufficient trade volumes, which has been also found by MacDonald et al., (2015), although the VW content of imported goods bears the potential to balancing out the country's international VW exports.

### 3.2.2 Interstate Virtual Water Trade in Indian agricultural goods

This section is dedicated to the second part of the meta-analysis that consists in examining Indian inter-regional VWT and how it contributes to the country's water shortages or, conversely, how it improves the country's water availability. To recall, the republic of India is a union consisting of 28 states and 7 union territories (see figure 3.4), that all contribute differently to the country's total VW flows.

*Figure 3-4 Map of Indian States & Union territories*


Source: Maps of India, 2020.

Freshwater availability, quality, management and allocation have emerged as pivotal issues at regional scales particularly for populous countries such as India and China (Cai and Rosegrant, 2005). Evidence on water scarcity relative to interstate VWT suggests that water-scarce Indian states are further stressed by VWT patterns, but VW flows are apparently influenced by factors different than water endowments of states (Bogra et al., 2016; Katyaini and Barua, 2017). A similar pattern can be found in China, where the water-scarce North exports water-intensive goods to the water-rich South, which ultimately may exacerbate the Northern water shortages (Guan and Hubacek, 2007; Wang et al., 2014). Other subnational studies stress opportunities to enhance national water distribution efficiency in the agricultural sector (Zhang and Anadon, 2014; Dalin et al., 2014) by relocating water-intensive goods' production to water-abundant locations (Mubako and Lant, 2013). Since Indian states are primarily constitutionally empowered to manage their own water resources and agricultural trade, these considerations are of particular interest (Government of India, 2014).

The first study has been conducted by Kampman (2007) and investigates why some water scarce Indian regions also have a water deficit between 1997-2001. Kampman calculates per capita water footprints ranging between 451 and 1357 $m^3$/yr with an average of 777 $m^3$/yr within the states. In light of earlier findings that stressed the importance of green water resources, too (Chapagain and Hoekstra, 2003a), Kampman finds for green, blue and grey average per capita WF of 459, 227, and 92 $m^3$/yr, respectively. Thus, the rainfall footprint seems to be twice as important as the blue one in explaining national water consumption of agricultural goods during the time period.

When looking at crop composition, table 3.12 presents 16 selected primary crops, ranked by and representing 87 per cent of Indian total water use. Products with the highest water contents like rice, paddy, wheat, seed cotton and sugar cane also have the highest production values of all agricultural output. Observing crop production, it is not surprising that sugarcane displays the highest yields, since it is among the country's most prominent cash crops that occupies a relatively low land use share, being in the bottom third.

*Table 3-12 Selected primary crops in the period 1997-2001, ranked by water use*

| Primary crops in FAOSTAT | Crop production[1] | Water use[2] | | Production value | | Land use | |
|---|---|---|---|---|---|---|---|
| Name | $10^6$ ton/yr | $10^9$ $m^3$/yr | % | $10^9$ US$/yr | % | $10^6$ ha/yr | % |
| Rice, Paddy | 130.9 | 373.1 | 39.3 | 16.5 | 21.4 | 44.6 | 25.0 |
| Wheat | 70.6 | 116.8 | 12.3 | 10.4 | 13.5 | 26.7 | 15.0 |
| Seed Cotton | 5.7 | 47.2 | 5.0 | 2.9 | 3.8 | 8.9 | 5.0 |
| Sugar Cane | 286.0 | 45.6 | 4.8 | 5.1 | 6.7 | 4.1 | 2.3 |
| Millet | 10.2 | 33.2 | 3.5 | 1.0 | 1.3 | 12.6 | 7.0 |
| Sorghum | 8.0 | 32.4 | 3.4 | 0.9 | 1.2 | 10.1 | 5.7 |
| Soybeans | 6.4 | 26.2 | 2.8 | 1.5 | 1.9 | 6.3 | 3.5 |
| Groundnuts in Shell | 7.0 | 23.9 | 2.5 | 2.3 | 3.0 | 6.8 | 3.8 |
| Maize | 11.8 | 22.8 | 2.4 | 1.3 | 1.7 | 6.4 | 3.6 |
| Beans, Dry | 2.6 | 21.7 | 2.3 | 0.8 | 1.0 | 6.7 | 3.8 |
| Coconuts[3] | 9.3 | 21.1 | 2.2 | 0.8 | 1.1 | 1.8 | 1.0 |
| Mangoes[3] | 10.6 | 16.1 | 1.7 | 3.8 | 4.9 | 1.4 | 0.8 |
| Chick-Peas | 5.5 | 14.9 | 1.6 | 1.9 | 2.5 | 6.8 | 3.8 |
| Rapeseed | 5.4 | 14.1 | 1.5 | 1.7 | 2.2 | 6.1 | 3.4 |
| Pimento, Allspice[3] | 1.0 | 10.6 | 1.1 | 0.8 | 1.1 | 0.9 | 0.5 |
| Pigeon Peas | 2.4 | 9.9 | 1.0 | 0.9 | 1.2 | 3.5 | 1.9 |
| Other crops[3] | 145.6 | 119.2 | 12.6 | 24.3 | 31.5 | 24.4 | 13.7 |
| Total | 718.9 | 949.0 | 100.0 | 77.0 | 100.0 | 178.0 | 100.0 |

Source: Kampman (2007), derived from FAO and Chapagain and Hoekstra (2004b).
Notes: Shaded crops were excluded from study.

Table 3.13 sums up the most important information to assess interstate VWT, including state-wise total water use, and export and import categories further distinguished into interstate and international contributions (see appendix H for detailed matrix of gross total interstate VWT). Further, it shows that interstate VWT equals 13 per cent of total water use with 106 billion $m^3$/yr between 1997-2001. The shares for VW exports make up for 4 per cent and 29 billion $m^3$/yr of total water use, which compares to 14 billion $m^3$/yr allocated for imports, ultimately equalling 15 billion $m^3$/yr of net exports. Consequently, 17 per cent of total volume of water for crop production is exported to other states or countries.

At state level, the northern states Punjab, Haryana and Uttar Pradesh display the largest VW exports, in contrast to the states Bihar, Jharkhand and Kerala having the largest VW imports. Madhya Pradesh is the largest net international exporter of VW, being mainly due to its international export of soybean cake. Crops with largest trade flows are milled rice, wheat and sugar underlying the Public Distribution System, being controlled by the Indian government in form of the Food Corporation of India (FCI). It procures the crops mainly in the northern states Punjab, Haryana, Uttar Pradesh, partly due to their well-developed trade infrastructure. An illustration of all VW import flows is figure 3.5, indicating the trend that highest net exports of VW are directly connected to states with the highest net imports, illustrated by arrows leading from Punjab, Haryana and Uttar Pradesh in the North (dark red) to Bihar in the East and Kerala in the South (dark green) with also higher flow shares to Gujarat, Maharashtra in the West and Jharkand in the East (medium green). This suggests that the states Punjab and Haryana are the main food producing states of India.

*Table 3-13 Water use, virtual water flows and net import by state*

| States | Water use | Virtual water export | | Virtual water import | | Net VW import |
|---|---|---|---|---|---|---|
| | | Interstate | International | Interstate | International[1] | |
| Unit | $10^6$ m³/yr | | | | | |
| Year | 1997-2001 | | | | | |
| Andhra Pradesh | 66652 | 4952 | 1711 | 569 | 774 | -5319 |
| Assam | 17812 | 4 | 0 | 2304 | 155 | 2455 |
| Bihar | 38283 | 149 | 1 | 14469 | 983 | 15302 |
| Chhattisgarh | 27912 | 2835 | 699 | 2544 | 558 | -431 |
| Delhi | 267 | 0 | 0 | 4026 | 683 | 4709 |
| Gujarat | 42678 | 3847 | 3120 | 9186 | 941 | 3160 |
| Haryana | 31956 | 13006 | 2105 | 638 | 339 | -14134 |
| Himachal Pradesh | 2439 | 26 | 0 | 1439 | 212 | 1626 |
| Jammu & Kashmir | 4143 | 26 | 0 | 3101 | 178 | 3254 |
| Jharkhand | 11593 | 0 | 0 | 8853 | 430 | 9283 |
| Karnataka | 43358 | 3130 | 365 | 3699 | 214 | 418 |
| Kerala | 2897 | 0 | 2 | 10180 | 891 | 11069 |
| Madhya Pradesh | 64863 | 7671 | 8254 | 4933 | 162 | -10831 |
| Maharashtra | 80390 | 5788 | 3949 | 11836 | 1461 | 3560 |
| Orissa | 37801 | 149 | 21 | 4552 | 416 | 4797 |
| Punjab | 43036 | 19351 | 4095 | 1658 | 914 | -20874 |
| Rajasthan | 60169 | 9852 | 388 | 5504 | 512 | -4224 |
| Tamil Nadu | 35496 | 4293 | 285 | 1397 | 967 | -2214 |
| Uttar Pradesh | 127855 | 24542 | 2988 | 4777 | 1953 | -20800 |
| Uttaranchal | 5581 | 1447 | 126 | 960 | 164 | -449 |
| West Bengal | 47141 | 4447 | 1094 | 6238 | 749 | 1445 |
| Total | 792321 | 105516 | 29203 | 105516 | 13953 | -15250 |

Source: Kampman, 2017.
[1]National import is blue and green water only (Chapagain & Hoekstra, 2004b). Since no distinction is made between green and blue by Chapagain & Hoekstra, the total international virtual water import is contributed entirely to the blue external water footprint.

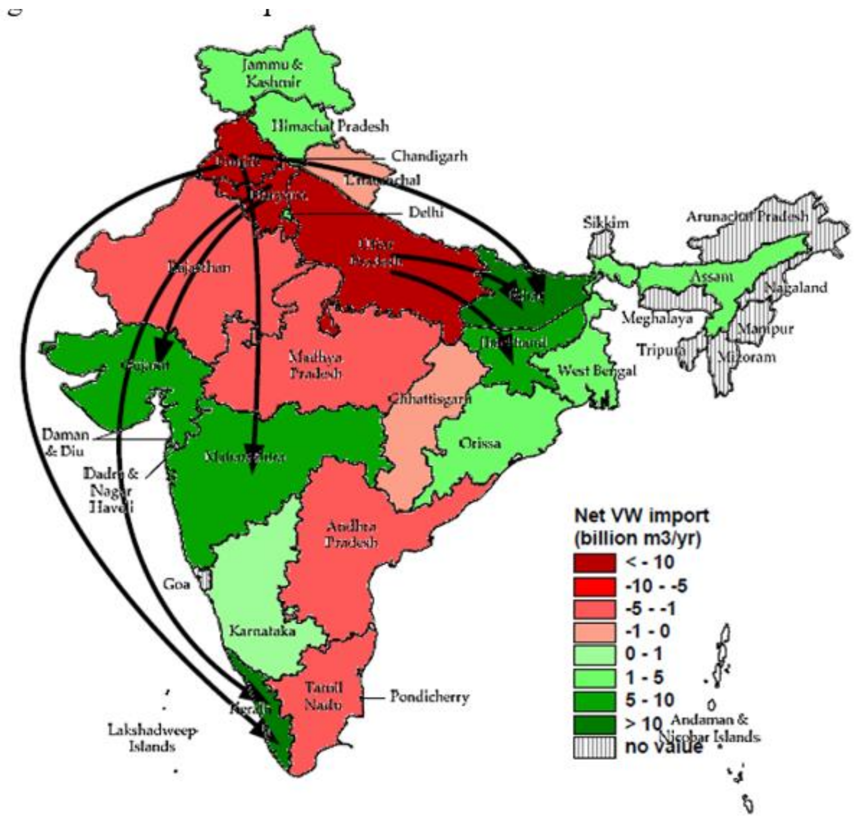


*Figure 3-5 Net VW imports of Indian states between 1997-2001*

Source: Own representation, based on Kampman, 2007.
Note: Arrows illustrate biggest VW flows

VW savings originating from Indian interstate VWT also prove to be significant and essentially contribute to better the country's position regarding its water stress (see appendix H for detailed volumes).

The next paper is authored by Kumar and Jain (2011) and investigates Indian inter-state VWT with focus on two major food grains, wheat and rice, during the years 2003–04 to 2005–06. The authors find for VWT in wheat a varying volume from 754 to 9405 $m^3$/tons and 2502 to 9562 $m^3$/tons for rice with Punjab, Haryana, Chattisgarh and Uttararkhand being net exporters to the central pool, whereby all other regions are net importers. Notably the VW exporters Punjab and Haryana are characterised by recent water shortages, while other regions importing VW are largely water abundant. This suggests that, apart from freshwater availability considerations, other major factors determine interstate VWT. This is also consistent with the Kampman findings (2007), covering an earlier period (1997-2001).

VW content for wheat and rice production also varies substantially across states, due to varying requirements (see figure 3.6). Wheat VW is lowest in the high wheat crop yield states of Punjab (745 $m^3$/ton) and Haryana (989 $m^3$/ton), whereas it is very high in the low wheat crop yield states of Karnataka (9405 $m^3$/ton) and Andhra Pradesh (8800 $m^3$/ton). VW requirements for rice vary from 2502 $m^3$/ton in Punjab to as high as 9562 $m^3$/ton in Madhya Pradesh. Once again, the aforementioned FCI acts as the nodal governmental agency that procures, stores, transports and sells food grains. As a result, some states procurements exceed sales, thus directing food to the central pool, while for others applies the reverse.

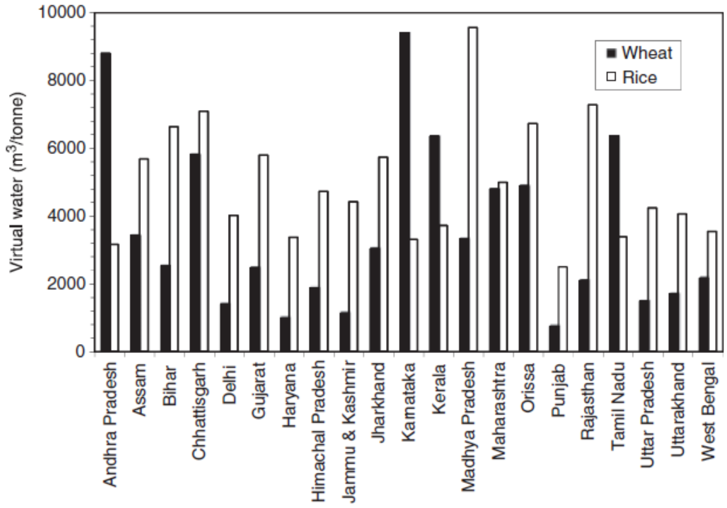


*Figure 3-6 VW requirements for wheat and rice in different Indian states*

Source: Kumar and Jain, 2011.

Regarding interstate VWT in both grains, table 3.14 shows net VW exports and confirms the general trend in VWT patterns that Kampman (2007), which allows to infer a trend for these states between 1997-2006 for Punjab and Haryana proved to be major net VW exporters. Chhattisgarh is second biggest net exporter according to Kumar and Jain the more recent suggesting the state is either is chiefly involved in wheat and rice trade ,which explains the major trend-break of being a net VW importer 1997-2001, or VWT patterns between states changed to the disadvantage of Chhattisgarh's water resources. The composition of major VW recipients is slightly different with Maharashtra still being a major inflow region.

*Table 3-14 Interstate VW net exports of wheat and rice 2003-2004 to 2005-2006*

| | | Wheat | Rice | Total | Wheat | Rice | Total | Wheat | Rice | Total | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| S No | State | 2003–04 | | | 2004–05 | | | 2005–06 | | | |
| 1 | Andhra Pradesh | −752 | −4513 | −5265 | −694 | 832 | 138 | −937 | −752 | −1690 | −6816 |
| 2 | Assam | −992 | −7772 | −8764 | −1495 | −8706 | −10202 | −1066 | −9166 | −10232 | −29198 |
| 3 | Bihar | −2532 | −1549 | −4081 | −2613 | −3017 | −5630 | −2083 | −2449 | −4533 | −14244 |
| 4 | Chattisgarh | −1070 | 6783 | 5714 | −1136 | 13053 | 11916 | −1096 | 19408 | 18312 | 35942 |
| 5 | Delhi | −658 | −314 | −972 | −621 | −632 | −1253 | −701 | −466 | −1167 | −3392 |
| 6 | Gujarat | −2179 | −1474 | −3653 | −2001 | −1439 | −3441 | −2132 | −1663 | −3795 | −10888 |
| 7 | Haryana | 5706 | 3891 | 9597 | 4965 | 5490 | 10455 | 4070 | 6764 | 10835 | 30887 |
| 8 | Himachal Pradesh | −283 | −831 | −1114 | −333 | −888 | −1221 | −356 | −986 | −1342 | −3677 |
| 9 | Jammu & Kashmir | −362 | −1998 | −2360 | −386 | −2068 | −2454 | −396 | −2150 | −2545 | −7360 |
| 10 | Jharkhand | −1058 | −1531 | −2588 | −1197 | −2327 | −3524 | −1505 | −3051 | −4556 | −10668 |
| 11 | Karnataka | −4270 | −9535 | −13805 | −4588 | −8430 | −13018 | −5919 | −6945 | −12864 | −39687 |
| 12 | Kerala | −1424 | −2898 | −4322 | −2123 | −2973 | −5096 | −2874 | −2389 | −5263 | −14681 |
| 13 | Madhya Pradesh | −6235 | −3248 | −9483 | −5627 | −3499 | −9126 | −5493 | −3558 | −9052 | −27661 |
| 14 | Maharashtra | −9559 | −4483 | −14041 | −11233 | −5028 | −16261 | −9259 | −5466 | −14724 | −45027 |
| 17 | Orissa | −1433 | −4667 | −6100 | −988 | −2174 | −3162 | −1058 | −1497 | −2555 | −11816 |
| 18 | Punjab | 5486 | 17865 | 23351 | 7636 | 22088 | 29725 | 6659 | 20968 | 27628 | 80703 |
| 19 | Rajasthan | −6208 | −67 | −6275 | −3961 | 67 | −3894 | −4087 | −266 | −4352 | −14521 |
| 20 | Tamil Nadu | −1013 | −10285 | −11298 | −785 | −10836 | −11621 | −1716 | −11082 | −12798 | −35717 |
| 21 | Uttar Pradesh | −2201 | 3660 | 1459 | −2045 | −20 | −2065 | −2441 | 1465 | −976 | −1582 |
| 22 | Uttarakhand | −123 | 246 | 123 | −116 | 514 | 398 | −153 | 660 | 507 | 1028 |
| 23 | West Bengal | −2808 | −2408 | −5216 | −3914 | −2773 | −6687 | −4170 | −1958 | −6128 | −18031 |

Source: Kumar and Jain, 2011.

Note: VW volumes expressed in $10^6$ $m^3$.

Karnataka's and Assam's VWT pattern did not change inasmuch as they are still net importers when comparing to Kampman (2007). Tamil Nadu and Madhya Pradesh, in turn, are net exporters of VW according to Kampman (2007), but are, considering only wheat and rice VWT, net importers.

At last, Katyaini and Barua (2017) provides an analysis covering the longest existing time period for Indian interstate VWT in 9 crop categories, linking flows to state water scarcity levels and elements of state and national water policies for the post-reforms (1996-2005), and recovery (2005-2014) periods of India's agriculture. They find net water savings (WS) of 207.5 PL (peta litre = $10^{15}$ litre) having increased during 1996–2014, with from annual 11.2 $Bm^3$ for the first and 25931.7 $Bm^3$ during the second period.

Using the authors' two time-period division approach, it becomes apparent that a substantial WF decrease for grains took place between 1996-2005 and 2005-2014. The improvements are mainly due to increased efficiency in use of inputs, including water, that resulted in higher yields (Government of India, 2014). It also reflects that the National Water Policies (NWP) of India, i.e., 1987, 2002, and 2012 eventually translated into the desired increase in water use efficiency for sustainable water resources use (Katyaini and Barua, 2016).

Regarding the VW flows assessed by Indian zones during 1996-2005, the Northern recently water-stressed region counts the highest water loss (-19.8 TL/yr), while the West shows the highest WS (11.1 TL/yr), and the South ranks second (9.7 TL/yr), being also the main beneficiaries of the Northern outflows (see figure 3.7). For the second period, the North remains the region with most water losses, albeit having decreased to 16.2 TL/yr (see figure 3.8). Looking at the Central, it developed from WS 3.2 PL/yr in the first period to water losses being second highest among all zones with -11.7 PL/yr. This development is mainly due to a surge in exports from the region. South and West zones continue to display highest WS 11.1PL/yr and 10.8PL/yr, respectively, although Southern WS are higher in the second period relative to the West, compared to the previous one where the reverse holds.

Overall quantity changes of WS and losses must be also highlighted because they increased between the periods, which is chiefly explained by more interstate food grain trade. For the interstate VW flows for both periods, 1996-2005 and 2005-2014, please consult appendix I.

Differing water productivity levels seemingly explain best the regional mismatch and also the net WS, as VW flows from high to low productivity states (Novo et al., 2009; Yang and Zehnder, 2007). Further, Net VW imports were found to be driven by larger population, whereas arable land ostensibly explains net VW export flows (Katyaini and Barua, 2017).

All in all, the three sources above share the same inference in regard to the potential of interstate VWT to ensure water and food security: interstate VWT ostensibly has the potential to redistribute agricultural goods to install food security and is also expected to grow more important given the increasing VWT flows. Water security is, however, a different matter, because regional patterns suggest water endowments are not the main factor explaining trade dynamics, but water productivity, land at disposal, inadequate water infrastructure as well as population sizes also determine the flow directions, too. General VWT patterns demonstrate major VWT flows from the water abundant North to the water scarce South and West, and also to the water abundant, yet infrastructure-poor East. An additional altering twist, revealing itself between 2005-2014, shows VW flows from highly water-scarce zones to other water-stressed regions. Consequently, subnational scale VW flows are not consistent with relative water scarcity and are not leading to efficient water redistribution.

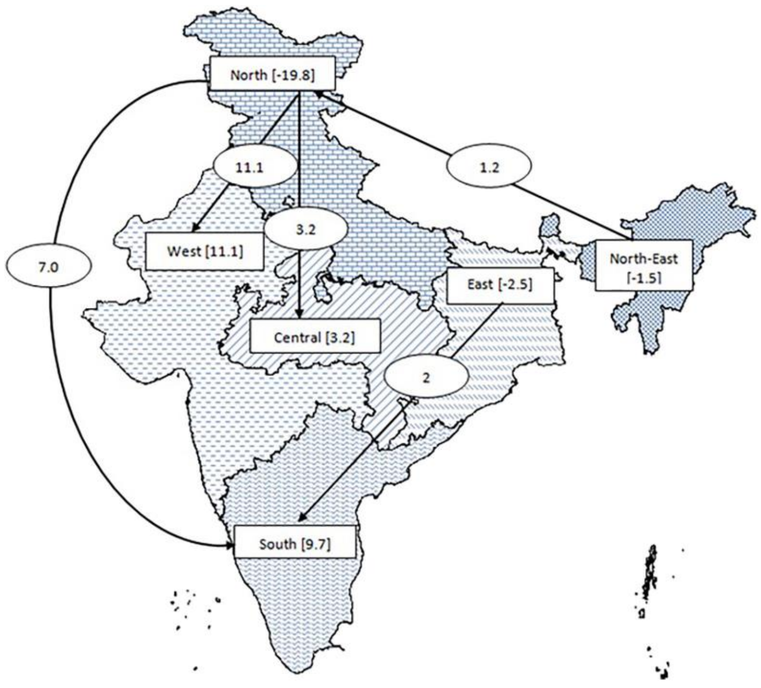


*Figure 3-7 Zone-wise Indian VW-flows during 1996–2005*

Notes: Value in boxes are net VW exports or imports in tera litres per year. Values in circles indicate major flows between zones.

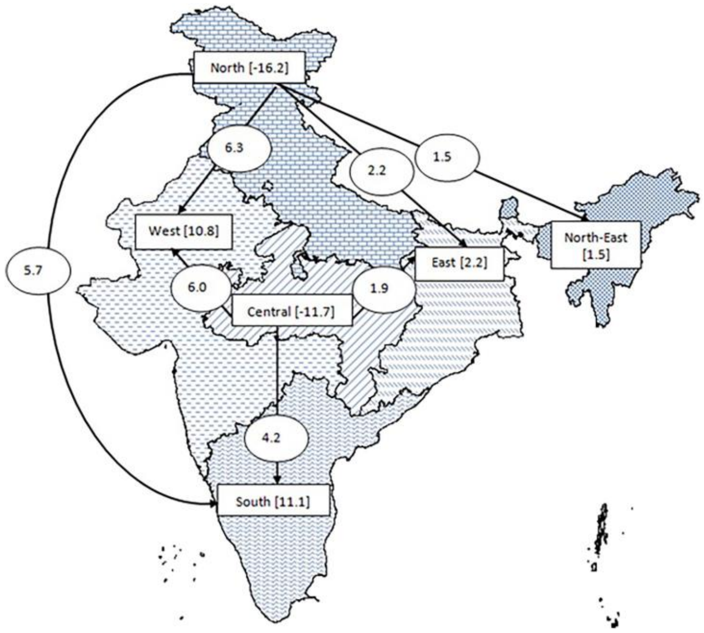


*Figure 3-8 Zone-wise Indian VW-flows during 2005–2014*

Notes: Values in boxes are net VW exports or imports in peta litres. Values in circles indicates major flows between zones.

It is still noteworthy that water savings prove to be substantial (Kampman, 2007; Katyaini and Barua, 2017) and are of particular interest for future national and state water management that will need to be coined by decentralized decision-making and coordination among trading entities. Particularly Katyaini and Barua (2017) provide a lion share in assessing policy relevance of VW-flows assessment at subnational scale to distribute water scarcity in an emerging economy like India. These insights together with the ones gained in the previous sections bring to light how policies at national and subnational are decisive in ensuring states' food and water security, being further addressed in the subsequent section.

# 4 Policy Interventions for Indian water security

The previous sections have highlighted what dimensions water scarcity can take in a water-stressed country like India and what crucial role VWT has to play in either alleviating or exacerbating regional water shortages. Particularly the latter reiterates the need to pass on policies, that take into account both aspects, economic and environmental ones to create sustainable VW flows. It is therefore also paramount to recognize the significance of water policies at national and subnational scales to sustain agricultural growth and water use, as there are widely heterogenous agro-climatic conditions and regional water endowments in India. Consequently, this section sets out to examine policies at international and state-level that have already aided in reducing Indian regional water-stress and how most recent policies have made debate as to ensure future water security in the context of the globalisation of trade. Hence, the guiding question for this section is as follows:

*"What measures were taken or currently discussed by the Indian government and state authorities to mitigate regional water stress in the long-run since the country's trade liberalisation in 1991?"*

## 4.1 International Policy Measures

### 4.1.1 Water prices and quotas

At international level, water pricing and quotas repeatedly make the case, and usually encompass options such as water allocations, limiting withdrawal, pumping restrictions, rotational deliveries and restrictions pertaining to cropping patterns. This would also align with many scholars' opinion, who advocate to treat water as economic good. Low prices would thus signal scarcity to farmers in most agricultural settings (Tsur 2010). However, for every successful implementation of water price in the primary sector, there are as many cases where the attempt failed. These can be chiefly explained by political and cultural reasons impeding their use, and also due to their limited modifiability once implemented (Ruijs et al., 2008; Dono et al., 2010; Cooper et al., 2014). Vague predictability of outcomes resulting from policy interventions are essentially also a common obstacle. Impacts must be measured for farm-level economics, including volatility of farm production output and potential investment choices, to make policy more attractive to achieve (Viaggi et al., 2010; Lehmann and Finger, 2014; Shi et al., 2014).

Two prominent caveats do, however, hamper the whole debate surrounding water prices. First, inadequacy in ensuring efficient water use; second, the illusion that water pricing alone can effectively convey water scarcities to a broader audience. Regarding the first caveat, water supply service is key, with displayed willingness to pay higher water prices if water management services, quality, or water metering and billing procedures are improved for farmers (FAO and WWC, 2015). At the same time, awareness campaigns also bear the potential to efficiently reflect scarcities and explain necessity for water pricing, too. Yang et al., (2003) have conducted a case study in Northern Chinese districts on the effectiveness of pricing-based water policies and found regional shortages did not level off, although higher irrigation costs were in place. On the contrary, over-exploitation of groundwater resources has even intensified with a shift to higher value-added, but oftentimes more water-intensive crops. In turn, Dietzenbacher and Velazquez (2007) find in their Input-Output-based study on international VW outflows from Andalusia, that water pricing might be used as policy option, when reflecting on sensitivity of product prices to a cost push.

Having the discussion above in mind, India is still a particular case, where surface water of rivers and basins is fully controlled by the government, whereas water users do not possess any rights in form of water licences, etc. However, the actual ownership of water per se being an element of the natural environment is questionable. Therefore, questions such as proprieties of basins, being subject to be shared with non-basin states, the metering and assessment of a "surplus level" of the basin, as well as the manner basin states deem fit to be used and dispose of surplus water would require a meticulous discussion of water rights (Jain et al., 2007, p. 1100).

Hence, it can be concluded that water pricing can be measure in some areas, while efficient programmes to increase public awareness or water use restrictions might make the trick, too. One common denominator in all scenarios is yet to ensure all farms, homes, and factories, and across river basins are made aware of water scarcity conditions and animated to adjust water use patterns accordingly.

### 4.1.2 Water markets

Another prominent option on international scale to alleviate regional shortages are water markets. The FAO (2015) suggests water constraints to generate regional use efficiencies, if farmers are allowed to trade portions of their water allocations. This would trigger overall productivity gains across a region or river basin, because more productive farmers could purchase water from farmers who generate lower value. Nevertheless, this would require a clear ascription of water rights and regional communication of scarcity conditions. In the same vein, strong institutions to ensure compliance and providing necessary infrastructure to move water across a basin or between them – being commonly absent, are vital, too. Moreover, domestic consumers would not have to incur price increases either, if governments e.g. introduced export tariffs that are equal to the price of increases (Dietzenbacher and Velazquez, 2007).

### 4.1.3 Economic restructuring and import of water-intensive goods

Throughout this study, the examination of VWT patterns has revealed that water-stressed countries can remedy their shortages by importing water-intensive goods while limiting the export of said goods. Hence, restructuring the domestic economy to foster such trade pattern would help in lifting the stress from such countries that otherwise would continue steering the economy for water-intensive exports. Dietzenbacher and Velazquez (2007) claim that a reduction in the exports of agricultural products yields considerable water savings, compared to minor back draws. This also needs to align with environmental impact tracking and prevention policies in the context of globalization. Since consumers are increasingly, geographically separated from the environmental impact of their lifestyles, transnational trade catalyses displacement of ecological costs (Gupta, 1998, p.304). Gradual changes in consumption baskets, favouring other, less water-intensive staples would also lift water-stress in the long-run (Indian Ministry of Finance, 2016).

A predominant factor for global success would, however, be international cooperation for sustainable use and management of agricultural production factors like land and water (Chen et al., 2017). Supranational institutions play also a pivotal role in orchestrating the transformation of rural and urban landscapes to create sustained consumption and use patterns of resources. A prime example are agricultural funds from the Common Agricultural Policy of the EU that contributed e.g. in Spain to widespread access to irrigation, better transport and energy infrastructure, as well as dissemination of agricultural knowledge and R&D (Cazcarro et al., 2013). In larger countries such as China or India, appropriate policy responses and investments may yet differ essentially across regions, depending on regional conflicts that lie in the pursuit of environmental and economic interest.

Generally speaking, trade policy is not able to directly address distinct environmental issues. On the contrary, trade policy alone as means to achieve environmental goals might result in further global environmental degradation and welfare loss, rather than resolving the problem (UNEP, 1999). Nonetheless, more balanced trade patterns for net exporters of VW such as India are advocated by numerous scholars and prove to be an adequate means to relieve water shortages. Yet, restructuring a whole economy to become a net importer of VW, that has to sustain almost 1.2 billion livelihoods also faces constraints other than sole water availability, like productivity of water, land, cultivation and agro-climatic conditions, as well as incomes. Thus, the whole discourse must be launched at state-level, too.

## 4.2 National and interstate level

### 4.2.1 Legal clarity for higher incomes

The last section highlighted options that might help alleviate India’s water stress at international level. This section will provide potential solutions to state-related issues that require attention of state authorities, as much as the national Indian government. A recurring issue is the size of India and its geographical, agro-climatic and political divide, partially arising from its centralistic governance. Therefore, the emphasis of decentralization of agriculture and related political decision-making are key for effective implementation and management of agriculture at state and national level (Government of India, 2008, 2010). On this account, Indian has already made progress by passing the National Food Security Act, 2013 that delegates to monitoring and evaluation of food security programmes to state governments (Government of India, 2013b). At the same time, coordination between states is also crucial, which is why the national government’s Five-Year-Plans (FYP) act as guidelines for all states to ensure implementation of a homogenous development strategy, as well as the NWP. The FYP 2012-2017 for instance grounds on “inclusive and sustainable” growth with water and agriculture figuring as two of the eight main categories for financial investments. It is above all noteworthy that water features as a major category in it for the very first time, since initiation of FYP (Government of India, 2013a). Such shift ushers a paradigm change towards valuation, integration and management of water in economic planning. This being said, challenges arise across states in designing state-fit institutional strategies to allocate scarce water, given varying complex legal and constitutional landscapes as well as greatly differing economic activity and incomes across states (Brindha, 2017).

The last argument requires special attention, given farmers' incomes make up for more than 40 per cent as a share of Indian total employment, and are still the main source to provide livelihoods. A blessing and a curse are the MSP, guaranteeing future prices for crops. Usually, farmers face price uncertainties after their harvest and buying a mitigating option contract could reduce price uncertainty and make cultivation decisions accordingly, but such options are available for a minor share of all Indian farmers. Although the government announces MSP for 23 crops, effective MSP-linked procurement occurs mainly for wheat, rice (in some states even half of all farmers report unawareness of MSP for these crops) and cotton, with special ruling for sugar cane likening the MSP concept. Effectively, MSP is thus restricted to a small subset of farmers in a few states, being also reflected by a widespread lack of awareness of the MSP policy (Indian Ministry of Finance, 2016a). Such shortcomings in information dissemination bear an unexploited, considerable potential to secure farmers' incomes, that ultimately could enhance productivity through private investments, too.

Another solution to improve farmers' livelihoods are advances in the definition of rights over land and water. The past has already confirmed that farmers were enabled and encouraged to make better use of land and water resources in a clear allocation of those rights (Kassie et al., 2013, 2015). The Indian Easements Act (1882) might have been a landmark in facilitating water use by conceding owners of land the right to collect and dispose all water under their land. Yet, this has led to enterprising farmers digging deeper tube-wells and pump large amounts of water from nearby land owners, who see themselves deprived from their legal property (Jain et al., 2007, p. 1037). Therefore, current legal schemes need a recalibration towards protection of individuals' rights over water and land while being consistent with state and national policy.

Another, broader spectrum of policies is concerned with water allocation, use, and management practices that can be assessed from different angles. Wichelns (2010) posits that national and state governments are the main culprits for water mismanagement. They have the responsibility to protect and use wisely natural resources by conveying water scarcity and quality issues via public policies that reinforce appropriate use of natural resources. This being said, they do not always act in the best interest of resource protection.

Hence, the next subsection is structured in regard to the following aspects deemed relevant for a national and state level inspection: management of groundwater supply and irrigation systems, R&D and investments in technology, waste water management, reuse capabilities, and food waste, and further development of water measurement metrics.

### 4.2.2 Efficient management of water supply, irrigation, and productivity

Rockström and Karlberg (2010) advocate a green revolution focusing on rainfed systems and improved accounting of water at global regional scales. Policies for Indian irrigation regulation aim to promote rainwater harvesting like the Rainfed Area Development

Programme, implemented in 22 states during 2012–2013. It was a crucial program as 67% of arable land is under rainfed agriculture which contributes around 44% of food grains (Katyaini and Barua, 2017). Pulses, maize, and millets are the most cultivated food grains in rainfed dry lands and therefore already have been subject of a technology mission to enhance their productivity (Government of India, 2006, 2013a).

It is, however, groundwater-fed crops that represent the main obstacle in India's long-run water security. The past taught that most detrimental for efficient use of water are subsidies on power for agriculture that, apart from its benefits towards farmers, entailed wasteful use of water and constantly declining groundwater levels (Indian Ministry of Finance, 2016a). A first step in achieving efficient groundwater use was made by a the 11th FYP (2007-2012) to regulate water-intensive food grains, being consistent with the plan's main guideline to promote agricultural growth and environmental sustainability for inclusive growth (Government of India, 2008). Another sign for improvement is the amalgamation of numerous ongoing irrigation schemes[1] into the Prime Minister's Krishi Sinchayi Yojana plan in 2015, creating convergence of investments in irrigation (Indian Ministry of Finance, 2016a).

Investments are, however, one of the most prominent bottlenecks in Indian agricultural development ever since the setting of the green revolution. Since the early mid-1990's, the country initiated steps to mitigate price distortions, but failed to increase public investment in the agricultural sector. Haq (2015) reports a disproportionate allocation of investment to urban sectors, which led to an investment bias in the 1980s and 90s, being only recently reversed by the 10th and 11th FYP (2002-07 and 2007-12)

Not only underinvestment, but first and foremost, funding for R&D and technology to improve agricultural productivity urgently required. Technological change is brought to the fore in shape of widespread irrigation systems. In times of climate change, irrigation via drip and sprinkler technologies (realizing "more crop for every drop" through micro irrigation) are crucial, rather than untargeted subsidies in power and fertiliser (Indian Ministry of Finance, 2018c). Obstacles for implementation are unsurprisingly high initial installation costs and skill required for system's maintenance (FAO and WWC, 2015; Dietzenbacher and Velazquez, 2007), but fixed costs can be revoked via increases in yields and lower costs for power and fertiliser. Likewise, financial support via credit provision to farmers can incentivise greater system's adoption, too.

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[1] Accelerated Irrigation Benefit Programme (AIBP) of the Ministry of Water Resources, River Development & Ganga Rejuvenation (MoWR,RD&GR), Integrated Watershed Management Programme (IWMP) of Department of Land Resources (DoLR) and the On Farm Water Management (OFWM) of Department of Agriculture and Cooperation (DAC).

Such micro irrigation schemes already proved successful. Impact evaluation of the National Mission on Micro Irrigation of the Ministry of Agriculture conducted in 64 districts of 13 states – Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Haryana, Karnataka, Maharashtra, Odisha, Rajasthan, Tamil Nadu, Sikkim, Uttar Pradesh and Uttarakhand – revealed the benefits of drip irrigation (Indian Ministry of Finance, 2016a). Such results also align with widespread consensus that small and medium farm-level perspectives need to be taken into account along with economic irrigation technology choices (Vico and Porporato, 2011; Finger and Lehmann, 2012; Heumesser et al., 2012). Nevertheless, greater financial investments also entail greater financial risk, which is why aggregate outcomes of programmes promoting more elaborate irrigation systems are oftentimes not realized (Van der Kooij et al., 2013; Burnham et al., 2014).

Another opportunity to make water use more sustainable is improved waste and polluted water management. Higher industrial activity, waterlogging through monsoon-induced flooding, and drilling deeper for groundwater result in degradation of water available and quality. In China for instance, cumulative water pollution is viewed as a major contributor to the emerging gap between water supply and demand by degrading surface water and aquifers (Guan et al., 2014). Therefore, the main Chinese governmental policy document of 2011 improved water conservation through investments in infrastructure and technology development (Guan et al., 2014). India could proceed similarly to alleviate water shortages, create business opportunities through waste water management also in areas without public collection (Murray et al., 2011; Otoo et al., 2015), and achieve further objectives pertaining to water security.

Further, curbing food waste would go to the root of the problem, because Gustavsson et al. (2011), estimate one-third of the food produced for human consumption is lost or wasted at some point along supply chains, although African, South and Southeast Asian waste is found lowest. By optimizing food production quantities in the first place, which tend to increase along with a country’s income level (Gustavsson et al. 2011), India could use solely efficient volumes of water for food production.

Last but not least, it is its own Indian Ministry of Finance (2018a) that takes stance for revision of its ostensibly cereal-centricity of policies to overcome water shortages. Limiting for instance consumptive use could call for substantial shifts in cropping patterns, possibly including reduced irrigated areas (Balwinder-Singh et al., 2015). Reducing agricultural production to a single crop, from two or three crops per year, to bring consumption into balance with available water supply could potentially lower water use significantly (FAO and WWC, 2015). Household incomes and regional food security must be however, considered prior to implementation to avoid trading water for food security.

A mentioned before, cereal cultivation that usually grounds on other indicators of productivity such as land or water, rather than water availability, begs for revision, too. Maximising crop land productivity is per se not wrong in land- and water- abundant countries, but not so in water-stressed regions. Therefore, crop water productivity should be promoted via policy to also increase efficiency while stabilizing land productivity simultaneously (Geerts and Raes, 2009). The Indian Ministry of Finance (2016a) reports for instance that some states do much better than the all-India average in productivity terms for pulses, but even the key pulses producing state of Madhya Pradesh has yields (938 kg/ha) barely three-fifths that of China’s (1550 kg/ha), which exhibits lacking productivity too well.

Yet, use of scarce water is not necessarily detrimental to economic growth. On the contrary, producing high VA products is wise and efficient in many settings (Wichelns, 2010). Cultivation of fruits and vegetables in arid regions during seasons when domestic or international market prices are high can generate large return being reason why using scarce water to produce high VA agricultural goods is oftentimes sensible from an economic angle.

At last, it must be reiterated that Indian water scarcity is an enduring combat, due to gaping fields of science and policy. Essentially, the absence of a holistic water policy inhibits adequate water management. Section 3 revolved around the analysis of Indian international and inter-state VWT in agricultural goods. Preliminary assumption is thus that the concept of VW holds and can be used in analysing VW savings. Wichelns (2010) objects the meaningfulness of this indicator by stating water savings do not reflect actual production opportunities or true water-saving potentials. For instance, arid countries like Alegria and Morocco have important, but limited, agricultural sectors that are anything, but water-abundant. Hence, the notion of saving water by importing water-intensive goods is inherently wrong, because of the absence of said water in the first place. Therefore, the VW concept shows only limited capacity to enhance one’s understanding of policy alternatives to improve water management in agriculture. This points into the direction that novelty in assessing and improving natural resource management and metrics is key and water is by far not the only variable that must be considered when analysing international trade relations (Zhang-Ming and Chen, 2012).

### 4.2.3 Indian water infrastructure improvements

The last subsection is dedicated to evince more distinct, state-targeted policies on redistribution capabilities though water infrastructure, which has not been addressed, yet, which directly resolves the driving issue of uneven distribution of water sources.

As demonstrated in section 2, India is a highly heterogenous country in terms of geographical distribution of water. Therefore, inter-state water flows in the context of large inter-basin transfer plans are no novel idea. In fact, they have been in practice for over five centuries to transfer large amounts of water over long distances and generate great economic prospects for water-receiving regions, while high infrastructure costs and extensive and irreversible environmental consequences are on the downside (Jain et al., 2007, p. 1069).

In recent years, Indian water transboundary transfers and improvements have made the case more than ever. Verma et al., (2008) conduct a study that explores factors that influence inter-state VWT in India and found that trade was exacerbating scarcities in already water scarce states and VW flows are more determined by factors like "per capita gross cropped area" and "access to secured markets", rather than states’ water endowments. However, they also make an evaluation of the country’s National River Linking Project, which has been proposed in 2002 by the Indian National Water Development Agency. The project aims to link 37 Himalayan and Peninsular rivers (see figure 30) for a total estimated cost of US$ 120 billion (Verma et al., 2008). As a result, an enormous water grid in the South will annually handle 178 x $10^9$ $m^3$/year, a total of 12,500 km of canals would be built, and it would add 35 million hectare of irrigated area (25 million from surface and about 10 million by higher use of ground water) to India’s existing water infrastructure (Gupta and Van der Zaag, 2007). Moreover, the project would aid in resolving two critical problems in water management – floods and droughts; improve municipal water supply demand, and create water infrastructure for transport at lower environmental and financial cost (Jain et al., 2007, pp. 1083).

Confronted with a relatively water scarce North and abundant South, China launched the South-North Water Transfer Project in the1990's (Ma et al., 2006), to reduce regional water shortages. Yet, it is important to assess the direction and quantum of VWT within such a case with the backdrop of the project's implementation.

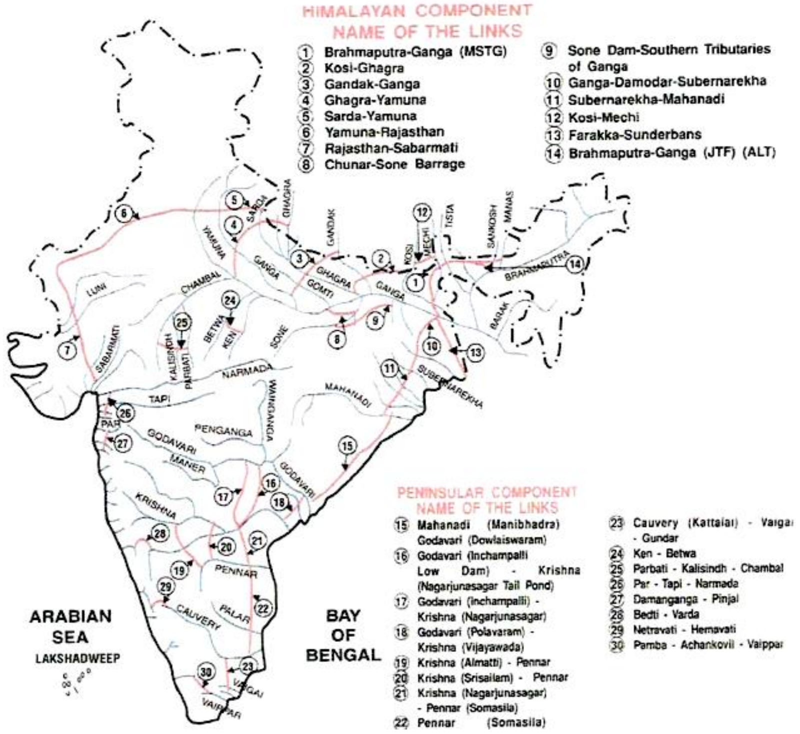


*Figure 4-1 India's proposed National River Linking Programme (NRLP), with the Himalayan component (North) and the Peninsular component (South)*

Source: Jain et al., (2007, p. 1082).

Ma et al., (2006) find that similarly to Indian inter-state VWT, the water-scarce North exports much more VW than envisioned by the project. Hence, such a "perverse" direction of the Chinese VWT would need to be reversed to serve the project's actual purpose.

Finally, all insights gained above together are used to deduct what essentially helps India to overcome its regional water shortages in the long-run and thus also answers the sub-research question that aimed to guide the whole discourse on policies since India's trade liberalisation.

Most recent studies suggest policies that can be geographical separated according to Kampman (2007) or Verma et al., (2008) and are reinforced by a broader policy message proposed by Subramanian (2017), who distinguishes Indian agricultural and water policy in two – the well-irrigated, input-distorted, and price-and-procurement-supported cereal-centric North; and the South and West coined by inadequate irrigation, continued rain dependence, ineffective procurement, insufficient investments in research and technology (non-cereals such as pulses, soybeans, and cotton), high market barriers and weak post-harvest infrastructure (fruits and vegetables), and challenging non-economic policy (livestock) (Indian Ministry of Finance, 2018c).

It is the North's challenge to abolish support and price schemes to less detrimental support in form of direct benefit transfers to tackle the regions relentless groundwater depletion that also led to bankrupt power suppliers (Brindha, 2017). Inter-state VWT plays a pivotal role here as this region's states Delhi, Haryana, Himachal Pradesh, Punjab, and Uttar Pradesh count the highest water losses and have not implemented any state water policy (SWP) (Katyaini and Barua, 2017). This is emblematic for India's issue lying in its lacking legal coherence and sluggish policy implementation process: Although both agriculture and water are state-ruled, none of the states formulated or implemented agricultural policy to address state-specific challenges during the post-reform's period (1996-2006). With three versions of NWP (1987, 2002, and 2012), having failed to arrest rising water stress, any perceptible difference in improving the country's water management is yet to hope for. Until 2012, a total of 14 states had formulated their state water policy (Ministry of water resources, 2012), but it took until 2019 that Meghalaya became the very first state to adopt its SWP, addressing water issues, conservation, and protection of water sources in the state.

Turning to the South and West, Tamil Nadu in the South and Maharashtra in the West face similar issues as Northern Punjab, but Maharashtra together with its neighbour Madhya Pradesh have made headways lately with reforming their water institutions and governance structures to promote participative irrigation management (Brindha, 2017). Yet, Katyaini and Barua, (2017) have demonstrated that water savings in Tamil Nadu and Maharashtra have only increased by means of imports from the Northern states. Hence, regional shortages can be overcome via interstate VWT with water-abundant states, but distortions have currently still a major stake in making other regions worse off, illustrated by VW flows from water-stressed to other water deprived regions.

To complete the picture, the Eastern corridor is sitting on abundant aquifers and the countryside got de-electrified; and irrigation by the poor has been impeded by high and rising costs of diesel. An evident lack in infrastructure prompts the states to import VW, rather than prospering economically themselves through VW exports. In sum, this underlines the fact that all Indian regions not only face state-specific issues that need to be resolved in cooperation with national legislation. Otherwise, water scarcities are only displaced within the nation, which does not aid in achieving future Indian water security.

A ray of hope for interstate cooperation is the cooperative federalism initiative via the Goods and Services Tax Council, bringing the central and states' governments together, that sets the course not only for agricultural reforms, but for a sound national and state water policy scheme, too.

The following list of policy conclusions are the main outcome of insights gained throughout the previous sections and their discussion, with the general message that the Indian national economy needs to turn away from producing water-intensive crops like rice and sugarcane in water stressed regions, while curbing the export of high VW content crops such as rice and cotton. Policy enforcement, monitoring, and communicating regional scarcities also promote efficient water governance both, at national and state level.

1. Widespread technological adoption of irrigations system should be popularized, as to enhance water use efficiency and productivity;
2. Promotion of sustainable subsidies for crops deemed conducive to restructuring the agricultural sector away from its cereal-centric focus in Northern regions, towards convergence of national agricultural activity;
3. Communication of pricing mechanisms and incentives for crops in appropriate agro-climatic environments to safeguard farmers' incomes;
4. Water pricing for quotas for withdrawal for the agriculture sector should be reviewed and implemented, if feasible in economic and environmental terms;
5. Watershed and infrastructure development must be planned to pave way to safeguard surface and ground water recharge mechanisms as well as alleviate national water stress;

6. Dissemination of information on scarcity levels to increase awareness to boost efficient water use and conservation;
7. Facilitation of credit provision for agricultural smallholder investments and strengthening R&D to  productivity in agricultural sector in the long-run;
8. Strengthening cross-sectoral and interstate water governance for better co-ordination and resolving of water conflicts and efficient waste water treatment through implementation of performing National and State Water Policy.

# 5 Conclusion

This study was set out to analyse Indian national and regional measures in a world of increasing water scarcity. Since the country's trade pattern suggests that it is a major exporter of water embedded in agricultural goods, the study period was set by its recent economic take-off since its trade liberalisation in 1991 until 2019. Three levels were used for assessment, including factors influencing the agricultural sector's water use, Indian trade in virtual water (VW) and policies interventions aiming to promote water security. Their interplay demonstrates the significance and multitude of aspects one has to consider in analysing Indian water stress, which also constitutes for the scientific contribution of this study.

Given India faces a looming national water crisis, that partially is already the case in some regions, the first main section was dedicated to investigate the concept of water scarcity by examining how India's water scarcity positions relative to the rest of the world, how its agricultural sector used water in the past, and what main factors might be closely linked to the country's water use and economic growth prospects.

The country's trade integration in the world economy gave rise to examine in detail its virtual water trade (VWT) patterns not only on international, but also on interstate scale as previous literature suggests potential for water-stress alleviation and exacerbation. To revisit the state of knowledge on VWT, a meta-analysis was used to show how other scholars contributed to understand Indian water stress. At last, relevant policy measures were gathered, tackling the issue of water shortages at international and state-level, for acknowledging and considering both, separately and together is crucial in alleviating water-stress.

The answers to both, the main and sub-research question, are reported in the last section on policy interventions to install Indian water security and cover a wide range of measures that can be taken. Economic restructuring towards import of water-intensive goods and limiting export of said goods along with implementation of coherent national and state water policy would to raise awareness for water scarcities and improve efficient use, allocation, and redistribution, too. Taking into account the country's divers agro-climatic landscape for appropriate choice of crop cultivation is key here. Investments in R&D, water infrastructure, provision of credits for farmers would not only improve agricultural productivity – a main retardant in Indian economy growth, through installation of micro-irrigation systems, but also farmers' incomes. Last but not least, pricing and quotas should be reviewed to create economic incentives and assign water a discernible value in agricultural production to overcome overexploitation and foster its sustainable use in the long-run.

Future research could aim to further investigate water use in all economic sectors, including industry and services, but also households' consumption, to complete the picture of Indian water use. The use of Global Multi-Regional Input-Output databases such as EXIOBASE (Tukker et al., 2013) or EORA (Lenzen et al., 2013b) could further the debate of international trade's impact on water use and flows and how India positions. Moreover, revisiting state-specific policies and their impact analysis could be another route to append on the insights gained in this study and display state-specific solutions.

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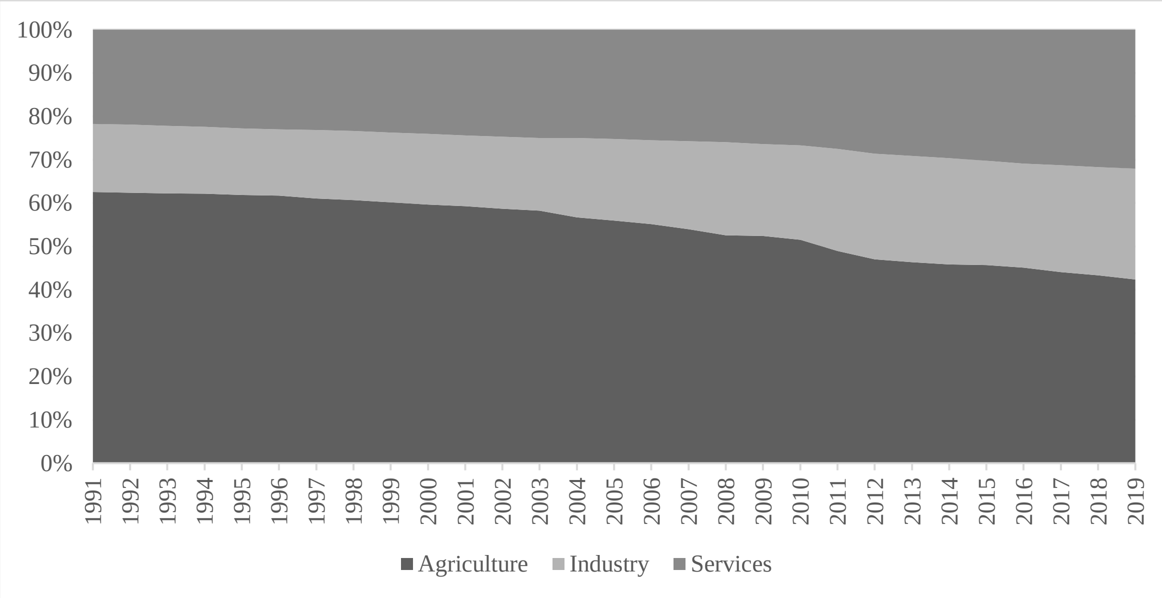
# Appendix A

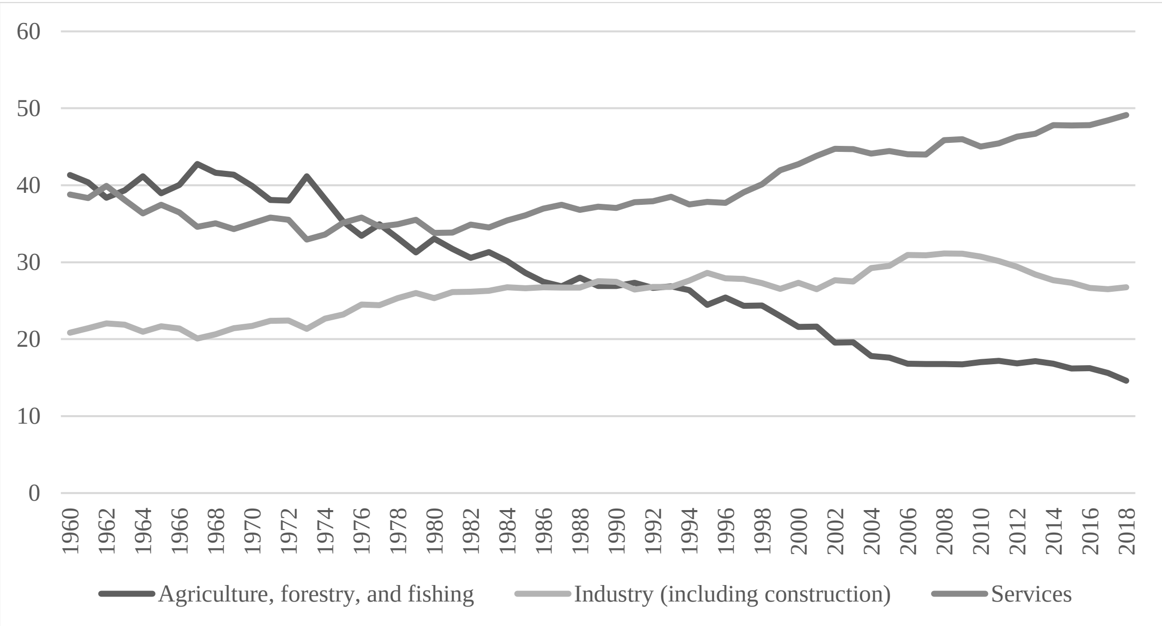
**Evidence on structural transformation in India**

Employment share in each sector of India between 1991-2019



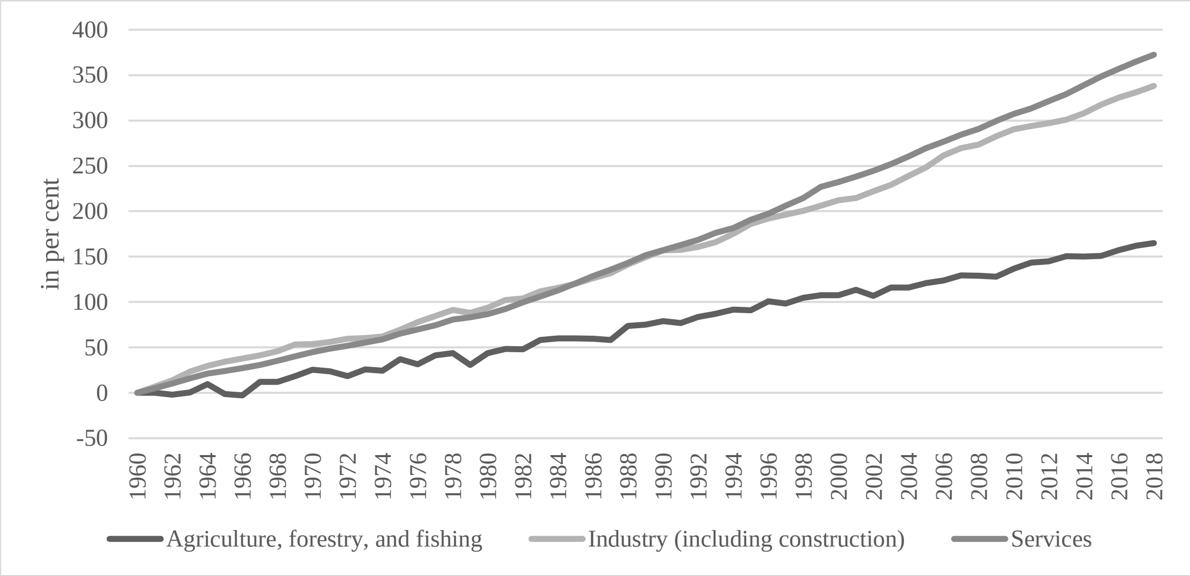

Source: World Bank, 2020.

Sector value added as percentage of GDP in India between 1960-2018




Source: World Bank, 2020.

Cumulated Indian sector value added growth between 1960-2018




Source: World Bank, 2020.

# Appendix B

Virtual water balance of the thirteen world regions in relation to the trade in crops, livestock and livestock products (Giga $m^3$ /yr) in the period 1995-99.

| World regions | Virtual water balance ($Gm^3$/yr) = gross import - gross export | | |
|---|---|---|---|
| | Crops | Livestock and livestock products | Total |
| North America | -206.2 | -41.9 | -248.0 |
| South America | -47.9 | -21.4 | -69.3 |
| Oceania | -28.0 | -41.3 | -69.3 |
| South-east Asia | -27.1 | 13.9 | -13.1 |
| Eastern Europe | -1.0 | -0.8 | -1.8 |
| Former Soviet Union (FSU) | -8.9 | 9.6 | 0.7 |
| Central America | -4.4 | 6.2 | 1.7 |
| Central Africa | 2.3 | 0.4 | 2.7 |
| Southern Africa | 4.0 | 2.0 | 6.0 |
| Middle East | 30.2 | 13.2 | 43.4 |
| North Africa | 44.4 | 5.3 | 49.8 |
| Western Europe | 76.1 | 5.6 | 81.7 |
| Central and South Asia | 166.5 | 47.2 | 213.7 |

Source: Chapagain and Hoekstra (2004)

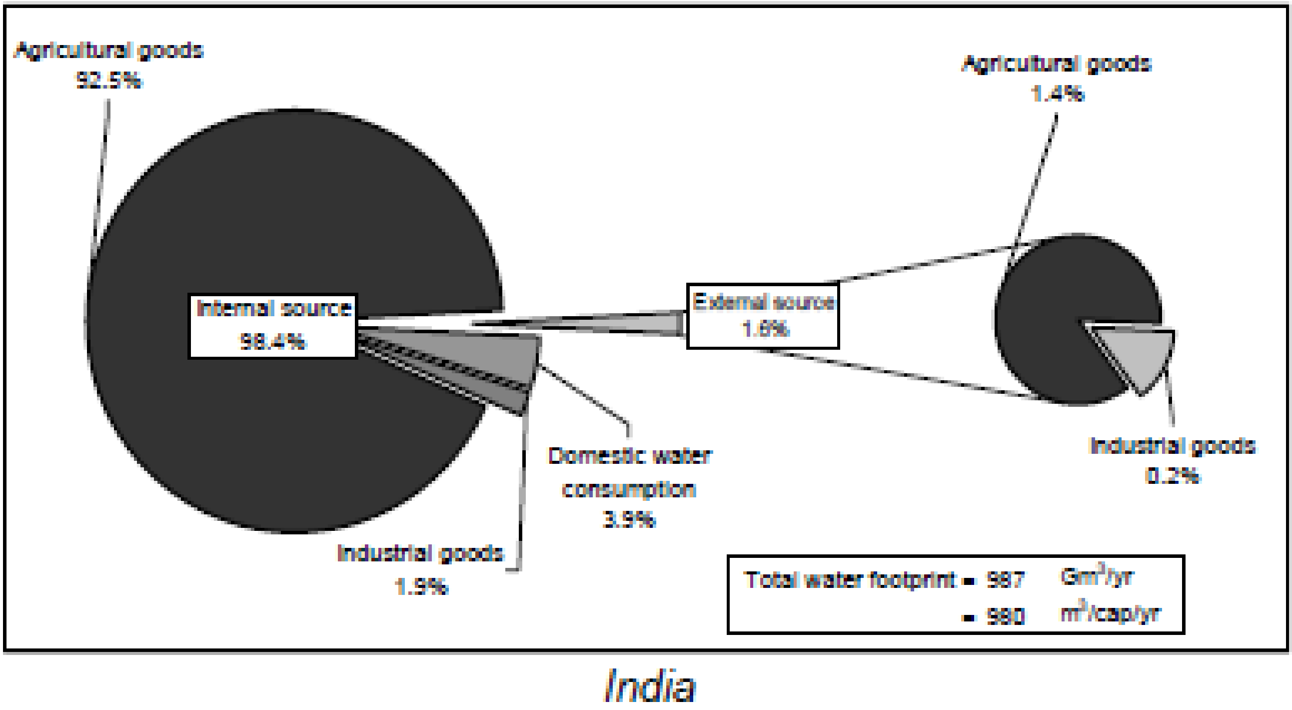
# Appendix C

Composition of the water footprint for China, USA and India. Period: 1997-2001.

| **Country** | **Population** | **Use of domestic water resources** | | | | | | **Use of foreign resources** | | | **Water footprint** | | **Water footprint by consumption category** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Domestic water withdrawal | Domestic evapotranspiration | | Industrial water withdrawal | | | For national consumption | | For re-export of imported products | Total | Per capita | Domestic water | Agricultural goods | | Industrial goods | |
| | | | For national consumption | For export | For national consumption | For export | | Agricultural goods | Industrial goods | | | | Internal water footprint | Internal water footprint | External water footprint | Internal water footprint | External water footprint |
| | | $Gm^3/yr$ | $Gm^3/yr$ | $Gm^3/yr$ | $Gm^3/yr$ | $Gm^3/yr$ | | $Gm^3/yr$ | $Gm^3/yr$ | $Gm^3/yr$ | $Gm^3/yr$ | $m^3/cap/yr$ | $m^3/cap/yr$ | $m^3/cap/yr$ | $m^3/cap/yr$ | $m^3/cap/yr$ | $m^3/cap/yr$ |
| China | 1257521250 | 33.32 | 711.10 | 21.55 | 81.531 | 45.73 | | 49.99 | 7.45 | 5.69 | 883.39 | 702 | 26 | 565 | 40 | 65 | 6 |
| USA | 280343325 | 60.80 | 334.24 | 138.96 | 170.777 | 44.72 | | 74.91 | 55.29 | 45.29 | 696.01 | 2483 | 217 | 1192 | 267 | 609 | 197 |
| India | 1007369125 | 38.62 | 913.70 | 35.29 | 19.065 | 6.04 | | 13.75 | 2.24 | 1.24 | 987.38 | 980 | 38 | 907 | 14 | 19 | 2 |

Source: Chapagain and Hoekstra, 2004

Details of the water footprint of India. Period: 1997-2001.




Source: Chapagain and Hoekstra, 2004.

# Appendix D

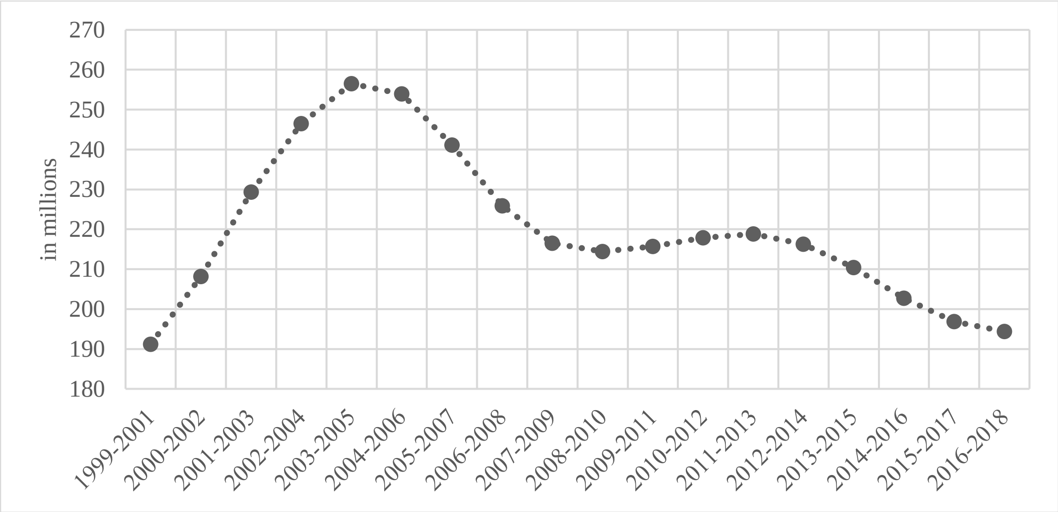
Virtual Water (VW) content of crop and livestock products for India (1997-2001)

| Product | VW content (cubic m/tonne) | Product | VW content (cubic m/tonne) |
|---|---|---|---|
| Crop and crop products | | | |
| Wheat | 1654 | Palm oil | 5169 |
| Rice (paddy) | 2850 | Sunflower/safflower oil | 8541 |
| Rice (husked) | 3702 | Mustard oil | 4643 |
| Barley | 1966 | Linseed oil | 19159 |
| Maize | 1937 | Banana | 415 |
| Millet | 3269 | Orange | 364 |
| Sorghum | 4053 | Lemon and lime | 611 |
| Sugarcane | 159 | Grapefruit | 411 |
| Lentils | 6652 | Apple | 1812 |
| Soybeans | 4124 | Pear | 1287 |
| Oats | 1597 | Apricot | 2424 |
| Rye | 901 | Cherry | 2532 |
| Jute | 2823 | Peach | 1564 |
| Cotton lint | 18694 | Plum | 1907 |
| Potatoes | 213 | Grapes | 238 |
| Sweet potato | 277 | Watermelon | 362 |
| Beans (green) | 487 | Mango/guava | 1525 |
| Beans (dry) | 8335 | Pineapple | 305 |
| Castor beans | 9807 | Papaya | 922 |
| Urad/mung/gram beans | 3078 | Dates | 3030 |
| Peas (green) | 178 | Avocado | 1284 |
| Peas (dry) | 3040 | Strawberry | 296 |
| Chick pea | 2712 | Almond (in shell) | 9769 |
| Pigeon pea | 4066 | Cashewnut | 15340 |
| Cabbage | 180 | Walnut (in shell) | 11721 |
| Onion (fresh) | 214 | Arecanut (betal) | 9985 |
| Onion (dry) | 538 | Groundnut (in shell) | 3420 |
| Tomato | 302 | Coconut | 2255 |
| Cauliflower | 100 | Coffee (roasted) | 14500 |
| Pumpkin, squash, gourd | 238 | Coffee | 12180 |
| Cucumber and gherkin | 357 | Cocoa beans | 13775 |
| Garlic | 1268 | Cocoa powder | 8994 |
| Carrot/turnip | 192 | Tea (black) | 7002 |
| Spinach | 144 | Tea (green) | 1804 |
| Sunflower seed | 4304 | Sugar (raw) | 1301 |
| Safflower seed | 6864 | Sugar (refined) | 1391 |
| Sesame seed | 8415 | Clove | 61304 |
| Cotton seed | 8264 | Turmeric | 1556 |
| Linseed | 11080 | Pepper | 8333 |
| Rape seed | 2618 | Ginger | 1556 |
| Corinader seed | 949 | Tobacco | 2627 |
| Groundnut oil | 8875 | Natural rubber | 7626 |
| Olive oil | 21106 | Beer | 411 |
| Coconut oil | 3051 | Grape wine | 341 |
| Livestock and livestock products | | | |
| Bovine | 7386 | Milk powder | 6368 |
| Swine | 4119 | Yogurt/milk product | 1592 |
| Sheep | 3397 | Buttermilk | 2068 |
| Goat | 3018 | Cheese | 6793 |
| Fowl/poultry | 6024 | Egg (birds) | 7531 |
| Horse/ass/mule | 2849 | Leather (bovine) | 17710 |
| Milk (fat <1%) | 1369 | Goat meat | 5187 |
| Milk (fat >1% and <6%) | 1415 | Sheep meat | 6692 |
| Milk (fat >6%) | 2547 | Chicken meat | 7736 |

Source: Kumar and Jain, 2007, derived from Chapagain and Hoekstra, 2004.

# Appendix E

Number of undernourished people (millions) 3-year average.




Source: FAOSTAT, 2020.

# Appendix F

Categorization of blocks/taluks/watersheds as over exploited and dark on all India basis

| S. No. | States | No. of Assessment units (Blocks/ Taluks/ Watersheds) | Assessment units (Blocks/ Taluks/ Watersheds) | | | |
|---|---|---|---|---|---|---|
| | | | Over exploited | | Dark/Critical | |
| | | | No. | % | No. | % |
| 1 | Andhra Pradesh | 1,157 | 118 | 10.20 | 79 | 6.83 |
| 2 | Arunachal Pradesh | 59 | 0 | 0 | 0 | 0 |
| 3 | Assam | 219 | 0 | 0 | 0 | 0 |
| 4 | Bihar | 394 | 6 | 1.52 | 14 | 3.55 |
| 5 | Chhatisgarh | 145 | 0 | 0 | 0 | 0 |
| 6 | Delhi | 6 | 3 | 50 | 1 | 16.67 |
| 7 | Goa | 12 | 0 | 0 | 0 | 0 |
| 8 | Gujarat | 180 | 41 | 22.78 | 19 | 10.56 |
| 9 | Haryana | 111 | 30 | 27.03 | 13 | 11.71 |
| 10 | Himachal Pradesh | 69 | 0 | 0 | 0 | 0 |
| 11 | Jammu & Kashmir | 69 | 0 | 0 | 0 | 0 |
| 12 | Jharkhand | 193 | 0 | 0 | 0 | 0 |
| 13 | Karnataka | 175 | 7 | 4 | 9 | 5.14 |
| 14 | Kerala | 151 | 3 | 1.99 | 6 | 3.97 |
| 15 | Madhya Pradesh | 312 | 2 | 0.64 | 1 | 0.32 |
| 16 | Maharashtra | 2,316 | 154 | 6.65 | 72 | 3.11 |
| 17 | Manipur | 29 | 0 | 0 | 0 | 0 |
| 18 | Meghalaya | 39 | 0 | 0 | 0 | 0 |
| 19 | Mizoram | 12 | 0 | 0 | 0 | 0 |
| 20 | Nagaland | 52 | 0 | 0 | 0 | 0 |
| 21 | Orissa | 314 | 0 | 0 | 0 | 0 |
| 22 | Punjab | 138 | 81 | 58.70 | 12 | 8.70 |
| 23 | Rajasthan | 237 | 86 | 36.29 | 80 | 33.76 |
| 24 | Sikkim | 4 | 0 | 0 | 0 | 0 |
| 25 | Tamil Nadu | 385 | 138 | 35.84 | 37 | 9.61 |
| 26 | Tripura | 38 | 0 | 0 | 0 | 0 |
| 27 | Uttar Pradesh | 819 | 2 | 0.24 | 20 | 2.44 |
| 28 | Uttaranchal | | | | | |
| 29 | West Bengal | 275 | 0 | 0 | 61 | 22.18 |
| | Total States | 7,910 | 671 | 8.48 | 424 | 5.36 |
| UT's | | | | | | |
| 1 | Andaman & Nicobar Islands | 1 | 0 | 0 | 0 | 0 |
| 2 | Chandigarh | 1 | 0 | 0 | 0 | 0 |
| 3 | Dadra & Nagar Haveli | 1 | 0 | 0 | 0 | 0 |
| 4 | Daman & Diu | 2 | 1 | 50 | 1 | 50 |
| 5 | Lakshadweep | 9 | 0 | 0 | 0 | 0 |
| 6 | Pondicherry | 4 | 1 | 25 | 0 | 0 |
| | Total UT's | 18 | 2 | 11.11 | 1 | 5.56 |
| | Grand Total | 7,928 | 673 | 8.49 | 425 | 5.36 |

Source: Jain et al., 2007.

# Appendix G

Classification of Indian trade partners based on net trade and total internal renewable freshwater resources per capita.

| Country (Net virtual water import) | Net virtual water import | Water abundance | Trade partner type |
|---|---|---|---|
| China (−7.5 $Bm^3$/y) | No | No | Supported |
| Bangladesh (−4.8 $Bm^3$/y) | No | No | Supported |
| UAE (−2.3 $Bm^3$/y) | No | No | Supported |
| Vietnam (−2.3 $Bm^3$/y) | No | No | Supported |
| Saudi Arabia (−2.2 $Bm^3$/y) | No | No | Supported |
| Pakistan (−2 $Bm^3$/y) | No | No | Supported |
| Japan (−1.9 $Bm^3$/y) | No | No | Supported |
| South Korea (−1.6 $Bm^3$/y) | No | No | Supported |
| Netherlands (−1.6 $Bm^3$/y) | No | No | Supported |
| USA (−1.4 $Bm^3$/y) | No | Yes | Unilateral benefit |
| Indonesia (7.2 $Bm^3$/y) | Yes | Yes | Mutual benefit |
| Argentina (2.2. $Bm^3$/y) | Yes | Yes | Mutual benefit |
| Malaysia (2.0 $Bm^3$/y) | Yes | Yes | Mutual benefit |
| Ivory coast (1.8 $Bm^3$/y) | Yes | No | Double pressure |
| Benin (1.3 $Bm^3$/y) | Yes | No | Double pressure |
| Canada (1.0 $Bm^3$/y) | Yes | Yes | Mutual benefit |
| Ukraine (0.9 $Bm^3$/y) | Yes | No | Double pressure |
| Brazil (0.8 $Bm^3$/y) | Yes | Yes | Mutual benefit |
| Guinea-Bissau (0.8 $Bm^3$/y) | Yes | Yes | Mutual benefit |
| Myanmar (0.7 $Bm^3$/y) | Yes | Yes | Mutual benefit |
| Australia (0.7 $Bm^3$/y) | Yes | Yes | Mutual benefit |

Source: Brindha, 2016.

# Appendix H

Interstate gross total virtual water flows

| States | AP | AS | BH | CG | DL | GJ | HR | HP | JK | JH | KT | KL | MP | MH | OR | PJ | RJ | TN | UP | UA | WB | Export |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AP** | | 35 | 110 | 481 | 46 | 0 | 0 | 14 | 21 | 36 | 529 | 77 | 0 | 1814 | 1051 | 0 | 92 | 190 | 259 | 21 | 144 | **4952** |
| **AS** | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | **4** |
| **BH** | 0 | 0 | | 1 | 0 | 78 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 63 | 0 | 0 | 0 | 0 | **149** |
| **CG** | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2524 | 0 | 296 | 0 | 15 | 0 | 0 | 0 | 0 | **2835** |
| **DL** | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **GJ** | 0 | 120 | 530 | 84 | 155 | | 0 | 49 | 99 | 188 | 0 | 168 | 87 | 561 | 178 | 0 | 0 | 5 | 874 | 83 | 572 | **3847** |
| **HR** | 80 | 101 | 1647 | 49 | 1560 | 2369 | | 86 | 549 | 415 | 148 | 2098 | 0 | 1877 | 189 | 0 | 542 | 94 | 478 | 50 | 510 | **13006** |
| **HP** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 26 | 0 | 0 | 0 | 0 | **26** |
| **JK** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 26 | 0 | 0 | 0 | 0 | **26** |
| **JH** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **KT** | 19 | 12 | 39 | 10 | 16 | 97 | 0 | 5 | 7 | 13 | | 27 | 95 | 663 | 17 | 0 | 1900 | 1 | 91 | 7 | 51 | **3130** |
| **KL** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **MP** | 112 | 147 | 470 | 739 | 266 | 312 | 83 | 114 | 150 | 297 | 600 | 273 | | 999 | 932 | 348 | 43 | 513 | 518 | 122 | 532 | **7671** |
| **MH** | 11 | 122 | 343 | 873 | 169 | 1279 | 16 | 60 | 85 | 153 | 85 | 251 | 686 | | 121 | 82 | 0 | 137 | 680 | 79 | 455 | **5788** |
| **OR** | 0 | 0 | 0 | 140 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 9 | 0 | 0 | 0 | 0 | **149** |
| **PJ** | 124 | 75 | 3123 | 18 | 450 | 1542 | 0 | 181 | 1410 | 453 | 228 | 6109 | 0 | 4167 | 159 | | 344 | 144 | 156 | 13 | 341 | **19351** |
| **RJ** | 18 | 289 | 1620 | 138 | 390 | 1542 | 27 | 147 | 331 | 674 | 13 | 140 | 0 | 130 | 407 | 138 | | 224 | 1721 | 242 | 1517 | **9852** |
| **TN** | 128 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 905 | 944 | 1541 | 738 | 0 | 0 | 15 | | 0 | 0 | 0 | **4293** |
| **UP** | 76 | 502 | 6503 | 9 | 930 | 1591 | 480 | 371 | 424 | 5450 | 1190 | 94 | 0 | 851 | 80 | 1022 | 2227 | 88 | | 341 | 1995 | **24542** |
| **UA** | 0 | 31 | 86 | 3 | 44 | 348 | 32 | 411 | 25 | 52 | 0 | 0 | 0 | 27 | 0 | 67 | 182 | 0 | 0 | | 121 | **1447** |
| **WB** | 0 | 868 | 0 | 0 | 0 | 28 | 0 | 0 | 0 | 1122 | 0 | 0 | 0 | 2 | 1122 | 0 | 15 | 0 | 0 | 0 | | **4447** |
| **Import** | **569** | **2304** | **14469** | **2544** | **4026** | **9186** | **638** | **1439** | **3101** | **8853** | **3699** | **10180** | **4933** | **11836** | **4552** | **1658** | **5504** | **1397** | **4777** | **960** | **6238** | **105516** |

Source: Kampman, 2007.

# Appendix I

Net blue, green, grey and total global water saving as a result of interstate trade by crops

| Crop | Blue | Green | Gray | Total |
|---|---|---|---|---|
| Unit | million m³/yr | | | |
| Year | 1997-2001 | | | |
| Milled rice | -2490 | 14108 | 1339 | 12957 |
| Wheat | 17241 | 1235 | 4349 | 22824 |
| Maize | -18 | 363 | 33 | 378 |
| Millet | 10 | 1536 | 135 | 1680 |
| Sorghum | 106 | -2816 | -86 | -2796 |
| Raw sugar | 3795 | 1972 | 492 | 6259 |
| Pulses | -1238 | 428 | -63 | -872 |
| Groundnut oil | 196 | -18 | 6 | 184 |
| Rapeseed oil | -2495 | 2661 | 765 | 931 |
| Remaining edible oil | 5 | -71 | -2 | -68 |
| Cotton lint | -38 | 31 | -4 | -11 |
| Total | 15074 | 19429 | 6964 | 41466 |

Source: Katyaini and Barua, 2017.

Major food grains producing states.

| Food Grains | Major Food Grains Producing States Zone-Wise | | | | | |
|---|---|---|---|---|---|---|
| | North | North-East | East | Central | West | South |
| Rice | Haryana, Punjab, Uttar Pradesh | Assam | Bihar, Orissa, West Bengal | Chhattisgarh | | Andhra Pradesh, Karnataka, Tamil Nadu |
| Wheat | Haryana, Punjab, Uttar Pradesh, Uttaranchal | | Bihar, West Bengal | Madhya Pradesh | Gujarat, Maharashtra, Rajasthan | |
| Jowar Bajra | Haryana, Jammu and Kashmir, Uttar Pradesh | | | Chhattisgarh, Madhya Pradesh | Gujarat, Maharashtra, Rajasthan | Andhra Pradesh, Karnataka, Tamil Nadu |
| Maize and millet | Himachal Pradesh, Uttar Pradesh, Uttaranchal | Arunachal Pradesh | Bihar, Jharkhand | Chhattisgarh, Madhya Pradesh | Gujarat, Maharashtra, Rajasthan | Andhra Pradesh, Karnataka, Tamil Nadu |
| Gram | Haryana, Uttar Pradesh | | Bihar, Jharkhand | Chhattisgarh, Madhya Pradesh | Gujarat, Maharashtra, Rajasthan | Andhra Pradesh, Karnataka |
| Pulses other than gram | Uttar Pradesh | | Bihar, Jharkhand, Orissa | Chhattisgarh, Madhya Pradesh | Gujarat, Maharashtra, Rajasthan | Andhra Pradesh, Karnataka, Tamil Nadu |
| Other sorts of grains (Barley) | Haryana, Himachal Pradesh, Jammu and Kashmir, Punjab, Uttar Pradesh, Uttaranchal | | Bihar, Jharkhand, West Bengal | Chhattisgarh, Madhya Pradesh | Rajasthan | Tamil Nadu |

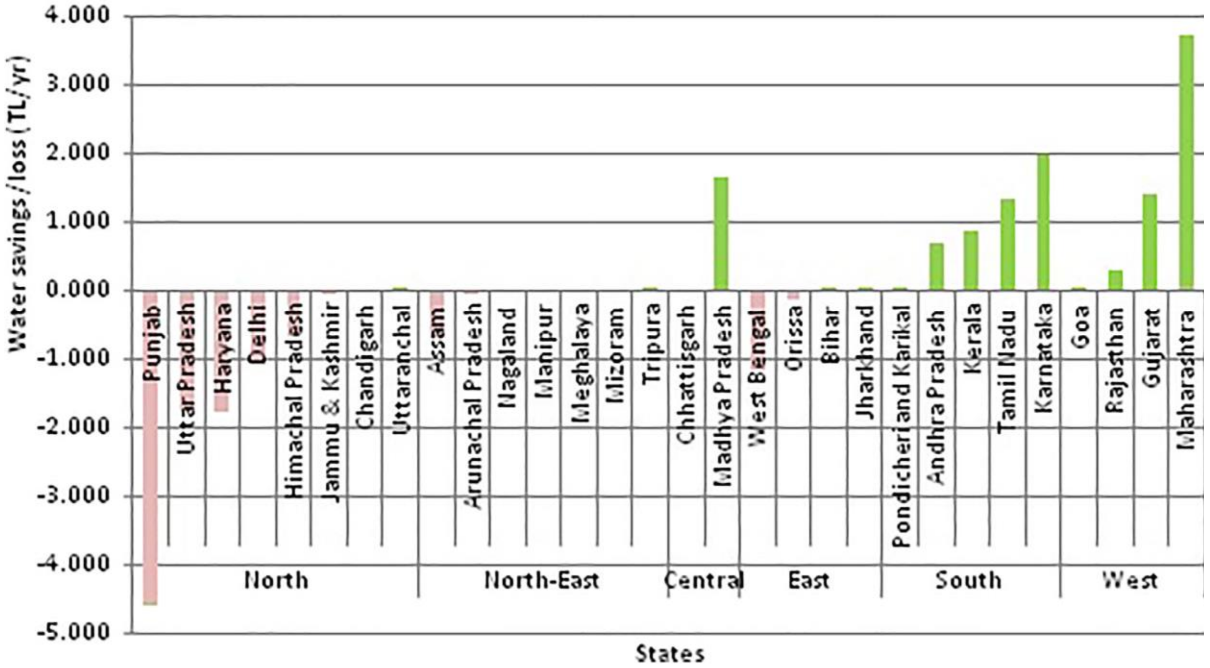
Source: Katyaini and Barua (2017)

VW-flows Crop Wise and Year-Wise for the Period of 1996-2014

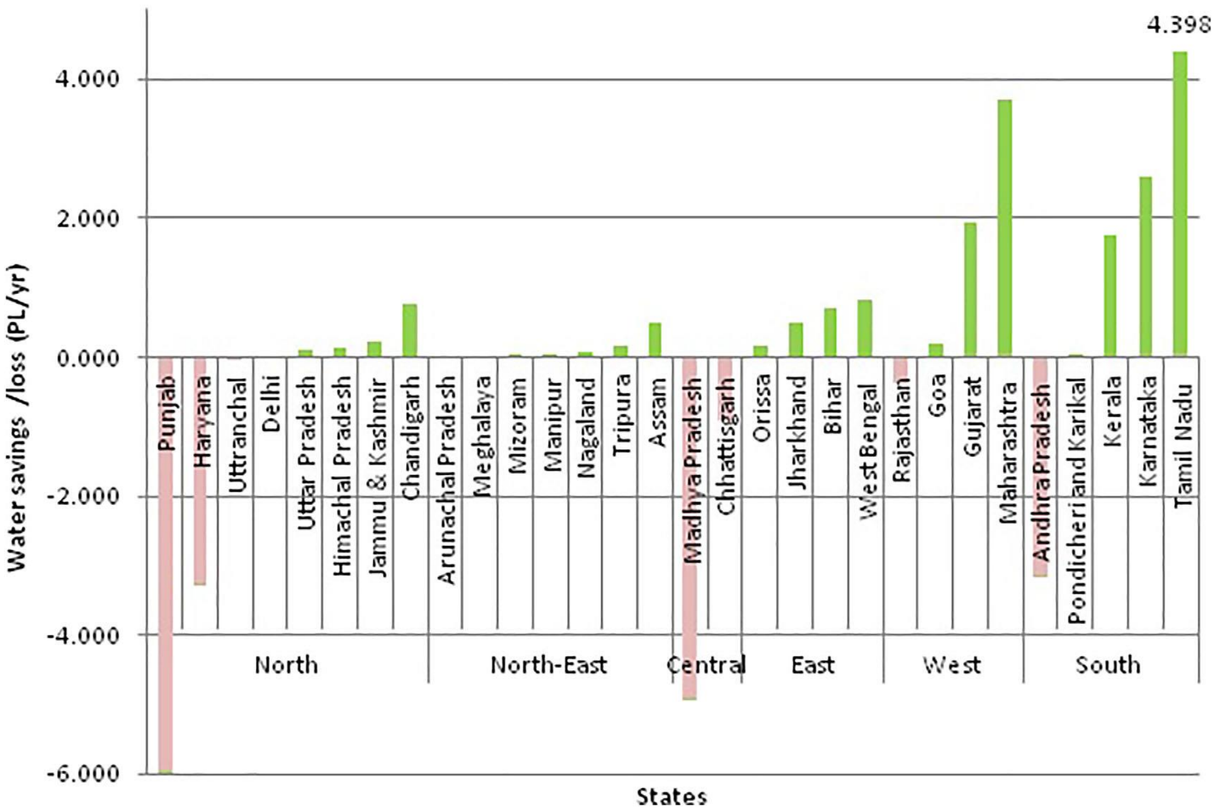
| | Year | Crop-Wise and Year-Wise VW-flows (Giga Litres = GL = ×10⁹ L) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Rice in the Husk | Rice not in the Husk | Wheat | Wheat Flour | Gram and Gram Products | Pulses Other Than Gram | Sorghum and Millet | Maize and Millet | Other Sorts of Grains | Total |
| Postreform Period | 1996–1997 | 34 | 2 | 975 | 11 | −2 | 94 | 0 | 0 | −3 | 1111 |
| | 1997–1998 | 3 | −55 | 854 | 111 | −15 | 152 | 0 | 0 | 1 | 1050 |
| | 1998–1999 | 10 | 1 | −5 | 56 | −107 | 24 | 0 | −2 | −2 | [−]25 |
| | 1999–2000 | 0 | −4 | −3 | 11,998 | −2 | 3142 | 0 | 0 | 0 | 15,131 |
| | 2000–01 | 1 | −1185 | 6561 | 16 | −46 | −43 | −7 | −201 | −208 | 4888 |
| | 2001–02 | 0 | −1429 | 14,610 | 83 | −6 | −146 | 46 | 808 | 10955 | 24922 |
| | 2002–03 | −482 | −1387 | 4998 | 1 | −18 | −172 | 1962 | −124 | −173 | 4606 |
| | 2003–04 | 49 | −2992 | 18,555 | 6 | −10 | −68 | 26 | −33 | −313 | 15,222 |
| | 2004–05 | 50 | −2251 | 24,734 | 7 | 155 | −196 | 48 | 8 | −224 | 22,330 |
| Period of Recovery | 2005–06 | 219 | 2248 | 12,871 | −5 | −11 | −49 | 22 | −209 | 150 | 15,237 |
| | 2006–07 | 16 | −332 | 6609 | 5 | 164 | 52 | 24 | −35 | 158 | 6660 |
| | 2007–08 | 46 | −4485 | 4566 | 1 | 142 | −106 | 30 | −680 | −17 | [−]504 |
| | 2008–09 | 19 | −4325 | 10,504 | 1 | 83 | −58 | 53 | 97 | 0 | 6372 |
| | 2009–10 | 17 | 1943 | 10,175 | −3 | 49 | −153 | 102 | −383 | 595 | 12,343 |
| | 2010–11 | 28 | 673 | 3501 | 2 | 13 | −227 | 65 | −954 | 0 | 3102 |
| | 2011–12 | −1 | 105,811,625 | 9816 | 2 | 28 | 3688770 | 82 | −715 | 35 | 109,509,642 |
| | 2012–13 | 44 | 1950 | 97,885,464 | −2 | 64 | −296 | 26 | −307 | 83 | 97,887,026 |
| | 2013–14 | 27 | 2090 | 11,297 | 0 | 6 | −122 | 12 | −593 | 286 | 13,004 |
| | Total | 79 | 105,802,087 | 98,026,081 | 12,289 | 490 | 3,690,599 | 2492 | [−]3324 | 11325 | 207,542,117 |
| | Water loss (Max) | −482 | −4485 | −5 | −5 | −107 | −227 | −7 | −954 | −313 | |
| | WS (Max) | 219 | 105,811,625 | 97,885,464 | 11,998 | 164 | 3,688,770 | 1962 | 808 | 10955 | |

Source: Katyaini and Barua (2017)

**1996-2005**




**2005-2014**




Source: Katyaini and Barua, 2017.