Economic accounting of green, blue, and gray water consumption in agriculture in India

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ABSTRACT

India is a water-stressed country and is projected to face an acute water crisis in the next 10 years (2020 to 2030). Due to hydrological limits, the utilizable water cannot be increased in the country. However, prudent policies can be framed to judiciously use water in different sectors of the economy. In particular, it is important to account for the green (rainwater), blue (irrigation), and gray (wastewater) water flow in the economy, especially in agriculture as it is the most water intensive sector in the country. The study estimates water saving from adopting alternate cropping patterns and irrigation technologies in 2030. In this context, four simulation exercises are conducted. These include shifting government procurement from staple to coarse cereals, upgrading irrigation technologies, adopting a water saving genomic variety of rice, and reducing irrigation subsidies in agriculture. The Input-Output framework is used to estimate inter-sector flows of water withdrawal and consumption in different sectors of the economy in 2030. Results reveal shifting government procurement from staple to coarse cereals saves 20.86 billion cubic meters (BCM) of blue water, however, trade-offs between green, blue, and gray water must be considered in the context of climate change. In comparison, adopting a genomic variety of rice saves 42.58 BCM of blue water. The highest blue water saving is estimated in upgrading irrigation technology and ranges from 588.06 BCM to 1445.54 BCM. Increasing the average irrigation cost by 30 percent saves 104.3 BCM of blue water, implying the importance of pricing incentives in water conservation in agriculture. To sustainably manage water in the 2020-30 decade, a mix of demand-side, technology, and pricing policies are required with a focus on water-stressed regions. The results provide the policymaker a platform to provide incentives to

reduce green, blue, and gray water consumption in agriculture and understand the trade-offs between these three categories of water consumption.

RÉSUMÉ

L'Inde est un pays soumis à un stress hydrique et devrait être confrontée à une grave crise de l'eau au cours des dix prochaines années (2020 à 2030). En raison des limites hydrologiques, la quantité d'eau utilisable ne peut être augmentée dans le pays. Toutefois, des politiques prudentes peuvent être élaborées pour utiliser judicieusement l'eau dans différents secteurs de l'économie. En particulier, il est important de prendre en compte les flux d'eau verte (eau de pluie), bleue (irrigation) et grise (eaux usées) dans l'économie, notamment dans l'agriculture qui est le secteur le plus gourmand en eau du pays. L'étude estime les économies d'eau qui résulteraient de l'adoption de modèles de culture et de technologies d'irrigation alternatifs en 2030. Dans ce contexte, quatre exercices de simulation sont réalisés. Ceux-ci comprennent le passage des marchés publics des céréales de base aux céréales secondaires, la mise à jour des technologies d'irrigation, l'adoption d'une variété génomique de riz économe en eau et la réduction des subventions à l'irrigation dans l'agriculture. Le cadre Input-Output étendu à l'environnement est utilisé pour estimer les flux intersectoriels de prélèvement et de consommation d'eau dans différents secteurs de l'économie en 2030. Les résultats révèlent que le passage des marchés publics des céréales de base aux céréales secondaires permet d'économiser 20,86 milliards de mètres cubes d'eau bleue. Toutefois, les compromis entre l'eau verte, bleue et grise doivent être pris en compte dans le contexte du changement climatique. En comparaison, l'adoption d'une variété génomique de riz permet d'économiser 42,58 milliards de mètres cubes d'eau bleue. La plus grande économie d'eau bleue est estimée dans l'amélioration de la technologie d'irrigation, et varie de 588,06 BCM à 1445,54 BCM. En augmentant le coût moyen de l'irrigation de 30 %, on économise 104,3 milliards de mètres cubes d'eau bleue, ce qui montre l'importance des

incitations tarifaires pour la conservation de l'eau dans l'agriculture. Pour gérer durablement l'eau au cours de la décennie 2020-30, il convient de combiner des politiques axées sur la demande, la technologie et la tarification, en mettant l'accent sur les régions soumises à un stress hydrique. Les résultats fournissent aux décideurs politiques une plate-forme pour inciter la production agricole à réduire la consommation d'eau verte, bleue et grise et pour comprendre les compromis entre les trois catégories d'utilisation de l'eau.

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LIST OF ABBREVIATIONS

APMC Agricultural Produce Market Committee

BCM Billion Cubic Meters

BOD Biological Oxygen Demand

CA Conservation Agriculture

CDP Crop Diversification Programme

CGE Computable General Equilibrium

CSA Climate Smart Agriculture

CSO Central Statistics Office

CSS Carbon Capture and Storage.

CWC Central Water Commission

DBT Direct Benefit Transfers

DT Drought Tolerant

FCI Food Corporation of India

FTT Future Technology Transformation

GDD Growing Degree Day

GWF Gray Water Footprint

HRD Hardy Rice

HYV High Yielding Varieties

IO Input-Output Framework

IOTT Input Output Transaction Table

IPPS Industrial Pollution Projection System

KVK Krishi Vigyan Kendras

LLL Laser Land Leveling

MOSPI Ministry of Statistics and Programme Implementation

MRIO Multi Regional Input-Output Model

MRT Mechanical Rice Transplanting

MSP Minimum Support Prices

NRRI National Rice Research Institute

NSO National Statistics Office

NSSO National Sample Survey Office

PMKSY-PDMC Pradhan Mantri Krishi Sinchayee Yojana-Per Drop More Crop.

RKVY Rashtriya Krishi Vikas Yojana

SDG Sustainable Development Goals

SRI System of Rice Intensification

SUT Supply-Use Tables

SWI System of Wheat Intensification

SWAT Soil and Water Assesment Tool

TCWU Total Consumptive Water Use

TPDS Targeted Public Distribution System

TSS Total Suspended Solids

WSI Water Stress Index

WUA Water User Association

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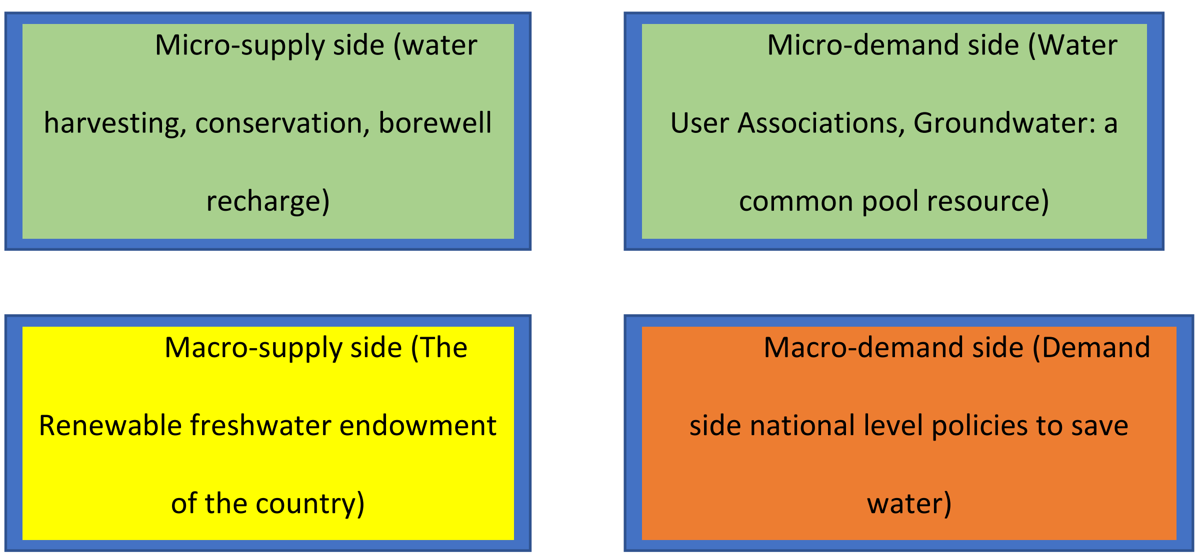
CHAPTER 1: INTRODUCTION

1.1 The Problem Statement

India is a water-stressed country. A country is water-stressed if the annual per capita availability of water is less than 1700 m^3 which is an indicator of the country's ability to meet freshwater demand. In the last 70 years, the per capita availability of water in India has decreased from 5200 m^3 in 1951 to 1545 m^3 in 2011 and is projected to decline to 1340 m^3 in 2025 (NITI Aayog, 2019; Gulati & Banerjee, 2016; GOI, 2018). Since water is a crucial resource for sustaining livelihoods, this decline in the per capita availability of freshwater resources in India is worrisome from a policy perspective (FAO,2020). The Government of India in 2019 in response to the water stress has embarked on a set of policies to conserve water. These include *Jal Shakti Abhiyan*, an initiative to accelerate water harvesting, conservation, and borewell recharge in 255 water-stressed districts (GOI, 2019). *Atal Bhujal Yojana* is another initiative to improve groundwater management through community participation in seven states (GOI, 2019). It is important to note these government policies in response to the water stress are either from a micro-supply side (*Jal Shakti Abhiyan*) or from a micro-demand side (*Atal Bhujal Yojana).* A micro-supply side policy boosts the supply of water through water recharge and conservation of water at the local level, whereas the micro-demand side reduces water demand through efficient water management at the local level. These two policy initiatives focus on addressing water management at the local level. There is no concrete policy framework and plan to address water stress and demand at the macro level. The National Water Policy developed in 2012 does not provide any robust macro-demand side policies to reduce demand for water (CWC, 2012). Macro-demand side policies reduce the aggregate demand for water through changing production patterns and adopting water-saving technology across different economic sectors. Due to hydrological and geographic constraints, the utilizable water resources in the country, i.e. macro supply side cannot be increased (CWC, 1993). Therefore, the only lacuna at the policy level is at the macro-demand side where national level demand-side policies need to be developed to address water stress in India.

Figure 1: The three policy categories to address water stress in India



A major user of freshwater resources in India is the agriculture sector. The sector uses 78 percent of the country's freshwater resources, the largest by any sector in the economy (Gulati & Banerjee, 2016; Sharma et al., 2018). Therefore, saving water in the agriculture sector is of utmost importance to address water-stress in India. The current cropping pattern is skewed towards the production of water-intensive staple cereal crops such as paddy and wheat (Gulati &

Sharma, 1995). The most common irrigation technology of canal irrigation used in India has a low water-use efficiency[1] (Gulati & Banerjee, 2016). Given the current water-intensive cropping pattern and inefficient irrigation technology used, there is scope for saving water in the country through the adoption of alternate cropping patterns and new efficient irrigation technologies.

Research Question: Can the adoption of an alternate cropping pattern (alternate to traditional rice-wheat crop rotation) and new irrigation technologies (alternate to the traditional canal irrigation) save freshwater in agriculture in India? If yes, to what extent is the freshwater saving?

Hypothesis: The adoption of alternate cropping patterns and new irrigation technologies saves freshwater (bluewater) in agriculture in India in 2030.

1.1.1 Climate Change

The projections for climate impact on agriculture for South Asia are quite alarming, particularly when weighed together with the adaptive capacity and a projected population growth of more than 2.3 billion and significant fall in agricultural productivity. In India, it is estimated that extremes in maximum and minimum temperatures are expected to increase under changing climatic condition, with few places get more rain while others remain dry (Pal et al., 2019). The

[1] Water Use Efficiency (WUE) is the volume of water at delivery points and inflow at entrance. Along a canal, WUE is termed conveyance efficiency

number of rainy days could reduce but the intensity of rain is expected to rise in most parts of India. According to projections, rice, which is India's major food crop, would suffer yield losses of 4-20% under irrigated conditions and 35-50% under rainfed conditions as early as 2030 (GOI, 2010).

1.1.2 Water Pollution

Agriculture is the major contributor to non-point source pollution of surface water and groundwater worldwide. The excessive use of fertilizers, herbicides, and pesticides have the most impact on groundwater quality (Damania et al., 2019). Almost 70 percent of India's surface-water resources are contaminated by biological, toxic, organic, and inorganic pollutants. Water pollution can affect human health due to polluted groundwater being used for drinking and cooking. In India, diseases like diarrhea, hepatitis, and occasional outbreaks of typhoid and cholera are associated with polluted groundwater due to agricultural run-offs (Chakraborty & Mukhopadhyay, 2014).

In the context of climate change which leads to uneven rainfall patterns and water pollution due to agriculture, in addition to estimating freshwater (also termed blue water) savings, there is a need to estimate green water[2] and gray water saving[3] in agriculture (Mekonnen & Hoekestra, 2011). This gives the policymaker a wholistic picture of water use in agriculture and provides an understanding of the trade-offs between the three categories of water use (blue

[2] Green water refers to the amount of rainwater consumed in the agriculture sector

[3] Gray water refers to the volume of freshwater that is required to assimilate the load of pollutants in agriculture based on existing water quality standards

water, green water, and gray water) to any change in cropping patterns. Therefore, it is important to study water use in agriculture based on the three categories to conserve the country's limited renewable freshwater resources, to increase the adaptive capacity of agriculture to changing rainfall patterns and reduce wastewater release from agriculture.

1.2 Water Scenario in India

India is a water-stressed country and soon is going to be a water-scarce country. A country is termed water-stressed if the annual per capita availability of water is less than 1700 cubic meter (m^3) and water scarce if the same is less than 1000 $m^{3.}$ In the last 50 years, per capita availability of water of India has decreased from about 5200 m^3 in 1951 to 1545 m^3 in 2011 and is projected to decline further (Gulati & Banerjee, 2016).

Table 1: Annual per capita availability of water (m^3) in India (in Billion Cubic meters) (forecast)

Year	Annual per capita availbility of water (m^3)	
1951	5200	
2001	1816	
2011	1545	< 1700 (water stressed)
2025	1340	
2050	1140	

Source: Gulati & Banerjee (2016)

For comparison purposes: Canada, has the most renewable freshwater per capita each year: 103,899 m^3 per capita compared with Brazil, at 43,756 m^3 per person (Statistics Canada, 2010). The bulk of water resources in India are used for agricultural purpose ,78 percent of the water is used in the irrigation sector, and a relatively small proportion is used for industrial, household and other purposes (Gulati & Banerjee, 2016). Surface-water and groundwater are the two main sources of water in India. According to the estimates of the Central Water Commission (CWC, 1993), the average annual water resources potential in the country is 1869 billion cubic meters (BCM). Due to topographic, hydrological, and other constraints, the utilizable water is estimated at 1123 BCM which comprises 690 BCM of surface water and 433 BCM of replenishable groundwater resources. The stage of development[4] of groundwater in the country is increasing between 2004 and 2013, vast tracts of land mainly in the western part of the country have increased their stage of development of groundwater from 0-50% to 50-100% clearly indicating the stress endemic to the system (Gulati & Banerjee, 2016). The stage of groundwater development in few western states of India are: Maharashtra (53%), Gujarat (67%), Madhya Pradesh (57%). Since a major proportion of total irrigation comes from groundwater, the depleting reserve of groundwater is affecting the total area of cultivated land and food production in the country (Gulati & Banerjee, 2016). India has 18 percent of the world's population but only 4 percent of world's freshwater. An average of 4,000 billion cubic meters of precipitation is received in the country every year. However, only 48 percent of it is utilizable from the surface and groundwater bodies. The actual water used is even lower, around 18-20 percent of the total rainfall received. Reasons for this low water use include inadequate water conservation infrastructure and inappropriate water management. The country's annual rainfall is around 1183 mm, out of which 75 percent is received

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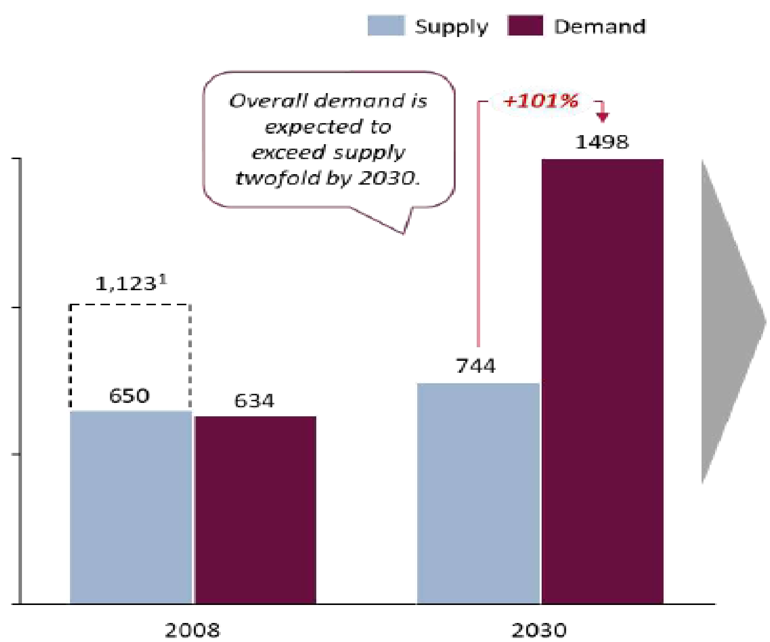
4 Stage of development is defined by the total draft of groundwater for all purposes as a percentage of the net annual groundwater availability

in a short span of four months during the ‘monsoon’ season (July to September). This results in run-off calling for watershed development and irrigation investments in the country (Dhawan, 2017).

According to the NITI Aayog (2019), the projected overall water demand in India is expected to increase over total supply twofold by 2030 (figure 2).

Figure 2: Demand and Supply of water in India (in Billion Cubic Meters) (forecast)



Source: NITI Aayog (2019)

Water stress in India is primarily due to three reasons: Firstly, inefficient use of water in the agriculture sector in India due to perverse incentives for water intensive crop production. One such inefficiency could be seen in the production of cereals which are a dominant part of Indian diets and contribute to 50 percent of the total water used in agriculture in India. Between 2005 and 2014, there has been a shift in cereal production away from Kharif (rainy season) to Rabi (dry season) leading to higher dependence on the limited surface and groundwater resources (Kayatz et al., 2019). Staple cereals such as paddy and wheat have large total consumptive water use (TCWU)(km^3)/year of 206.2 and 82.7, in comparison to other crops such as Maize and Chickpeas which have a TCWU(km^3)/year of 18 and 10.7 (Sharma et al., 2018). Rice consumes 3,500 litres of water for a kilogram of grain produced. Since agriculture uses 78 percent of the country's freshwater resources, it is of prime importance to optimize crop water use through incentives for the production of less water-intensive crops. Secondly, rising water demand from domestic and industrial sectors is leading to an increase in competition for already stressed local freshwater resources. Thirdly, a rising population implying an increase in household demand for water and the need to produce more food is putting pressure on freshwater resources. The population of India is likely to be 1.6 billion by 2050, resulting in increased demand for water, food and energy. Therefore, there is a need to judiciously manage water at a national scale, and develop policies to conserve and use water efficiently in the country (Gulati & Banerjee, 2016; FAO, 2020). In this context, it is important to understand the historical use of water in India, especially in the agriculture sector to recommend current policy changes.

1.3 Public Irrigation in India in the Colonial Era (Pre-1945)

Canal Irrigation expanded rapidly in British India in the last years of the nineteenth century (Shah, 2011). Colonial investment in canal irrigation consistently yielded 8-10 percent return on investment until 1945 (Whitcombe, 2005). The study estimates that between 1912-13 and 1945-46, irrigation investments of the Government of British India returned a net profit increasing from 8.3 percent on productive works and 4.5 percent on all major works in 1912-13 to 12.8 percent on productive works 7.2 percent on all major works in 1945-46. Revenue management in the colonial era was through an elaborate but low-cost irrigation administration appropriate for large irrigation systems. Hardiman (2002) argues that due to the compulsory irrigation tax in the colonial era, farmers were forced to grow commercial crops to generate cash in order to pay the irrigation tax. Given the elaborate and compulsory irrigation tax, operation and maintenance of irrigation canals were well financed and deferred maintenance due to inadequate revenue was minimal. The colonial government maintained a large irrigation bureaucracy which managed water distribution and collected a fee on water use on all lands deemed to be irrigated.

1.4 Public Irrigation in India Post-Independence (Post-1945)

The finances of canal irrigation in post-colonial India are in stark contrast to that of the colonial era. The Central Water Commission (2006) reported that the water fee realized by all major and medium irrigation projects was 8.8 percent of the 'working expenses' during 1993-97 and the ratio had declined further to 6.2 percent during 1998-2002 compared to 2.5 to 3 times of water expenses around 1900. It is estimated that 19,000 crores should be provided for the maintenance of irrigation infrastructure but only Rs 2820 crore was spent on maintaining these public irrigation assets; water fee recovered from irrigators was all of Rs 652 crore, less than 10 percent of the 'working expenses' of Rs 8250 crore. A primary reason for the poor performance of canal irrigation as a commercial venture was that irrigation charges were drastically reduced, and even these were increasingly uncollected (Shah, 2011). The table below shows the substantial reduction in water fees as a percentage of capital investment and working expenses from the colonial period to the early 2000s.

Table 2: Water fees as a percentage of capital investment and working expenses, AD 1900 compared with AD 2000

	Major and medium systems in British India (1902-3)	Major, medium, and multi-purpose irrigation projects in India (1977-78)	Major, medium and multi-purpose irrigation projects in India (1986-87)	Major and medium irrigation systems in India (2001)
Water fees collected as percent of capital investment	10 percent	1. 43 percent	0.3 percent	0.2 percent
Water fees collected as percent of working expenses	280 percent	45 percent	20 percent	7.9 percent

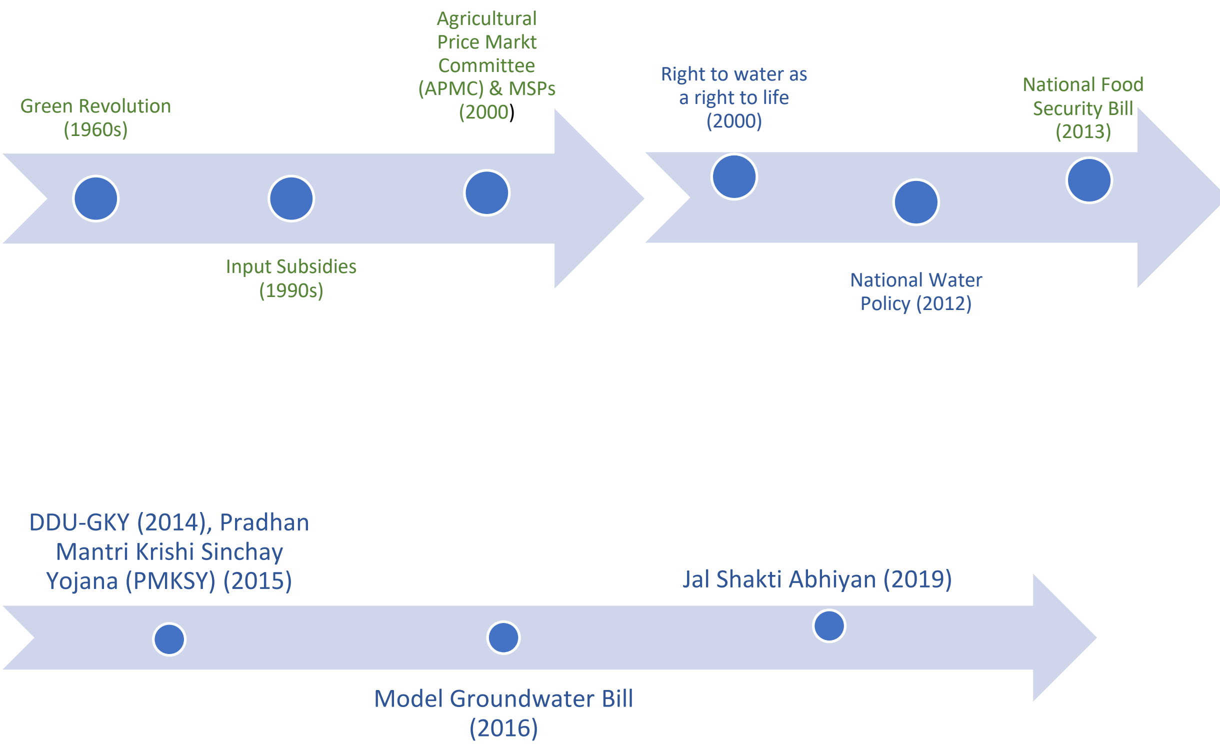
Source: Shah (2011)

The Indian irrigation system post-independence had two structural problems. Firstly, most irrigation canals built were overdesigned where the costs exceeded the benefits. Secondly, there was unauthorized over-appropriation of water by head reach farmers for growing crops that irrigation planners had never expected them to grow (Shah, 2011). Most irrigation systems in post-Independence India were designed for protective irrigation as a supplementary source of water over and above rainwater over large areas. According to Jurriens et al. (1996), the designers of these irrigation systems assumed that farmers would stick to subsistence production of food crops when supplementary irrigation is made available to them. However, the cropping pattern post-Independence did not always conform with the irrigation system created. For example, in Karnataka's Tungabhadra canal, systems designed for irrigating dry crops collapsed into rice irrigation systems and the original purpose of protective irrigation over large areas was defeated (Mollinga, 2003). There has been a decline in the performance of the Indian irrigation administration with minimal focus on operating and maintenance of existing systems. Along with the decline in the performance of surface irrigation is the emergence of a vast pump irrigation economy that has become all too common where pumping water from any proximate source - ground or surface - takes precedence over orderly gravity flow of irrigation (Shah, 2011).

1.5 Historical Timeline of Policies Related to Agriculture, Water Supply, and Irrigation Systems Post Green Revolution

Major policies are needed to improve the performance of the irrigation system in India. In this context, it is important to discuss the evolution of agri-food and water policies and their impact on water use in India post green revolution.

Figure 3: Evolution of agri-food and water policies in India



In order to address food sovereignty in the country, the Government of India, in the decade of 1960 embarked on a set of reforms to make agriculture productive. This set of reforms, often called the ‘Green Revolution’ introduced high yielding varieties (HYVs) of seeds, fertilizers, and modern irrigation techniques in Indian agriculture. This increase in agricultural productivity and expansion of irrigation increased the demand for water in the country (Pingali, 2012). Given the large proportion of the population employed in agriculture (41.4 percent in 2021), and to increase farmers’ income, policymakers in the decade of 1990 provided subsidies to farmers, especially relating to inputs such as fertilizers, water, and electricity. These subsidies in the following decades have led to perverse incentives for input use, especially irrigation water, which has been exploited by farmers due to a minimal input cost. In addition, the creation of the Agricultural Produce Market

Committee (APMC) and Minimum Support Prices (MSPs) for staple blue water intensive crops, paddy and wheat, have led to inefficient allocation of irrigation water in the country (Pingali, 2012). The National Food Security Bill (2013) guaranteed 2/3 rd of the population access to subsidized food grains procured by the government through the Targeted Public Distribution System (TPDS). This bill has secured the procurement of water-intensive crops, paddy and wheat, for provision at affordable prices to eligible ration card holders (NFSA, 2013). In 2020, the Government of India passed the Farmers' Produce Trade and Commerce Act (Promotion and Facilitation) Bill. This bill opened up direct trading of agricultural products between farmers and private players with the provision of electronic trading, thus providing an alternative to the state regulated APMC trading markets (*mandis*) (GOI, 2020). Trading outside these *mandis* incentivizes companies to invest in modern farming techniques and invest in agricultural infrastructure thus facilitating remunerative prices for farmers (Gulati, 2021; Kaur & Tiwari, 2020). However, due to pressure and reluctance from farmer unions to adopt direct trading with private players, the bill was scrapped a few months after the initial proposal.

To understand the demand for water in the country, it is equally important to study agri-food as well as water policies. The National Water Policy (2012) developed a framework for water resources to be governed from an integrated perspective considering local, regional, and national contexts. Given the limits on enhancing the availability of utilizable water resources and increased variability in supplies due to climate change, future water scarcity will depend on demand management (CWC, 2012). Hence, the policy gives priority through a.) evolving an agricultural system which economizes on water use and maximizes value from water, and b.) bringing in maximum efficiency in the use of water. In 2014, the government started separating electricity feeders for agriculture, reducing incentives for excess irrigation (NITI Aayog, 2019). A major policy initiative undertaken by the Government of India in 2015 is the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY). The main objective of PMKSY is to achieve convergence of investments in irrigation at the field level, expand cultivable area under assured irrigation, improve on-farm water use efficiency to reduce wastage of water, enhance the adoption of precision irrigation and other water saving technologies, enhance recharge of aquifers and introduce sustainable water conservation practices by exploring the feasibility of reusing treated municipal wastewater for peri-urban agriculture and attract greater private investment in precision irrigation systems (GOI, 2019). The four components of PMKSY are listed in the table below.

Table 3: The four components of Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)

PMKSY Component	Purpose
Accelerated Irrigation Benefit Program	Loan assistance to states complete major-medium irrigation projects
PMKSY (*Har khet ko pani)*	Increase the cultivable land under assured irrigation
PMKSY (More crop per drop)	Improving water use efficiency of irrigation techniques
PMKSY (Watershed development)	Harvesting rainwater, management of run-off water, improving soil-moisture conservation

Source: GOI (2019)

In 2016, the government drafted a model groundwater bill to convert groundwater from private property to a common pool resource. The bill seeks to place responsibilities on the groundwater user: for example, its efficient use, prevention of pollution, replenishing and recharging groundwater (Vishwanath, 2016). In 2019, the government in response to water stress across the nation launched the *Jal Shakti Abhiyan*, a water conservation campaign to recharge water in the most water stressed districts in the country. Intervention areas included: Water conservation and rainwater harvesting, renovation of traditional and other water bodies, reuse and recharge structures, watershed development, and intensive afforestation (GOI, 2019). The government has taken various micro-initiatives to conserve water across the country, however policies directed towards the treatment of agricultural graywater needs more attention in water policy in the nation to reduce demand on existing water resources.

1.6 Policies Directed Towards the Treatment of Agricultural Graywater

Agricultural runoffs affect groundwater and surface water resources due to the presence of fertilizer and pesticide residues. Fertilizers increase the nutritional content of water sources, allowing organisms that may be a disease vector or algae to multiply more in water.

The National Water Policy (2012) aims at meeting challenges that have emerged in the development and management of water resources, including non-point source water pollution due to the agricultural and related sectors (CWC, 2012; Chakraborty & Mukhopadhyay 2014). Some features of the policy relating to agricultural water-pollution are as follows:

a. Both surface water and groundwater should be regularly monitored for quality

b. Effluents should be treated to acceptable levels and standards before discharging

c. Principle of 'polluter pays' should be followed in management of polluted water

d. Necessary legislation is to be made for the preservation of existing water bodies by preventing encroachment and deterioration of water quality

The National Environment Policy (2006) has also outlined a plan to address water pollution in India and takes account of groundwater pollution in pricing policies of agricultural inputs, especially pesticides, and dissemination of best management agronomy practices such as Integrated Pest Management and use of biodegradable pesticides (GOI, 2006). Chhabra et al. (2010) indicate that leaching nitrogen losses in kharif and rabi rice dominate ammonia volatilization loss in Indo-Gangetic plain states. Nitrogen loss through leaching in kharif and rabi rice is of the order 34.9 percent and 39.8 percent of the applied N-fertilizer in the Indo-Gangetic plain. The high leaching intensity in coarse textured sand and sandy loam soils of Haryana and Punjab result in downward movement of leached nitrogen with percolating water leading to nitrate pollution of ground water. Therefore, it is important agricultural policies address the reduction in the use of nitrogenous fertilizer as a major source of non-point source pollution from agriculture since nitrogen use efficiency by crops seldom exceeds 50 percent. Another factor, in addition to the generation of gray water affecting agricultural water supply, is Climate Change which affects precipitation patterns, field level temperature, and soil moisture content.

1.7 Climate Change and Its Role in Worsening Agricultural Water Supply

Climate Change and the associated change in precipitation patterns has affected agriculture in India in recent decades impacting social and economic indicators in the sector. Carleton (2017) has demonstrated the association between crop damaging temperatures and farmer suicide rates in India. It is shown that high-precipitation years have a strong lagged effect in which heavy rainfall today causes lower farmer suicide rates in 2 to 3 years. Results show that growing season rainfall by 1 cm is associated with a decrease of 0.8 deaths per 100,000 lowering the suicide rate by 7 percent on average. In this context, it is important to understand the impact of changing precipitation patterns on water-supply in agriculture which further impacts agricultural yields and incomes.

Zaveri et al. (2016) ran an econometric model estimating the effect of total precipitation, rainfall distribution, and seasonal GDD (growing degree day) on seasonal, crop-wise irrigation decisions for six major crops in India which make up 80 percent of India's crop production table across districts in all major agricultural states in India from 1970 to 2005. Results show that precipitation plays a larger role than GDD in driving changes in irrigated area. The number of rainy days directly affects kharif (wet) season crop irrigation as too many dry days during critical crop stages can reduce yields or lead to crop failure. Supplemental irrigation in the wet season, largely relying on stored monsoon rainwater from previous years can help overcome this uneven distribution of rainfall but may not be able to offset decreases in total precipitation. There is a rise in irrigated areas for most wet season crops in response to fewer rainy days. Also, in the irrigation intensive rabi (dry) season, the capacity to irrigate rests on the amount of monsoon rainfall collected in surface and groundwater storage. Therefore, any decrease in precipitation during the previous monsoon season significantly reduces the area of crops such as wheat that are irrigated. The results of the study demonstrate that farmers assess the supply of rain during the monsoon season to make decisions about increasing or decreasing irrigated areas for different crops. Thus, there is a significant link between monsoon rainfall and irrigated areas in India.

Fishman (2018) studied the impact of rainfall variability on agriculture and water demand. The study used daily rainfall and crop yield data from across India from 1970 – 2003 and showed that irrigated locations experienced much lower damages from increasing precipitation variability implying that expansion of irrigation could protect India from climate change in the future. Expansion of irrigation areas can be adopted as an adaption technique in agriculture in the context of climate change. Under current irrigation practices, the use of irrigation water can mitigate less than a tenth of the climate change impact. It is shown how the depletion of groundwater resources constrains the capacity of India's agriculture to adapt to increasing precipitation variability. The analysis of the panel dataset shows that if India continues to deplete its groundwater resources, the impacts on agriculture of increased precipitation are likely to increase by half. In understanding the current impact of climate change on water resources in India, it is important to focus on the hydrology of various regions. One such study by Kumar et al. (2017) analysed the impact of climate change on water resources of the Upper Kharun catchment in Chhattisgarh, India using the Soil and Water Assessment Tool (SWAT). The study shows that changes in water balance components are a result of the interaction between climate change and land use changes. The authors demonstrate that the Upper Kharun Catchment features considerable population growth and dynamic changes in irrigation practices (extension, and intensification) for meeting increased food demand. It is expected that the impact of future climate change will be severe in the region as the economy largely depends on agriculture. Even with the uncertainty about the precise magnitude of climate change and its possible impacts, the study recommends measures must be taken to prevent or minimize the impacts of climate change on surface and ground water availability.

Therefore, in order to prepare for future agricultural yield shocks, it is important to understand the projected impacts of climate change on agricultural water supply. Studies indicate that Climate Change has the potential to affect agricultural water supply in India in the future (Mall et al., 2005; Pal et al., 2019). There are two mechanisms through which this occurs:

a. Uneven seasonal precipitation patterns and increased surface run-off in different regions of the country

b. Soil moisture content is affected by an increase in temperature and evapotranspiration rates (i.e. crop consumptive water use) increasing in drier parts of the country

It is forecasted that precipitation in India would be concentrated in the monsoon season (June to September) implying an increase in rain over fewer days causing increased frequency of floods and direct loss in surface run-off resulting in reduced groundwater recharging potential. Winter precipitation during December - February is forecasted to decrease (Mall et al., 2005). A study forecasts an increase in monsoon precipitation by 10-15 percent, decline in winter precipitation by 5-25 percent, and an increase in annual precipitation by 7-10 percent by the end of this century in India (Lal et al., 2001). Agricultural demand for water is considered more sensitive to climate change in comparison to other users of water such as domestic and industry. This is because of the agriculture sector's dependence on field-level (temperature and precipitation on agricultural fields) climate for its production. Increased dryness may lead to increased demand for water due to an increase in evapotranspiration, however, this demand could be reduced if soil-moisture content increases at certain times of the year. The projection shows that most irrigated areas in India in 2025 would require more water than in the preceding decades (Mall et al., 2005). However, when analysing the impact of climate change on water resources in agriculture in India, it is important to account for regional disparities. Some studies show that river basins located in drier regions in India are more sensitive to climate change. A study analysing the impact of climate change on arid regions of Rajasthan projects an increase of 14.8 percent in total evapotranspiration demand with an increase in temperature (Goyal, 2004). The study concluded that a marginal increase in evapotranspiration demand would have a larger impact on the resource-poor, arid ecosystem of the state of Rajasthan.

1.8 Research Objectives

In the context of water scarcity across the nation, and the water intensive nature of the agriculture sector, agricultural water demand needs to be estimated based on the current and projected demand of agricultural commodities Therefore, a core objective of the thesis is to estimate water demand in the context of changing agri-food policies and agricultural technology especially relating to irrigation which has the highest scope for saving water. Given the increasing generation of agricultural wastewater in recent decades, and observed changing precipitation patterns associated with climate change, the objective is to estimate the three categories of water demand: green water, blue water, and gray water.

In particular, the study has the following research objectives:

1. Estimate total water demand in agriculture in India for 2015 and 2030
2. Estimate direct and indirect impact on total water demand of domestic and exported agricultural commodities in India for 2015 and 2030
3. Estimate green, blue, and gray water demand of agricultural commodities in India in 2015 and 2030
4. Evaluate the impact of domestic agri-food policies on demand for water in India in 2030
5. Evaluate the impact of change in agricultural technology on demand for water in India in 2030

1.9 Structure of Thesis

The following is the outline of the thesis. Chapter 2 reviews the relevant literature estimating water demand in agriculture, and the contribution of historical agri-food policies, climate change, and domestic wastewater policies to the current water crisis in the country. In particular, there are sections on the impact of current agri-food policies on blue water demand, current and future impact of climate change on green and blue water demand, and the potential of using agricultural gray water generated as an alternate source of irrigation. Chapter 3 consists of describing the Input-Output methodology used in the study as well as how the water data has been incorporated in the static 2014-15 Indian Input-Output model. The sectoral demand growth rates used to project demand in 2030 is obtained from the dynamic E3-India model. It is important to note, that the Indian Input-Output model used has a disaggregated agriculture sector with 16 agricultural commodities, in order to focus on green, blue, and gray water demand in the sector. Chapter 4 discusses the development of scenarios in the model. The four scenarios simulated are discussed in comparison to the baseline 2030. Chapter 5 is a discussion of the results with a focus on the regional implications of policy changes simulated in the scenarios. Chapter 6 is the conclusion section which presents policy recommendations based on the thesis, and areas for future research on the topic.

1.10 Novelty of the Research

This research is the first of its kind in the context of India to include a ‘water commodity’ in the IOTT model, expressed in physical terms and segregated into three forms: green, blue, and gray water. Another novelty is the use of the dynamic E3-India model to make sectoral growth demand projections to 2030 for the different sectors in the model. The policy scenarios simulated are based on the most recent literature and reports recommending water saving policies in agriculture, distinguishing itself from past studies on the topic.

CHAPTER 2: LITERATURE REVIEW

Globally, water resources are under stress due to the imbalance between supply and demand of freshwater. The annual amount of freshwater per person has declined by more than 20 percent in the last two decades. The need to sustainably manage water for all is reflected in the Sustainable Development Goals (SDGs) 2030. In particular, SDG 6 which ensures availability and sustainable management of water and sanitation for all. The growing concern over water scarcity and misuse is reflected more specifically in SDG target 6.4, which calls ensuring **sustainable water withdrawals and supply of freshwater and increasing water use efficiency across different sectors in an economy** (FAO, 2020).

In this context, various studies have estimated water consumption and withdrawal in an economy in different regions and countries. Velazquez (2006) analyzes sectoral water relationships in the region of Andalusia in Spain using an Input-Output Model. It has been found that the region has been characterized by considerable water shortage, but has gradually specialized in sectors whose demand for water is really high. The study suggests alternative policies to aim at better management of the natural resource. Zhang & Anadon (2014) quantify China's inter regional virtual water trade and water footprint at a provincial level using a Multi-Regional Input-Output Model (MRIO). Virtual water trade embodied in international trade of agricultural products has received much attention, however, domestic virtual water trade embodied in interregional trade for all products has not been widely studied. This study analyzes local water withdrawals and consumption on domestic trade. The study found China has a north-to-south net virtual water trade pattern which is roughly the opposite of the distribution of its water resources implying water-use inefficiency. Boudhar et al. (2017) using an Input-Output Model of water analyzed the relationships between economic sectors and water resource use in Morocco (direct water use) as well as intersectoral water relationships (indirect water use). The study shows that agriculture and allied activities exhibit high direct water use. On the other hand, secondary and tertiary sectors display low direct water use but high indirect use of water. Chapagain, Geetha, & Fukushi (2020) is the first study to analyze manufacturing related direct and indirect water pollution in Nepal. The study determined manufacturer's direct discharges of Biological Oxygen Demand (BOD) and Total Suspended Solids (TSS) using the World Bank's Industrial Projection Pollution System (IPPS) method. The study found three industries – food, beverages, and paper, paper products, and printed materials accounted for 80 percent of BOD discharges and Nepal's basic metals sector accounted for 95 percent of TSS discharges. The study identified polluting sectors based on their direct emission intensity guiding policymakers to reduce manufacturing direct water pollution in Nepal. Carpentier (1994) analyses industrial sectors and final demands most responsible for particular types of residual discharge and resource use in Canada. The model estimates national erosion, pesticide and fertilizer use, air and water pollutants, solid waste, and water use associated with specific economic activities in Canada. Different scenarios of increasing final demand by 1 million dollars were analyzed using an economic-ecological Input output model. Chakraborty and Mukhopadhyay (2014) estimate water pollution generated by different industries and various economic activities of the Indian economy using an Input-Output framework. The authors constructed a water pollution coefficient matrix involving different types of water pollutants. The study estimated the total amount of water pollution generated directly and indirectly in different sectors and activities, and also calculates India's water pollution in foreign trade. The results show that the amount of total pollution generation per unit is significantly higher than direct pollution generation coefficients for all industries. This study estimates 'gray water' or 'water pollution' of different sectors including agriculture.

Incorporating physical units of water in an extended IO model framework is based primary on the rationale of maintaining critical stocks of freshwater resources below which has implications on water stress and scarcity in the region. In this context, Irwin et al. (2016) demonstrate the importance of strong sustainability which is based on the belief that some capital stocks are non-substitutable, implying that sustainability requires maintenance of critical stocks at specified levels. The authors also emphasize the concepts of tipping points and resilience when it comes to understanding biophysical dynamics and economic decisions and argue in systems with multiple stable states, the cumulative effect of economic decisions can push the system away from a stable attractor, resulting in a dramatic shift in the possible set of future actions. The moment marking this transition to instability is often termed a tipping point. Ecological resilience can be defined as the capacity of a system to remain within a given regime. The greater the resiliency of a system, the larger the shock it can absorb without undergoing a regime shift.

In this context, the present study provides a more comprehensive picture of the current structure of physical water accounting by including different water types which can be segregated into green water (rainwater), blue water (freshwater), and gray water (polluted water). It differs from the present literature by estimating the three types of water used in agriculture using the Input Output table in the context of India.

Mekonnen & Hoekestra (2011) analyse the global water footprint (green, blue, and gray) of crop production for the period 1996-2005. The largest water footprint is for rubber, gums, and waxes, followed by nuts, and then by spices. Results show that rice, wheat, and maize are the cereal crops with the largest water footprint globally. India has the largest water footprint for crop production in the world followed by China between 1996 - 2005. In conclusion, the study shows that the global water footprint of crop production for the period 1996-2005 was 7404 billion cubic meters (BCM) per year. The large fraction of green water (78%) confirms the importance of green water in global food production. The fraction of blue water is smaller (12%), however, the regions where blue water footprints are large are often arid and semi-arid regions where water scarcity is high. The share of gray water footprint is relatively small as well (10%), but this is a conservative estimate, because the analysis only includes the required assimilation volume of leached nitrogen fertilizers only, leaving out other pollutants such as phosphorus and pesticides. Therefore, given the importance of the water footprint of crops in agriculture, there is a need to discuss the three types of water consumption (green, blue, and gray) in agriculture in India.

2.1 Blue Water Consumption in Agriculture

Blue water refers to the volume of surface and groundwater consumed (evaporated) as a result of the production of agricultural commodities. It is expressed in blue water volume per unit of product (m^3 ton^{-1}) (Mekonnen & Hoekestra, 2011). Major blue water crops in India include rice and wheat. Rice, a global staple crop receives 34-43 percent of the world's irrigation water. Chapagain and Hoekestra (2011) estimated that the global water footprint of rice production is 784 km^3/year with an average of 1325 m^3/ton which is 44 percent of the blue water in agriculture. In India, rice irrigation alone accounts for about 28 percent of the total gross irrigated area in the country and almost all publicly financed major and medium surface irrigation projects developed, blue water resource are largely appropriated by rice and sugarcane. Another staple crop wheat responds favorably to optimal irrigation and unlike rice cannot withstand excessive water application. In water stressed states like Punjab where 80 percent of the total cropping area is under rice and wheat rotation, the threat posed by the water-intensive kharif rice crop to the groundwater status affects availability of water for the winter (rabi) wheat crop reducing potential yield (Sharma et al., 2018). Hence, there is discourse to shift to an alternate cropping pattern in India which is less blue water intensive in comparison to the current rice and wheat rotation system (Bhat et al., 2016). Since the Green Revolution, cereal production in India has shifted away from traditional cereals such as millet and sorghum, and towards higher yielding varieties of staple cereals such as rice and wheat (Kayatz et al., 2019). Consumption patterns in India have also shifted to more rice and wheat and less coarse cereals such as millet, maize, and sorghum. Authors have recommended increasing consumption of nutrient-dense coarse cereals in Indian diets as a large proportion of the population suffers from micronutrient deficiencies (DeFries et al., 2018; Rao et al., 2018). A switch in production from rice and wheat to maize, sorghum and millet has the potential to reduce blue water requirements for cereal production in India. Since India relies mainly on domestic production of cereals, a change in cereal cropping pattern can impact:

a) Nutrition at the consumer level: Trade-offs between macronutrients (calories, protein) and micronutrients (zinc, iron)

b) Land use efficiency: The efficiency in terms of yield per hectare

c) Blue water use: Crop consumptive water use or evapotranspiration rate

Davis et al. (2019) show that replacing rice with other cereals such as millets and sorghum for which local knowledge of production exists can reduce blue water use and increase nutritional yield. The study finds that the historical growth in wheat production during the rabi (non-monsoon) season has been the main driver of the country's increased consumptive irrigation water demand. It is also found that rice is the least water-efficient cereal for the production of key nutrients, especially for iron, zinc, and fiber. Replacing rice in districts with alternative cereals (maize, finger millet, pearl millet, or sorghum) with a lower irrigation (blue) water footprint, the study shows that it is possible to reduce irrigation water demand by 33 percent and improve production of protein, iron, and zinc with only a modest reduction in calories. In the present decade, efforts at altering cereal production should focus on those states where farmers are able to achieve high yields for alternative cereals avoiding any undesirable outcome for nutrient production particularly for calories. The trade-offs between nutrient supply (macronutrients and micronutrients) and water-use efficiency can be eliminated by focussing agricultural research on improving yields of these alternative cereals.

In the context of blue water use, it is also important to understand the interaction between different cropping seasons. In India, there are primarily two cropping seasons: a.) *Kharif* or the monsoon season (June to October) agriculture is dependent primarily on rainwater (green water) b.) *Rabi* or winter season (October to April) agriculture is primarily dependent on blue water (groundwater and surface water) for irrigation. Gupta et al. (2020) show that storage and use of rainwater for crop production can reduce pressure on blue water resources in the rabi season.

An example is conservation agriculture which leads to efficient green water management in sparing blue water resources for other uses. Conservation agriculture practices in many parts of the world are built on ecological principles making land use more sustainable and increasing resource use efficiency. The practice is based on three principles which are linked and must be considered for appropriate design, planning and implementation process (Bhan & Behera, 2014):

a.) **Minimal mechanical soil disturbance**: Soil biological activity produces very stable soil aggregates as well as various sizes of pores, allowing air and water infiltration. This process is called 'biological tillage' and is not compatible with mechanical tillage in conventional agriculture. The biological soil structuring process disappears with mechanical soil disturbance. Minimum soil disturbance provides/maintains optimum proportions of respiration gases in the rooting-zone, moderate organic matter oxidation, porosity for water movement. The retention and release limits the re-exposure of weed seeds and their germination.

b.) **Permanent organic soil cover**: A permanent soil cover is important to protect the soil against effects of exposure to rain and sun and to provide micro and macro-organisms in the soil with a constant supply of 'food'. The soil cover also alters the microclimate in the soil for optimal growth and development of soil organisms including that of plant roots. As a result, various parameters of interest improve, such as soil aggregation, soil biological activity, soil biodiversity, and carbon sequestration.

c.) **Diversified crop rotations**: The rotation of crops is not only necessary to offer a diverse 'diet' to the soil microorganisms but also for exploring different soil layers for nutrients that have been leached to deeper layers that can be 'recycled' by the crops in rotation. Furthermore, a diversity of crops in rotation leads to a diverse soil flora and fauna. Minimal rates of build-up of population of pest species and biological nitrogen fixation is improved due to cropping sequence and rotations involving legumes.

An important characteristic of conservation agriculture is improvement in water and nutrient-use efficiency. Studies indicate that zero-till planting and particularly in laser-leveled and bed-planted crops reduces water consumption by 20 to 30 percent (Bhan & Behera, 2014). It is also seen that higher soil water content under no-till than under conventional tillage indicates reduced water evaporation during the preceding period. The authors found that across growing seasons, soil water content under no-till was about 20 percent greater than under conventional tillage. The retention of soil-moisture in conservation agriculture is a key component to increasing efficiency of water-use in agriculture (Bhan & Behera, 2014; De Vita et al., 2007).

A major area of reform in water conservation is techniques and systems used to grow rice and wheat in the country. Bhatt et al. (2021) review sustainability issues in the rice-wheat cropping system in the northwest Indo-Gangetic plains of South Asia. The most common varieties of staple crops grown in this region are puddled transplanted rice (Oryza sativa L.) followed by intensively tilled wheat (Triticum aestivium L.). This combination of crops consumes high amounts of water, nutrients, and energy, resulting in increased production costs and increased emissions of greenhouse gases. There is a need to change the tillage and crop establishment practices in the conventional rice-wheat systems by replacing intensive tillage in wheat and puddling and flooding in rice for achieving the overall sustainability of this cropping system in the region. In this context, the authors recommend water saving technologies such as Laser Land Levelling (LLL), Mechanical Rice Transplanting (MRT), and short duration rice cultivars.

Water conservation techniques have gained importance in staple crop production over the years (Biswas & Das, 2021; Thakur et al., 2022). An agroecological strategy, the System of Rice Intensification (SRI) has demonstrated it can raise rice production by 25-50 percent and in some cases more than 50 percent while lowering production costs and raising farmer incomes (Thakur et al., 2022). Higher yield is achieved by using 25-50 percent less water, and SRI practices reduce net emission of greenhouse gases from paddy fields while reducing crops' vulnerability to the hazards of climate change. The advantages of SRI can be extended to crops beyond rice, like wheat, millet, and sugarcane. It is important to note SRI is not variety dependent, it gives better results with some varieties but can enhance the production of whatever varieties are suited to local conditions and preferred by consumers and the market.

Biswas & Das (2021) review the system of wheat intensification in the context of economic returns and sustainability of input resource use. The System of Wheat Intensification (SWI) involves different components such as Land Preparation, Seed Selection, Sowing Of Seeds, Irrigation, Manure and Fertilizer application, Weeding, and Harvesting. The benefits of adopting SWI range from requiring less water for wheat cultivation (20 – 30 percent) as compared to conventional practice to a high economic benefit for small scale farmers. SWI has proven to be more effective than the conventional practice under different climatic conditions. However, the technique requires more confirmation of results through various crop cutting experiments at different locations and situations. To provide farmers' with incentives to adopt this wheat cultivation technique, policy and subsidy back up is required along with extension services to disseminate the technical know-how to farmers.

2.2 Green Water Consumption in Agriculture

Green water refers to the amount of rainwater consumed (m^3 ton^{-1}) by an agricultural commodity. It has two components: a.) green water storage (soil moisture storage) and, b.) green water flow (evaporation plus transpiration). The fraction of the rainwater which stays on the top of the soil or vegetation, is absorbed by and retained by the soils and not converted to run-off or recharge the groundwater, is considered green water. Rainwater stored in rice growing fields during the wet season forms a part of the green water reservoir except the fraction that percolates to recharge groundwater or to surface run-off augmenting blue water availability (Gupta et al., 2020). Venkateswarlu & Prasad (2012) show the importance of rainfed agriculture in India; rainfed agriculture with around 58 percent of the cultivated area contributes 40 percent of the country's food production. Even after the full irrigation potential of the country is realized, half of the cultivated area will be under rainfed agriculture. The table below shows the acreage under rainfed agriculture for different crops in India.

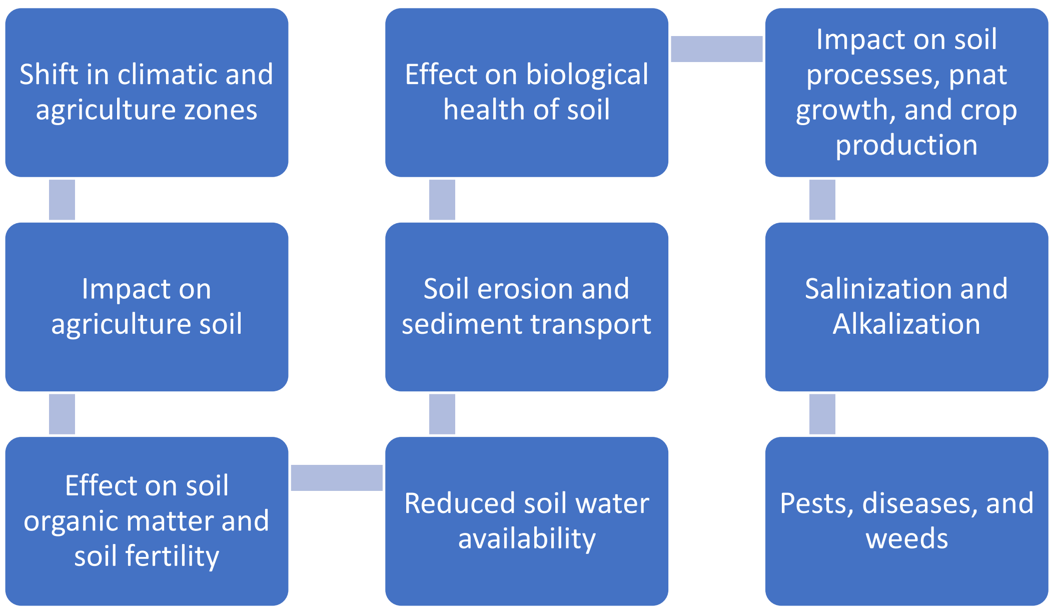
Table 4: Percentage area of crops under rainfed agriculture, 2008-09

Crop	Rainfed area (percentage)
Rice	42
Coarse Cereals	85
Pulses	83
Oilseeds	70
Cotton	65

Source: Venkateswarlu & Prasad (2012)

Therefore, it is important to discuss green water consumption in agriculture given the already existing stress on blue water resources and the impact of climate change on agriculture. In general, climate change can impact agriculture in a variety of ways. The figure below shows the different ways in which climate change can impact agriculture.

Figure 4: Different impacts of climate change on agriculture



Source: Khan et al. (2009)

The change in precipitation patterns associated with climate change has the potential to affect green water consumption with further implications on crop yields and water scarcity in agriculture. The National Mission for Sustainable Agriculture (2010) acknowledges the risks to Indian agriculture due to climatic variabilities and extreme events and seeks to encourage adoption of technologies for enhancing water-use efficiency. Birthal et al. (2014) study the impact of climate change on yields of major food crops in India from 1969 to 2005. The study finds the marginal effect of rainfall (green water) on kharif crops, except maize, was positive and significant. However, in the rabi season, the marginal effect of rainfall on yields of major crops was not statistically significant. The results indicate the vulnerability of kharif season crops to changes in precipitation patterns due to climate change. The non-significant effect of rainfall in the rabi season is expected as the amount of rabi rainfall in comparison to kharif season is usually less but more variable also. In general, the marginal effect of rainfall is estimated to be smaller than temperature. Birkenholtz (2017) forecasts the severe state of groundwater overdraft in the Indo-Gangetic plain can be exacerbated by climate change-induced perturbations in at least two ways. Firstly, an increase in temperature is expected to be accompanied by an increase in extreme events leading to an increase in runoff of up to 40 percent by 2090-99. It is predicted much of this runoff will not lead to an increase in aquifer recharge due to the intensity of the predicted events. Secondly, a lack of rainwater harvesting and recharge structures can lead to an increase in the demand for groundwater irrigation further increasing water scarcity in agriculture. Caparas et al. (2021) study the Water Stress Index (WSI) which reveals large areas of present-day global maize, soybean, rice, and wheat breadbaskets face high water scarcity. Authors show that water scarcity in breadbaskets will only become worse with shifting precipitation patterns due to climate change and potential irrigation intensification to close yield gaps. Mendelsohn (2008) describes several studies that measure the economic impact of climate change on agriculture in developing countries. The study confirms the hypothesis that tropical and subtropical agriculture is more climate sensitive than temperate agriculture, which implies even marginal warming can damage crops in Africa and Latin America. Since crops are sensitive to changes in precipitation, if climate scenarios turn out to be relatively hot and dry, a lot of damage can be caused in low latitude countries. However, the extent of the damage depends on the climate scenario – low, moderate, or extreme change in temperature. Lal (2011) studies the implications of climate change in sustained agricultural productivity in South Asia. The study finds climatic variability and frequency of occurrence of extreme weather events such as heat waves, droughts, floods and timing of rainfall have increased over the past few decades in South Asia, in particular India. Post 2000, the state of Orissa in India has experienced extreme weather conditions which have led to at least 490,000 ha of fertile lands being waterlogged and salinated by floods in recent years. Erratic summer monsoon rains affecting green water consumption in agriculture have become a common pattern in India in recent years. Taheripour et al. (2015) use an advanced Computable General Equilibrium (CGE) model coupled with biophysical data to estimate how water scarcity exacerbated by climate change can affect irrigation adoption and demand for water. The model shows that when water scarcity is ignored, irrigated areas (blue water) grow due to changes in crop yields induced by climate change. However, when water scarcity is introduced, competition for water increases reducing demand for irrigation (blue water) across river basins in India. In conclusion, water scarcity, induced by increased water demand in non-agricultural uses and lack of adequate water infrastructure, generates negative impacts on the economy and agricultural activities. The overall welfare losses due to water scarcity for the economy is expected to be about $3.2 billion (at 2007 prices) in 2030 (Taheripour et al., 2015). As climate change affects water consumption in agriculture, especially in the kharif season, various studies indicate increased demand for blue water resources. In this context, it is important to encourage climate-smart agriculture in the country in order to adapt to changing precipitation patterns and reduce pressure on stressed blue water resources.

An important Climate Smart Agriculture (CSA) technique promoted by the Government of India is micro-irrigation to improve water use efficiency in agriculture. The technique is promoted under the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) – Per Drop More Crop (PDMC) scheme since 2015-16. A recent study by the Government of India sampled 621 farmers across five states which included 500 micro-irrigation adopters to better understand the use of drip and sprinkler irrigation across different crops (GOI, 2021). The most commonly reported crops under micro irrigation for the adopter farmers are wheat, sugarcane, chickpea, cauliflower, cotton, broccoli, banana, chilli, and soybean. The table below shows the adopter farmers bring a large proportion of irrigated area of crops under micro irrigation, but the type of micro irrigation varies by crop between drip and sprinkler irrigation.

Table 5: Sample crop percentage area under drip and sprinkler irrigation by adopter farmers, 2017-18

Crop	Percentage area under drip irrigation	Percentage area under sprinkler irrigation
Wheat	-	96
Sugarcane	95	-
Chickpea	-	90
Cauliflower	-	85
Cotton	69	-
Broccoli	-	91
Banana	94	-
Chilli	78	-
Soybean	-	95

Source: Gandhi et al. (2021)

Climate Smart Agriculture technologies are used to counteract the costs of climate change at the national level. CSA technologies have the potential to fully compensate for the yield and production effects of climate change. These technologies fall under four broad categories: a.) seed varietal technologies, b.) soil – fertility management, c.) irrigation water management, and d.) crop protection. In relation to irrigation water management, there are four technologies that can help adapt to a changing climate and use water efficiently in agriculture (Perez et al., 2019). The table below shows these four different irrigation water climate-smart technologies that can be adopted at a national level.

Table 6: Irrigation water management and climate-smart technologies

CSA technology	Impact on water use in agriculture
Water harvesting	Channelling water toward crop fields through macro or micro catchment systems or by using earth dams, ridges or graded contours
Laser-land leveling	Use of precision laser technology in the construction of bunds and land preparation to efficiently manage water flow and the application of irrigation water

Alternate wet and dry system	Water saving technology that involves efficient application of irrigation water. Includes timing of irrigation to coincide with plant water demand at different stages of plant development. This is done in combination with fertilizer application and weed control
Precision water application	Similar to precision agriculture but limited to site specific and time specific application and efficient non-application of irrigation water. Included also are the types of water delivery like drip and sprinkler irrigation

Source: Perez et al. (2019)

There is a potential for additional productivity increases, and cost-savings by combining these technologies up to the extent of their complementarity. The application of complementary technologies is categorized as stacked technology where technologies are combined (or stacked over the other) in the sequence of crop production activities. The authors also run two simulations limited to rice and wheat in the context of India to a.) forecast potential rates of adoption of CSA technologies, and b.) determine the productivity and income gains from upscaling rice and wheat CSA technologies. Results indicate that adoption rates in 2030 for irrigation water management technology range from 40-55 percent in 2030 to 70-80 percent in 2050. The projected percentage increase in yields of irrigated rice with application of CSA technology is 22.50 percent and 21 percent for rainfed rice, 26.07 percent for irrigated wheat and 15.40 percent for rainfed wheat. The authors recommend intensifying the efforts of upscaling CSA technologies in agriculture to counter the impact of Climate Change. The benefits of CSA technologies have been highlighted by other authors too. De Pinto et al. (2020) conducted a global study to quantify the benefits of CSA on a global scale. Results show that widespread adoption of CSA practices can increase agricultural production and lower world prices of wheat, maize, and rice under future unfavourable climatic conditions. The reduction in prices is projected to make food products more accessible to millions of people lowering the number of undernourished children and people at risk of hunger. It is also seen that CSA improves soil fertility with a reduction in GHG emissions and can deliver benefits across its foundation pillars on a planetary scale. Lopez-Ridaura (2017) analyze the potential impact of the adoption of 'climate smart' agricultural practices (CSA) practices in the form of conservation agriculture (CA) and improved livestock husbandry, and environmental shocks on household potential food availability. Results indicate, in comparison to livestock interventions, CA holds considerable potential to boost household potential for food availability, primarily for wealthier and medium-scale farmers.

2.3 Gray Water Consumption in Agriculture

Gray water refers to the volume of freshwater that is required to assimilate the load of pollutants (m^3 ton^{-1}) in agriculture based on existing water quality standards. Mekonnen & Hoekestra (2017) estimate global anthropogenic phosphorus loads to freshwater and associated gray water footprints. In the period 2002-2010, the global gray water footprint (GWF) related to human-induced phosphorus loads to freshwater systems was 147 x 10^{12} m^3/yr. The global GWF increased by around 15 percent in the study period. The gray water footprint in the agriculture sector showed the largest growth in comparison to other sectors of around 27 percent. India contributes to around 8 percent of the global gray water footprint related to phosphorus. The country's share of the global agricultural gray water footprint related to phosphorus is around 10.72 percent. Another study by Mekonnen & Hoekestra (2020) estimates the global anthropogenic nitrogen loads to freshwater. India contributes 5 percent to the global anthropogenic nitrogen load. It is shown that 75 percent of the nitrogen load came from non-point sources in agriculture. Among the crops, production of cereals has the largest contribution to the nitrogen load (18 percent, of which 7 percent wheat and 6 percent maize), followed by vegetables (15 percent) and oil crops (11 percent). The study estimates that globally 18 percent of the total nitrogen input on crop fields leaches to freshwater systems.

Given the amount of gray water generated in agriculture in India, there is vast potential of gray water generated to supplement blue and green water irrigation in agriculture. Studies indicate the importance of using treated and untreated gray water for irrigation in agriculture. Gorgich et al. (2020) review the effects of graywater irrigation on the quality of crops, as well as soil properties. The study highlights the importance of fertilizer use to supply the nutrients which are not present in graywater to enable the optimal growth of plants. The study also states the importance of understanding the idiosyncrasies of the type of plant to better understand the effect of graywater use for irrigating crops. Finley et al. (2009) analyze domestic graywater for irrigation of home gardens. The authors examined the benefits and risks associated with domestic graywater use for the purpose of vegetable garden irrigation. Untreated (settled only) and treated (settling and slow sand filtration) gray water collected from a family home was analyzed for basic water quality parameters over a period of 8 weeks. In the experiment, gray water was used to irrigate individually potted plots of lettuce, carrots, and peppers in a greenhouse and where tap water was used as a control. Results show that contamination levels for all crops that used domestic gray water for irrigation were low and do not represent a significant health risk reinforcing the potential of domestic graywater to be used as an alternative irrigation source.

Travis et al. (2010) study the effect of gray water irrigation on soil properties. A controlled experiment was conducted on containers of sand, loam and loess soils which were planted with lettuce, and irrigated with fresh water, raw artificial gray water or treated artificial gray water. It was found that gray water can be effectively used as an irrigation source without any detrimental effects on soil or plant growth. However, raw (untreated) graywater can significantly change soil properties which could impact the movement of water in the soil. Godfrey et al. (2009) conduct a pilot study in residential schools in Madhya Pradesh, India where gray water treatment and reuse systems were constructed, and the treated gray water was used for domestic and irrigation purposes. Appropriate valuation methodologies were applied to measure external benefits such as savings on water infrastructure, reuse of pollutants (nitrogen, phosphorous, and potassium). The monetary values of external benefits and costs in terms of environmental and health benefits were derived which were estimated to be INR 44,000 and INR 793,380, respectively. The authors found the internal and external benefits of gray water reuse higher than the internal and external costs indicating the potential of gray water reuse in domestic and the agriculture sector. Molinos-Senante et al. (2010) present a cost-benefit analysis of wastewater treatment with a valuation of environmental externalities. This method is used for economic feasibility studies to be made for gray water treatment and reuse which take into account environmental externalities. The authors assume wastewater treatment is a productive process in which a desirable output (treated water) is obtained with a series of undesirable outputs. Both operating costs and environmental benefits derived from treatment are highly variable between wastewater treatment plants, the average value of the net profit for the three scenarios is positive demonstrating that gray water treatment is economically viable. Mandal et al. (2011) emphasize the importance of water conservation due to gray water treatment and reuse in the context of urban settings. The study concluded that treated gray water generated from a household can be self-sufficient to irrigate a small garden. However, there is a gap on the potential of scaling up gray water treatment for reuse, especially for irrigation in the agriculture sector which needs more attention in agri-food and water policies.

2.4 Research Gap

There is a research gap in the literature on estimating green, blue, and gray water consumption in agriculture in India for the present and the future. No study has considered the trade-offs between green, blue, and gray water consumption due to change in cropping patterns, adoption of agricultural and irrigation technology, which is important for creating a wholistic water and agriculture and food policy. Future estimates of all three water categories are needed to make appropriate policy decisions to conserve water in the country.

2.5 Focus of Thesis

The focus of the thesis is to estimate the three categories of water consumption in agriculture in India for the present, and the future under a business-as-usual scenario, change in cropping pattern scenario, and the adoption of efficient irrigation and agricultural technology scenario. These scenarios can provide a platform for the policymaker to understand the impacts of a potential change in agricultural policy on water consumption in the sector.

CHAPTER 3: METHODOLOGY AND DATA

3.1 Input-Output Model and Environmental Extension

In this section, the method used in the study is presented. The Input-Output (IO) framework that is used an extension of the basic IO model of Leontief (1951). The IO model primarily deals is a method of studying the interrelationships and interdependence among the different sectors of the economy. In this framework, the economy is divided into sectors and flow of goods and services among these sectors are recorded to study the relationship among them in a systematic and quantitative manner (Miller and Blair, 2009; Chakraborty and Mukhopadhyay, 2014; Sengupta and Mukhopadhyay, 2016). The basic Input-Output model can be explained by considering a simple hypothetical economy consisting of 'n' sectors. These 'n' sectors are interdependent in so far as they would purchase inputs from and sell outputs to each other. The IO matrix presents inter-industry flows of intermediate inputs among the various sectors of the economy. A column records all the inputs required from various sectors in the production process of a particular activity, while a row describes the flows of a particular sector to different sectors. A technology coefficient matrix is derived from the Input-Output transaction matrix by dividing all elements in the input column by the output level of a sector represented by the column. Thus, if $A= (a_{ij})$ is the Input-Output coefficient matrix, then a typical element 'a_{ij}' represents the amount of input required to produce one unit of output j. The direct input-output coefficient matrix is the core of the model. Since total output is equal to inter-industry sales plus final demand, we have

$X = AX + e$….. Eq. (1)

where,

A = Input-Output coefficient matrix (n x n)

X = vector of total output (n x 1)

e = vector of final demand (n x1)

The solution of Eq. (1) gives,

$X = (I - A)^{-1} e$…… Eq. (2)

where,

I = identity matrix (n x n)

$(I - A)^{-1}$ is the Leontief Inverse which depicts total (direct and indirect) input requirements

To calculate the water requirement (direct and indirect) in physical units, we have treated the water sector separately from the IO model. To study water consumption associated with inter-industry activity, let us consider a matrix of water output coefficients denoted by W [W_{kj}], each element of which is the amount of water consumed by type k, (e.g, green, blue, and gray) generated per rupee's worth of industry 'j's' outputs. Hence, the level of water consumed with a given total output can be expressed as,

R = WX …..Eq. (3)

where,

R is the vector of total water consumption of each type (k x 1), W is the vector of direct water coefficients (k x n), and X is vector of total output (n x 1).

Hence, by multiplying the direct water coefficients with the traditional Leontief's Inverse matrix $(I - A)^{-1}$, we can compute R', i.e., the total water coefficient of each type in the economy directly and indirectly by different sectors.

$R' = W (I - A)^{-1}$ …… Eq (4)

Here,

R' is the direct and indirect water coefficients matrix of different sectors (k x n)

W is the direct water consumption coefficient matrix of different sectors (k x n)

$(I - A)^{-1}$ is the Leontief matrix multiplier of different sectors (n x n)

The total amount of water consumed of each type can be calculated as a function of output of commodities. Then, the output of commodities can be presented with interdependence of industries and final demand. The water model is then prepared according to the Leontief model as follows. From equation (3) and equation (4), we can structure the water equation as:

$R = W (I - A)^{-1} e = R' e$ …..Eq (5)

where,

R gives the total water consumption of each type (k x1).

W is the direct water consumption coefficients matrix of different sectors (water consumption in billion cubic meters/ total input in lakh rupees) (k x n)

$[I – A]^{-1}$ is the Leontief matrix multiplier of different sectors (n x n)

e is the vector of final demand (in lakh rupees) (n x 1)

Here we elaborate on the total water consumption in the model which can be divided into three components – green, blue, and gray water. The specific equations are given below,

$W_b = w_b'[I – A]^{-1}. e$ ……. Eq. (6)

where,

W_b = total commodity blue water consumption (billion cubic meters) (1 x 1)

w_b' = direct blue water coefficients (water consumption in billion cubic meters/ total input in lakh rupees) (1 x n)

$W_g = w_g'[I – A]^{-1}. e$…… Eq. (7)

where

W_g = total commodity green water consumption (billion cubic meters) (1 x 1)

w_g' = direct green water coefficients (water consumption in billion cubic meters/ total input in lakh rupees) (1 x n)

$W_{gr} = w_{gr}'[I – A]^{-1}. e$….. Eq. (8)

where

W_{gr} = total (direct and indirect) commodity gray water consumption (billion cubic meters) (1 x 1)

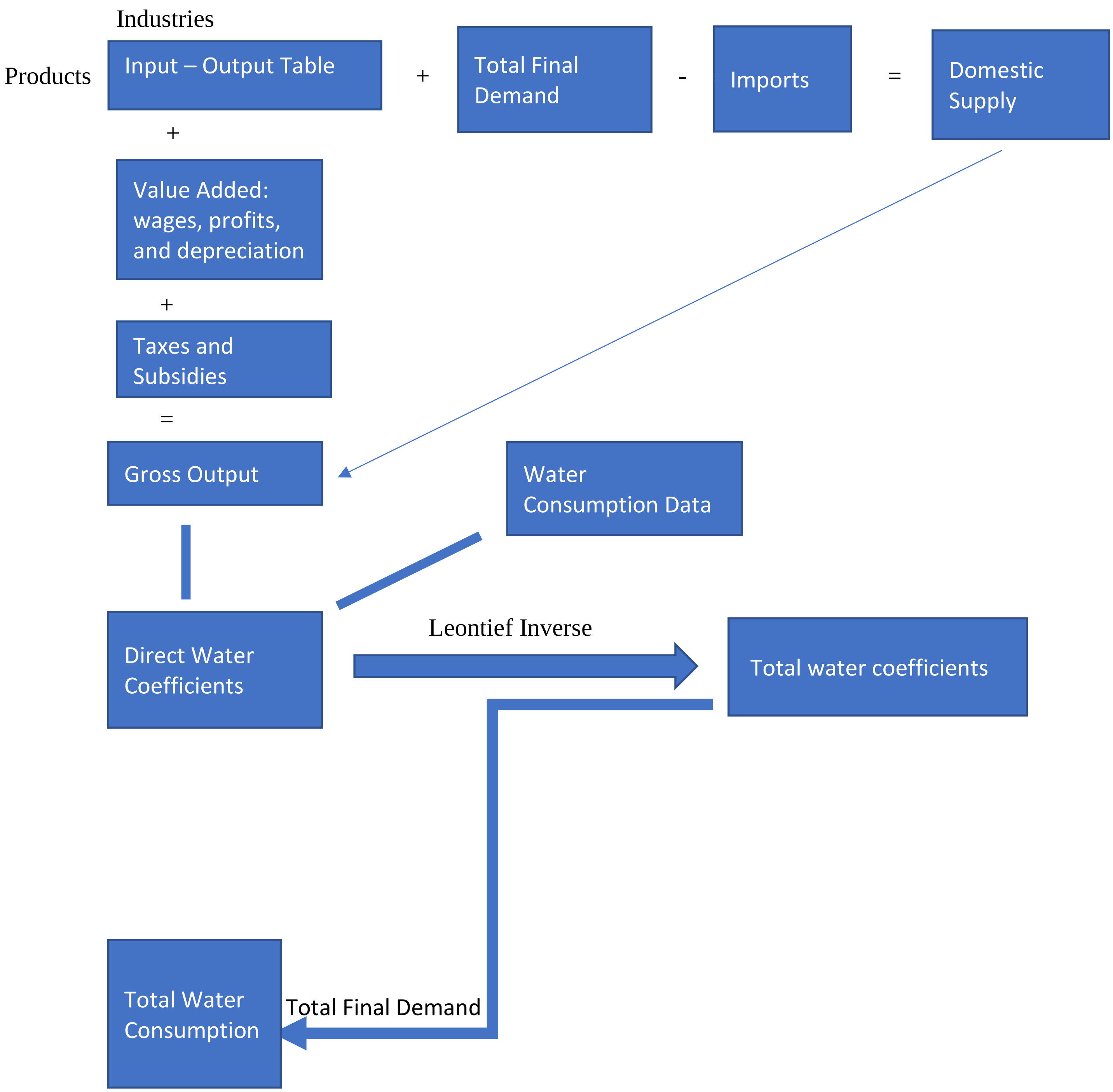
w_{gr}' = direct gray water coefficients (water consumption in billion cubic meters/ total input in lakh rupees) (1 x n)

3.2 Water Data

To implement the model and conduct the analysis of water requirements, we require input-output and water data. The study uses the Indian Supply-Use Table (SUT) 2014-15 (140 x 66) prepared by the Central Statistics Office (CSO) Government of India and was converted to a balanced IOTT (140 x 140). The IOTT has been further aggregated to 48 commodities. However, the agriculture sector is disaggregated, with 16 agricultural commodities in the model. This is because the focus of the study is to estimate green, blue, and gray water consumption in agricultural commodities.. **The 'water supply' commodity in the IOTT model represents the cost of collection, purification, and distribution of water in the economy but does not represent physical units of water withdrawn by different sectors. Also, the 'water supply' in certain sectors such as agriculture is subsidized. Therefore, in order to have a better representation of water consumption and withdrawals in the economy, the Input Output table has been extended to include a separate 'water' commodity. The 'water' commodity is expressed in physical terms and is segregated into three forms: Green water which refers to the rainwater consumed; Blue Water which refers to the volume of surface and groundwater consumed and Gray Water which refers to the volume of freshwater that is required to assimilate the load of pollutants based on existing water quality standards**. The water data adapted is in the form of m^3 ton^{-1}. The green, blue, and gray water data used in the model has been adapted from Mekonnen

& Hoekestra (2011) which quantifies the water footprint of crop production for the period 1996-2005. The green and blue water footprints of primary crops (m^3 ton^{-1}) are calculated by dividing the total volume of green and blue water consumption (m^3 yr^{-1}), respectively, by the quantity of production (ton yr^{-1}). The gray component of the water footprint (m^3 ton^{-1}) is calculated by multiplying the fraction of nitrogen that leaches or runs off by the nitrogen application rate (kg ha^{-1}) and dividing this by the difference between the maximum acceptable concentration of nitrogen (kg m^{-3}) and the natural concentration of nitrogen in the receiving water body (kg m^{-3}) and by the actual crop yield (ton ha^{-1}). The data for production of different crops in 2014-15 is adapted from NSO (2020). The water consumption for different agricultural commodities (m^3 ton^{-1}) for the IOTT model is then multiplied by the the production data for crops (in million tonnes, lakh tonnes, and lakh bales) to obtain water consumption for agricultural commodities in the year 2014-15. In the same year, for the industrial and service sectors, the aggregated blue water use data has been distributed to different industrial and service commodities, according to the ratio of the cost of water supply in the particular commodity to the total cost of water supply in the Industry. The aggregated blue water use data for the Industry and service sectors have been adapted from GOI (2018).

Figure 5: Schematic diagram of Input-Output table describing water as a component



3.3 Preparation of the 2030 Baseline

The static Input-Output model cannot estimate total output in the future. The data is available only for one particular fiscal year (in our case, the model is for the year 2014-15). Therefore, for the preparation of the 2030 Baseline, the study used the E3-India[5] Model (Pollitt, 2021). Economic growth is determined in the E3-India model by several recursive 'loops' within the Economy module that lead to Keynesian multiplier effects. Higher incomes boost expenditures leading to higher wages which boost incomes further. In addition, growth is also determined by the linkage between investment and output. The three loops in the model that determine economic growth are: investment (type 1 multiplier), income (type II multiplier), and trade. In the type I multiplier, the increase in demand leads to an increase in sectoral output as a result of which there is an increase in investment demand across the supply chain. In the type II multiplier, the increase in sectoral output also leads to an increase in employment demand, leading to a higher level of income and additional consumer expenditure. In the trade loop, the increase in domestic demand leads to an increase in demand for imported goods and services which leads to higher production levels in other states (within the country). Economic activities outside India are treated as exogenous to the model. Other studies too have estimated the economic growth of India to 2030. A pre Covid-19 report estimated India's GDP will grow to $8.4 trillion by 2030 at an average annual growth rate

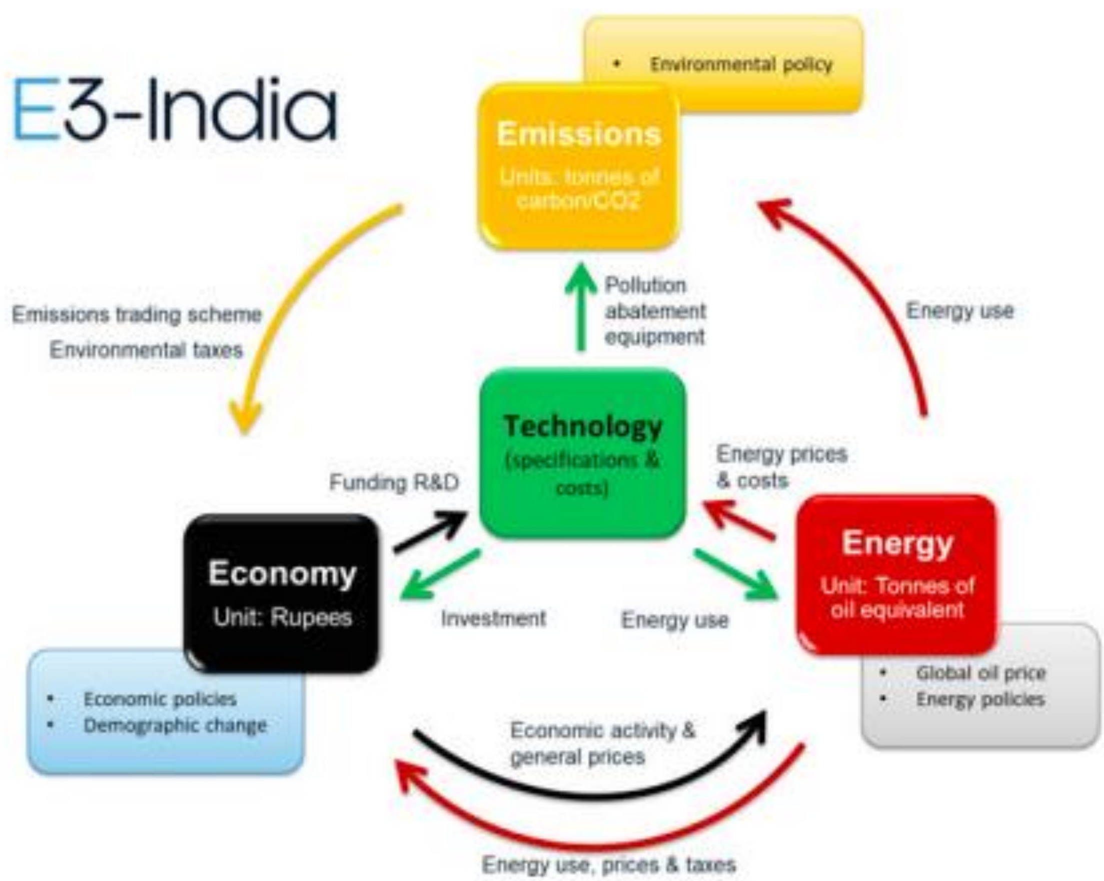
[5] E3-India (Economy, Energy, Emissions) is a macro-econometric model used to simulate the effects of economic and energy policy at the national and sub-national level within India, providing information that policy makers need when assessing the merits of new or existing policy proposals. The model has the capacity to assess energy-economy linkages for India across time. It has the following dimensions: 32 Indian states and territories, 38 economic sectors, 21 users of five different energy carriers, C02 emissions from 21 sources, annual projections to 2035. It produces a wide range of socio-economic outputs at the state and national level. These include employment and unemployment, GDP and sectoral output, Investment, International trade and trade between states, Household income (by income group) and consumption, Public balances, Prices and inflation.

of 8 percent (Bloomberg, 2019). It is projected that manufacturing and construction sectors due to rising urbanization will lead to highest sectoral GDP growth (McKinsey & Company, 2020).There are various factors that drive economic growth of India to 2030. These include: increasing population and urbanization, changing preferences to high value diets, and higher average per capita incomes and expenditure. However, many of these factors underlying economic growth to 2030 are region and state specific. Therefore, the focus on policy-making at the sub-national level (constituting 32 States and Union Territories) is one of the biggest advantages of E3-India as the economic endowments vary across states. This helps in developing an understanding of the multidimensional impact of a new or existing policy, why it might happen and the scale of the effect across various states in the country. In this study, the E3-India model projects sectoral output growth rate from 2015 to 2030. Based on this sectoral output growth data, an estimate of total output is developed for 38 sectors in the E3-India model. We then distribute the sectoral output estimates for 2030 across the 48 sectors in the national IO model. It is in this context, the current study used the E3-India model to estimate the sectoral output demand for 2030 which was used in the baseline 2030 in the national IO model. E3-India model also helps to derive the regional implications from the national level results. These include analyzing the impacts on water stressed states (such as Punjab, Haryana, Uttar Pradesh, and Maharashtra) of change in government agri-food and water policies.

3.4 E3-India Model

The E3-India model is split into three different modules: Economy, Energy, and Emissions. As each module uses different units, it is necessary to ensure consistency by matching levels with growth rates in a similar way to how systems dynamics modelling works. Technology is at the centre of the modelling approach and may influence the outcomes from all different modules. Technological development is a key driver of long-term economic growth. The choices of technology used may also determine the amount of energy used (and from which fuel it comes) and related environmental emissions.

Figure 6 : A diagrammatic representation of Economy, Energy, and Emission interactions in the E3-India model



3.4.1 The Economy Module

The Economy module is the largest of the three main modules. It provides an accounting framework that is consistent with national accounting conventions and representation of human behaviour through its econometric equations. Examples of accounting identities include the standard demand-side equation for GDP:

$$GDP = C + I + G + X - M$$

In which, GDP is equal to the sum of consumption, investment, government final consumption, and net trade. An example of an econometric equation is:

$$I = a + b1 * Y + b2 * PI + b3 * IR + e$$

In which investment (I) is a function of production (Y), relative investment prices (PI) and the interest rate (IR). The parameters a and b1 to b3 are elasticities that are estimated using econometric techniques and e is an error term.

Most calculations in the Economy module are carried out at the sectoral level within each state, while national level GDP is determined by summing across the sectors. Most of the econometric equations in the model are estimated and solved at the sectoral level. The 38 sectors in the model are linked by input-output coefficients that describe intermediate purchases between different sectors. Thus, supply chains are represented in the model. The interactions between different states and territories of India are represented by a bilateral trade matrix. The model consists of several recursive ‘loops’ within the Economy module that can lead to Keynesian multiplier effects. Higher incomes can lead to increased household expenditure and revenues for shops that in turn pay higher wages, boosting incomes further. Other loops include the linkage between investment and output representing ‘Keynesian’ animal spirits and the trade loop that shows how one state expanding production can pull its neighbors along too, which then feeds back into the first state. These loops are important for understanding the current dynamics of the economy, but also a source of economic growth.

Prices of energy goods and the wider economy are determined in the Economy module. There are also equation sets for employment and labor supply. Unemployment, a key indicator for policymakers, is determined as the difference between employment and labor supply. The economy module provides estimates of demand to the Energy module, which in turn provides estimates of activity in the energy sectors (i.e., electricity supply) Feedback from the environment module may also affect prices in the economic module if an emissions tax is imposed.

There is also an important interaction between technology and the economy module. The direction and pace of economic growth determines the level of technological growth. The state of technology in each sector, in turn, affects several of the model’s econometric equations, including prices, trade, and employment.

3.4.2 The Energy Module

The Economy module feeds measures of demand into the Energy module, demand for energy will increase if rates of economic production increase, not necessarily in proportion. For each sector, energy demand is estimated at an aggregate level, and then broken down to energy carrier (i.e. fuel type). The model thus allows for switching between different types of fuel in production. The Energy module provides feedback to the Economy module, through the energy sectors defined within the model. If the demand for electricity increases, economic production by electricity production sector will increase which will increase employment levels and creating further economic impacts. In scenarios that aim to limit future greenhouse gas emissions, the choice of production methods used by electricity production is critical. The E-3 India model therefore incorporates a more detailed treatment of the electricity sector, which is called Future Technology Transformations (FTT). FTT defines 24 different types of electricity production, including conventional (e.g. coal fired) methods, nuclear, renewables, and carbon capture and storage (CCS) options. The results from the FTT sub-model is important for the rest of E3-India. The sub-model determines the level of fuel demanded by the power sector and feeds this back to the main Energy module. Levels of investment (fed back to the Economy module) and electricity prices (fed back to both the Economy and Energy modules) and therefore plays a central role in the analysis.

3.4.3 The Emissions Module

Energy Consumption is converted into environmental emissions in the emissions module. Each unit of fuel consumption is given an emission coefficient, which is estimated in the final year for which data is available and is held constant over the period up to 2035. The level of emissions is dependent on dependent on both the level of energy consumption and the choice of fuel used. In E3-India, leaving aside electricity, there are four fuel types: Coal, Oil, Natural gas, and Biofuels. In the modelling, we assume a direct lifetime reduction coefficient of zero for biofuels. Substantial emission reductions could be achieved by switching between the different fuels.

If there are taxes on emissions, this will influence both the choice of fuels used in energy consumption in the Energy module and have effects on the wider economy through higher costs that may be passed on to the final product prices in the Economy module.

3.4.4 Technology in E3– India

In the modelling framework, technology may be modelled as a 'bottom up' (an explicit list of technologies) and 'top down' (an aggregated approach). The FTT model in E3- India is an example of a bottom-up approach. It is not possible to define every potential technology in every sector, so the rest of the model uses a top-down approach. The state of technology is called the knowledge stock, represented by accumulated investment within each sector. The technology variable provides a measure of product quality in the Economy module. It feeds into several of the model's economic equations, including those for prices, trade, and employment. This is also affecting energy demand because more advanced products are more efficient.

3.4.5 Data and Baseline Projections in E3-India Model

In the modelling exercise, the database used covers the period 1993 to 2015 on an annual basis, with most variables in the model disaggregated both by sector and by state. The main data sources from the model are from the Indian Ministry of Statistics and Programme Implementation (MOSPI) and Indian National Sample Survey Office (NSSO), in addition to other sources of data.

When carrying out ex ante analysis, it is necessary to have a business-as-usual baseline to which scenarios with additional policies are compared. The baseline case has been constructed by the modelling team based on extrapolation of previous sectoral growth rates that are constrained to match aggregate GDP projections. A method of 'calibration' that involves scaling model results is used to ensure that the model baseline is consistent with the constructed baseline. The same scaling is applied to all model runs so that it does not affect the comparison between scenarios. At a theoretical level, it is similar to adjusting the intercept terms in the econometric equations.

CHAPTER 4: SCENARIO DEVELOPMENT

The four scenarios developed in the model simulate changes in government agricultural policy and technology which has the potential to save water in agriculture in India by 2030. The scenarios are in comparison to the baseline 2030 forecasts obtained from the E3-India model.

The baseline simulation to 2030 assumes:

a.) the cropping pattern in 2030 (in terms of proportion of total output of agricultural commodity to total output of the agriculture sector) in the disaggregated agriculture sector remain same as in 2015,

b.) there is no change in agricultural technology leading to water-saving in crop production.

Both the absolute water as well as relative water saving (technology side vis-à-vis demand side policies) estimated are important for water and agriculture policy making in the country.

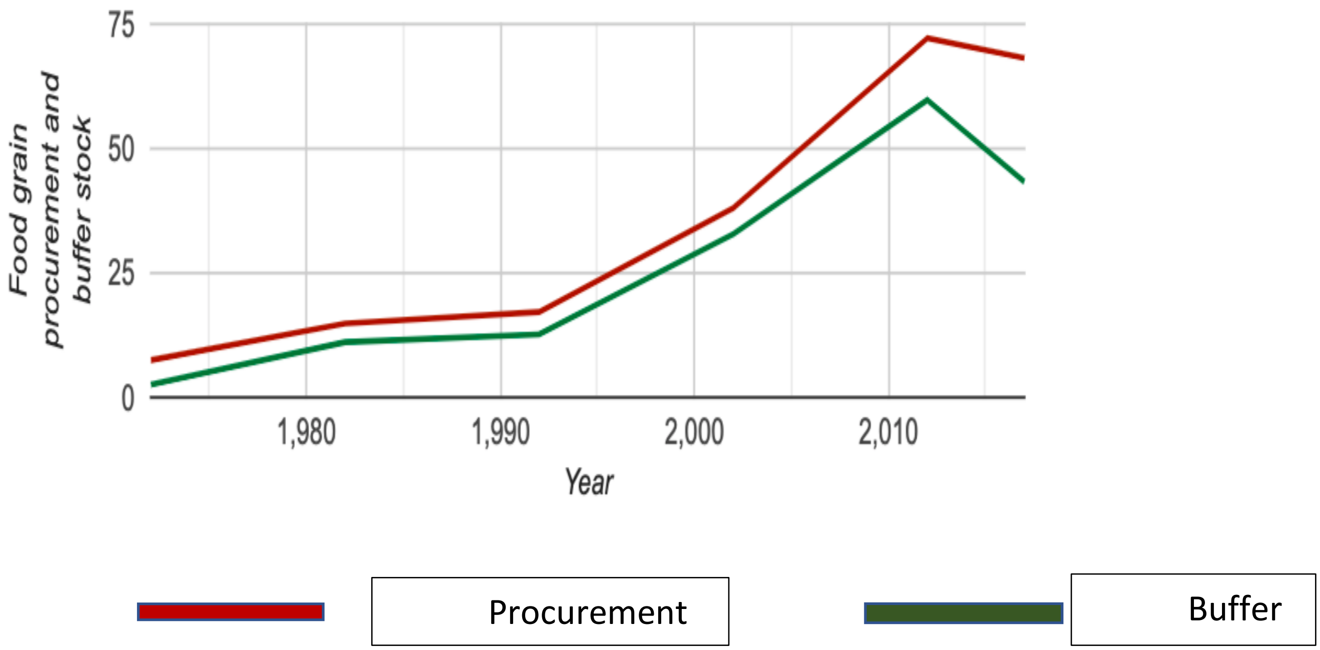
4.1 Scenario 1

Shift in government procurement from paddy and wheat to coarse cereals

(GOVTPROCURE)

The Food Corporation of India (FCI) established in 1965 ensured the expansion of procurement operations at Minimum Support Prices (MSPs) to ensure a stable market for farmers. It was because of this government demand side intervention, the Green Revolution expanded output of food grains in the 1970s. The food grain procurement in 1972-73 increased from 7.51 million tonnes to 68.20 million tonnes in 2017-18. With a buffer stock of 43.31 million tonnes in 2017-18, the country has now proven to be self-sufficient in food grains.

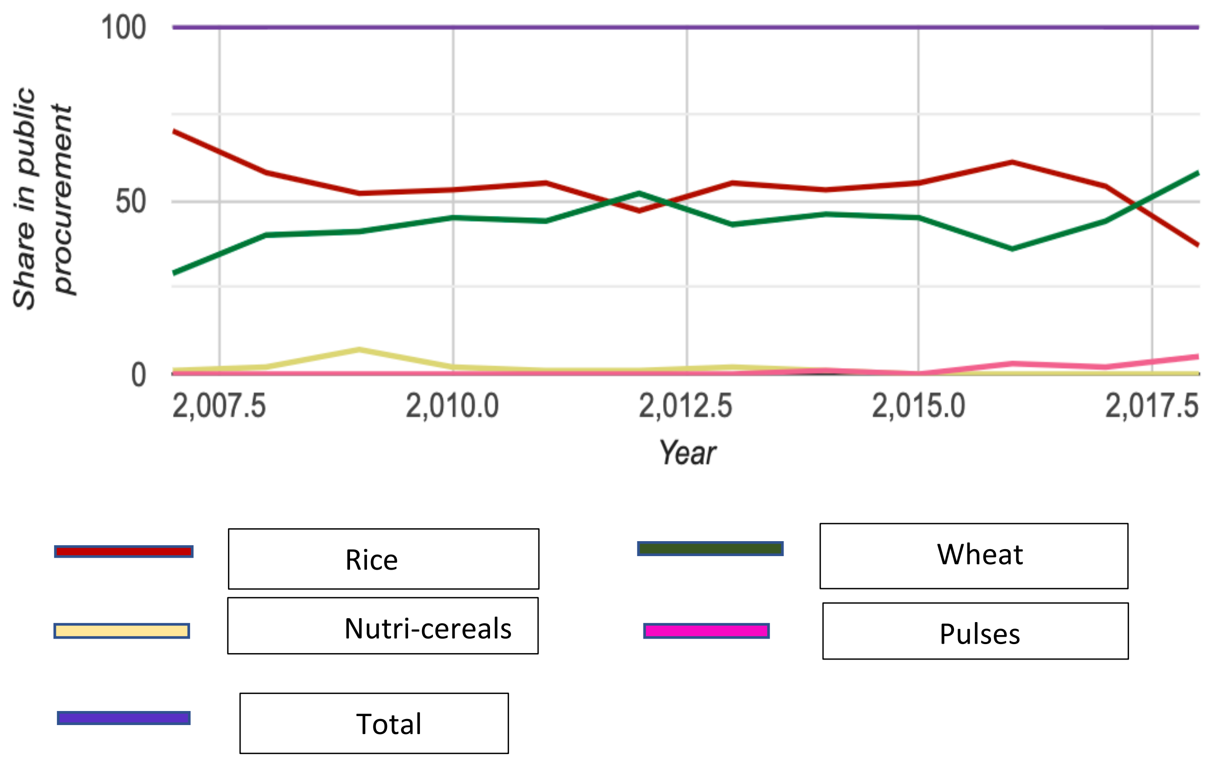
Figure 7: Food grain procurement and buffer stock, 1972-2018 (million tonnes)



Source: Department of Agriculture, Co-operation and Farmers' Welfare (2018)

However, since this policy change, the public procurement is skewed towards staple cereals such as paddy and wheat. The combined share of the staple crops in the government procurement system in 2018-19 is 95 percent. In the same year, there is no procurement for coarse cereals such as bajra and millet.

Figure 8: Share of crops in public procurement, 2007-2019 (%)



Source: Department of Agriculture, Co-operation and Farmers' Welfare (2020)

It is observed that increase in MSPs over the years is seen by farmers to opt for crops such as paddy and wheat which have an assured procurement system (GOI, 2020). This trend has two implications. Firstly, from a nutrition perspective this trend is worrisome as staple cereals are a source of macro-nutrients, whereas in comparison, coarse cereals are a valuable source of both macro-nutrients and micro-nutrients. Authors have argued to increase the procurement of coarse cereals to address malnutrition in the country (DeFries, Chhatre, & Davis, 2018). Secondly, incentives for producing paddy and wheat affect water demand in the country as these crops are water-intensive. Water demand is an important factor to consider for procurement given that the country is water-stressed (Gulati & Banerjee, 2016). Authors have argued shifting from rice and wheat cultivation in 11 major states of India to coarse cereals could save upto 18 to 36 percent of blue water in the country. Since these staple crops are also water-intensive, a shift is required to change the distorted structure of incentives in place through the government procurement system. In 2030, authors demonstrate that a 10-25 percent replacement of demand of staple cereals by coarse cereals is a realistic scenario, the interval contingent upon on the cropping season (Kharif or Rabi) (Shah & Vijayshankar, 2021). Therefore, based on this interval, the first scenario of the model is simulated.

In the scenario, aggregate demand for wheat and rice is decreased by 15 percent and aggregate demand for coarse cereals is increased by 10 percent in 2030.

4.2 Scenario 2

Adoption of high-efficiency irrigation systems and conveyance modernization of canals (WATEREFF)

In India, the most common surface water irrigation technique used is flood or canal irrigation which has a water use efficiency[6] of 65 percent (Gulati & Banerjee, 2016; FAO, 2021). Out of the 160 million hectare of cultivated land, 22 million hectares is irrigated by canals (Dhawan, 2017). Given the widespread use of the technique in irrigated agriculture, there is a need to upgrade canal infrastructure and adopt alternate irrigation techniques to improve water use efficiency. Table 7 shows efficiency levels of upgraded (lined) canals and of alternate irrigation techniques such as drip and sprinkler methods. High efficiency irrigation technologies include

[6] water use efficiency represents the ratio between effective water demand of crops and actual water withdrawal from the irrigation source used. The definition characterizes how effective is the use of water. However, it is important to note, water use efficiency is scale and process dependent. In terms of conveyance efficiency, efficiency is the volume of water at delivery points and inflow at the entrance. In terms of transpiration efficiency, effective water use is the water transpired by the crop which is compared to the actual water withdrawal from the irrigation source

furrow, drip and sprinkler, and centre pivot methods which have an average combined water use efficiency of 85 percent (Gulati and Banerjee, 2016; GOS, 2021).

Table 7: Different irrigation methods and their efficiencies

Irrigation methods	Efficiency (%)
Conveyance (through unlined canal)	55-60
Conveyance (through lined canal)	70-75
Flood irrigation	65
Furrow irrigation	80
Sprinkler	85
Drip	90

Source: Gulati & Banerjee (2016)

In this context, the Government of India launched *The Pradhan Mantri Krishi Sinchayee Yojana* (PMKSY) in 2015 to improve water use efficiency of irrigation systems (GOI, 2019). A major objective of this agricultural policy is to improve the efficiency of irrigation systems in the country through upgrading existing irrigation infrastructure and adopting water efficient technologies. Therefore, based on the government policy trajectory, the second scenario of the model is simulated. **In the scenario, two exogenous shocks are given to the model:**

1. **the total blue water saving is estimated in 2030 due to a transition from low efficient irrigation technologies (such as canal irrigation) to a combination of high efficient irrigation technologies (include furrow irrigation, drip and sprinkler irrigation, and centre pivot irrigation). The crop varieties chosen**

for this simulation are based on suitability of adopting the high-efficient irrigation technique to the particular crop.

2. **the total blue water saving is estimated in 2030 due to conveyance modernization of irrigation canals. The crop varieties chosen for the simulation use canal irrigation as the primary irrigation technique**.

4.3 Scenario 3

Adoption of a genomic water saving variety of paddy (GENOMPADD)

In India, several crop varieties have been developed in the recent past which require less water than corresponding Green Revolution varieties (Shah and Vijayshankar, 2021). Some examples of crops include: Low irrigation wheat varieties Amar (HW 2004), Amrita (HI 1500), Harshita (HI 15231), Malav Kirti (HI 8627), and Malav Ratna (HD 4672). These varieties demonstrate good yields at a much lower level of water consumption. However, the adoption of these varieties by farmers needs training and facilitation by Krishi Vigyan Kendras (KVKs) to understand new agronomic practices associated with these varieties. The widespread adoption of these water saving wheat varieties would go a long way in reducing the water footprint of the crop. In comparison, some of the recent rice-varieties developed by the National Rice Research Institute (NRRI) are resistant to pests and diseases, however, till 2020, there is no major genomic variety of rice developed by the Institute to save water in irrigated agriculture.

Table 8: Rice varieties developed by NRRI in recent years (2019-2021)

Variety	Ecology	Year of release	Reaction to diseases and pests, and average grain yield t/ha
CR Dhan 312	Irrigated	2019	Moderately resistant to leaf blast, neck blast, and rice tungro disease
CR Dhan 313	Irrigated	2020	Moderately resistant to blast and bacterial blight, 4.8 t/ha
CR Dhan 308	Irrigated	2020	Moderately resistant to bacterial leaf blight, brown spot and neck blast, 5.0 t/ha
CR Dhan 314	Irrigated	2020	Highly resistant to false smut, moderately susceptible to leaf blast and neck blast, 6.63 t/ha
CR Dhan 315	Irrigated	2020	Moderately tolerant to leaf blast, neck blast, and brown spot, resistant to leaf folder and moderately resistant to stem borer
CR Dhan 702	Irrigated and Shallow lowland	2021	Moderately resistant to leaf blast, neck blast, and resistant to false smut

Source: National Rice Research Institute (NRRI) (2021)

In this context, it is important to estimate the potential water saving due to the adoption of a genomic water saving variety of paddy. One such rice variety developed by a group of International plant scientists which has demonstrated to save water is HRD rice. The authors demonstrate the expression of Arabidopsis HARDY (HRD)[7] gene in rice improves water use-efficiency by 65 percent, i.e., the ratio of biomass produced to the water used, by enhancing photosynthetic assimilation and reducing transpiration (Karaba et al., 2007). The variety has the potential to be adopted in the Indian context, and is an alternate to the conventional varieties grown. Therefore, based on this water-saving variety of paddy, the third scenario is simulated. **In this scenario, the total water saving is estimated through adopting a genomic water saving variety of rice (HRD Rice) in 2030**.

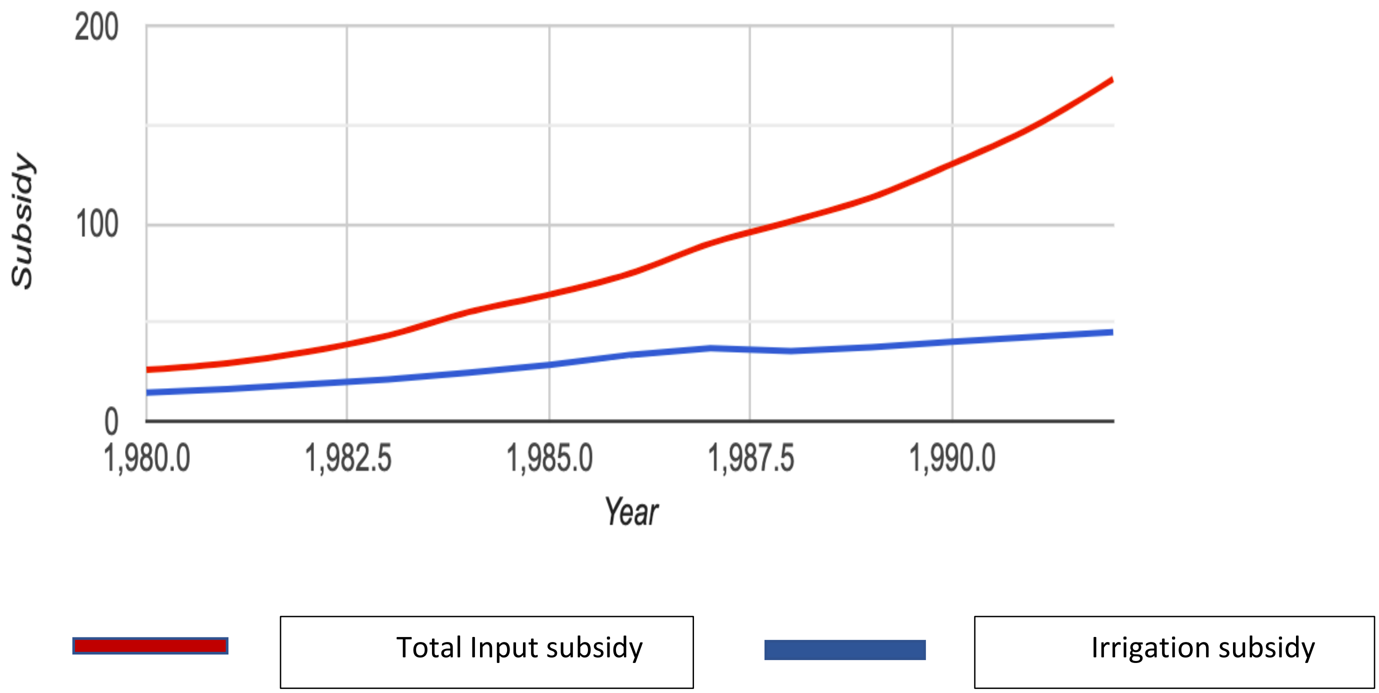
4.4 Scenario 4

Increase in the average cost of irrigation (IRRSUBSD)

Input Subsidies in agriculture in India have been popular in agricultural policy since the onset of the Green Revolution. Inputs like fertilizers, irrigation water, electricity used in the agricultural sector are supplied to farmers at prices which are below their open market prices (Gulati and Sharma, 1995). The prices of these inputs do not reflect their true value, i.e. the real operating cost of supplying these inputs.

[7] The HRD gene in rice produces thicker leaves with more choloroplast-bearing mesophyll cells, and in rice, there is an increase in leaf biomass and bundle sheath cells that contribute to increasing photosynthetic assimilation and water use efficiency

Figure 9: Historical data on total input and irrigation subsidies in Indian agriculture (Rs billion) (1980-1993)



Source: Gulati and Sharma (1995)

The subsidy for irrigation is estimated to be around 26 percent of the total input subsidies in 1992-93. Ever since, large-scale investments in irrigation have been made by states and the national government. These irrigation projects have considerable capital and operational costs. However, prices are fixed on the basis of farmers' ability to pay, which is determined by output, area irrigated based on the volume of water used, quality of irrigation, and recovery cost of equipment. Volumetric pricing is not allowed. The pricing system varies with season, crops, and between states. There is also a difference in levying of water rates by different states and union territories in India. This under-pricing of irrigation water leads to wastage of the water as a scarce natural resource as farmers do not have any price incentive to judiciously use the resource

(Palanisami, Kakumanu, and Malik, 2015). Therefore, based on the distorting nature of irrigation subsidies, the fourth scenario of the model is simulated. **In this scenario, the direct and total blue water saving is estimated due to a 30 percent increase in the average cost of irrigation allocated to crop varieties in the model**.

CHAPTER 5: RESULTS AND DISCUSSION

The environmentally extended Input-Output model derived in the data and methodology section is used to estimate the impact of exogenous changes in final demand, agricultural policy, and technology on the demand for water in India. The model focuses on the agriculture sector with its 16 agricultural commodities. The structure of the economy is described in terms of inter-industry and water-industry production relationships with direct blue water use estimated for all sectors, including agriculture, industry, and services in the model. Further, two baseline scenarios are estimated. Baseline 2015 estimates water demand for the 16 crop sectors in the agriculture sector for the year 2015. To estimate the baseline 2030, the E3-India model[8] is used, which calculates the sectoral growth for all sectors to 2030 at the national and regional levels. The four scenarios in the model simulate policy changes in the agriculture sector and the results are compared to Baseline 2030 to estimate blue, green, and gray water savings.

5.1 2015 Baseline

Using the IOTT 2014-15, the baseline water demand (green, blue, and gray) for 2015 is estimated and the results are provided below.

[8] E3-India is a dynamic macro-econometric simulation model developed as a tool for state and national level analysis in India (Pollitt, 2021). Detail is given in the methodology and data section.

Table 9: Green, Blue, Gray, and Total water demand (in BCM) of 16 crop sectors in India for 2015

Crops	Total Green water demand (BCM) 2015	Total Blue Water demand (BCM) 2015	Total Gray water demand (BCM) 2015	Total water demand (BCM) 2015
Paddy	422.63	136.97	67.96	627.59
Wheat	370.41	669.61	169.47	1209.50
Coarse Cereals	10434.67	865.96	718.04	12018.67
Gram	91.38	3.49	19.75	114.61
Arhar	23.15	0.76	5.09	29
Other Pulses	320.75	12.22	69.24	402.21
Coconut	501.09	59.91	36.31	597.32
Rapeseed & Mustard	36.56	32.64	5.22	74.42
Other oil seeds	238.13	6.64	9.96	254.72
Kapas jute mesta	4.79	1.58	0.68	7.05
Sugarcane	24	27.57	3.33	54.91
Coconut	566.24	0	9.93	576.18

Tobacco tea coffee rubber	0	0	0	0
Fruits	11338.59	2551.59	1028.30	14918.48
Vegetables	1968.05	974.33	681.06	3623.43
Other Food crops	258.02	127.19	89.04	474.25
TOTAL	26598.5	5470.46	2913.38	34982.31

As a single crop category, wheat has the highest blue water use, an estimate of 669.61 BCM in 2015. These results confirm the blue water intensive nature of the crop as it is primarily grown in the rabi (winter) season, and depends on irrigation, blue water for its growth and yield. In the fiscal year 2014-15, the national production of wheat is estimated to be 104.4 million tonnes, the highest for any cereal crop in the year. The country produces excess wheat, i.e., more production than its requirement, leading to procurement by the government. Given this excess production of wheat, there is scope in agricultural policy to reduce blue water use by reducing government demand and procurement of the staple crop. Since wheat is primarily grown in the non-rainy season from October to April, the green water demand for the crop is almost half of the blue water demand and is estimated to be 370.41 BCM in 2015. This partially insulates the crop from production risk emerging from change in weather and climate patterns affecting green water use. In comparison, paddy has an estimated blue water demand of 136.97 BCM and green water demand of 422.63 BCM. In the single crop category, paddy is the second most blue water intensive crop in the agriculture sector. Since paddy is grown in both the rainy (kharif) and winter (rabi) season, the crop has relatively less blue water demand in comparison to wheat.

In terms of gray water generated, wheat has the highest value as a single crop category estimated to be 169.47 BCM. The crop is fertilizer intensive using an average of 120 kg of nitrogen, 60 kg of phosphorous, and 30 kg of potash per hectare. In addition, the nutrient sulphur has been found beneficial for enhancing the productivity as well as the grain protein content of wheat implying the importance of prudent nutrient management.

Regional analysis demonstrates states such as Haryana, Punjab, Uttar Pradesh, and Madhya Pradesh which are the wheat baskets of the nation are estimated to be affected by regional water stress and scarcity. The skewed cropping pattern towards wheat in these states adds financial strain on the regional water supply agencies given the fact, both groundwater and surface water irrigation are subsidized. The cost of water-supply estimated by the E3-India model in these states is estimated to be 6705, 24914, 2059, 43214 million rupees respectively at 2011 prices in the year 2015 indicating significant differences in state irrigation and water pricing policies.

Due to the widespread production of wheat in Northern India, it is important to understand the area under production of the crop according to different regional zones. In this context, the following table indicates the 6 major wheat growing zones in the country.

Table 10: 6 major wheat growing zones in India in 2018

Zones	States/Regions Covered	Approx Area (million ha)
Northern Hill Zone (NHZ)	Hilly areas of J&K, Himachal Pradesh, Uttarakhand & Sikkim	0.8
North Western Plains (NWPZ)	Punjab, Haryana, Western UP, Rajasthan, Tarai region (Uttarakhand), Una and Paonta Valley of Himachal	11.55

	Pradesh, Jammu, Samba, and Kathua districts of J & K and Chandigarh	
North Eastern Plains Zone (NEPZ)	Eastern UP, Bihar, Jharkhand, West Bengal, Assam, Odisha, and other North Eastern States	10.5
Central Zone	MP, Gujarat, Chhattisgarh, Kota and Udaipur district of Rajasthan, and Jhansi Division of UP	5.2
Peninsular Zone	Maharashtra, Tamil Nadu, Karnataka, and Andhra Pradesh	1.6
Southern Hill Zone (SHZ)	Nilgiris and Panali hills of Tamil Nadu	0.1

Source: GOI (2018)

The North-western plains comprising of Punjab, Haryana, and parts of Uttar Pradesh, Rajasthan, Uttarakhand, Himachal Pradesh, and Jammu and Kashmir have the largest area under wheat production estimated to be 11.55 million hectare, followed by the North Eastern Plain Zone of eastern Uttar Pradesh, Bihar, Jharkhand, West Bengal, Assam, Odisha, and other North eastern states with an estimated area under production of 10.5 million hectares. Gulati and Banerjee (2016) demonstrate declining groundwater tables in the states of Punjab, Haryana, and western Uttar Pradesh is associated with wheat production in these states. Therefore, given the water stress in these northern plains, it is important to diversify the area under the production of wheat to other growing zones such as the Central and Peninsular zones for sustainable production of the crop.

The group crop categories such as coarse cereals, fruits, and vegetables are large consumers of green water. Since these groups are an aggregate of crop categories, the total water demand exceeds that of other single crop categories. In 2015, the green water demand for coarse cereals (such as millets, sorghum, etc.) is estimated to be 10434.67 BCM indicating the dependence of the group on the kharif (rainy) season.

In comparison to green water demand, the total blue water demand and gray water generated for the coarse cereal group category are relatively less and are estimated to be 865.96 BCM and 718.04 BCM respectively in 2015. In this context, it is important to note the environmental impact on major coarse cereal producing states. States such as Rajasthan, Maharashtra, and Karnataka are major producers of coarse cereals with an average production of 65 lakh tonnes in 2011-12. This implies the dependence of agriculture in these regions on green water consumption and the associated increased production risk due to climate change. Therefore, agricultural policies such as drought adaption measures and rainwater harvesting are needed to insulate farmers in these states from water scarcity and production risk.

Fruits is the group category which has the highest blue water demand in 2015 estimated to be 2551.59 BCM. The category also has the highest green and gray water demand (relative to other group categories such as coarse cereals and vegetables) which are estimated at 11,338 BCM and 1,028 BCM. The analysis of the group category demonstrates the growing importance of horticulture crops in the allocation of water in the agriculture sector. States such as Andhra Pradesh, Maharashtra, and Uttar Pradesh face increased blue and gray water demand with a relatively large horticultural agricultural production.

In terms of regional water scarcity, it is important to discuss the production of sugarcane in Maharashtra. The national model estimates 27.57 BCM of blue water consumed by sugarcane in 2015. A large proportion of the crop is produced in Maharashtra which contributes 22 percent of the total production in India (GOI, 2018). The state produced 1,013 lakh tonnes of the crop in 2020-21 (Bhosale, 2021). This figure is expected to increase in the coming years implying increasing blue water demand in the state. Sub-regions within the state such as Western Maharashtra and Marathwada face an acute water crisis due to the large regional blue water demand for the crop implying the importance of regional water discussion in addition to the national level discourse on water and agriculture policies.

In terms of categories of water demand, it is seen that total green water demand is the highest in agriculture and is estimated to be 26,598.50 BCM in 2015. This confirms the fact that more than 50 percent of the cropped area in Indian agriculture is rain-fed consuming green water (GOI, 2022). It must be noted that most of the water requirement is for agricultural products such as cereals, fruits, vegetables, and the demand gap between these and the other products is quite large indicating that there is a biasness in the demand for water reflected by a few specific agricultural commodities.

5.2 2030 Baseline

In preparing 2030 Baseline, an assumption of no change in agricultural policy and technology is made. The detailed assumptions are:

a.) The dominance of paddy and wheat in the public procurement system continues in 2030 with no reduction in the Minimum Support Prices (MSPs) and incentives for production for these crops;

b) There is no major change in irrigation technology or adoption of water saving genomic varieties of crops produced in India in 2030.

Using the E3-India model, the baseline water demand (green, blue, and gray) for 2030 is estimated and the results are provided below.

Table 11: Green, Blue, Gray, and Total water demand (in BCM) for 16 crop sectors for 2030

Crops	Total Green Water demand (BCM) 2030	Total Blue water demand (BCM) 2030	Total Gray Water demand (BCM) 2030	Total Water demand (BCM) 2030
Paddy	501.70	162.60	80.68	744.98
Wheat	439.71	794.90	201.18	1435.79
Coarse Cereals	12387	1027.98	852.38	14267.37
Gram	108.47	4.14	23.44	136.05
Arhar	27.48	0.91	6.04	34.43
Other Pulses	380.76	14.51	82.19	477.46
Coconut	594.85	71.12	43.10	709.08
Rapeseed & Mustard	43.40	38.75	6.20	88.35
Other Oil seeds	282.68	7.88	11.82	302.38
Kapas jute mesta	5.69	1.87	0.81	8.37
Sugarcane	28.50	32.72	3.96	65.18
Coconut	672.190	0	11.80	683.98
Tobacco, tea coffee rubber	0	0	0	0
Fruits	13460.04	3028.99	1220.69	17709.73

Vegetables	2336.27	1156.62	808.49	4301.38
Other Food crops	306.30	150.99	105.70	562.98
TOTAL	31575.04	6493.98	3458.48	41527.50

The baseline 2030 results demonstrate the increase in green, blue, and gray water demand for all 16 crop varieties due to an increase in aggregate demand from 2015 to 2030. The pattern of the highest water demand commodities in each of the categories (green, blue, and gray water) remains the same as in 2015. In 2030, wheat is the single-crop category consuming the highest blue water and is estimated to consume 794.90 BCM. In comparison, fruits are the group category, which consumes the largest blue water and are estimated to consume 3028.99 BCM, followed by coarse cereals which consume 1027.98 BCM of blue water.

The estimated increase in total blue water, green water, and gray water demand from 2015 to 2030 are 1,023 BCM, 4,977 BCM, and 545 BCM respectively. The increased demand for these water categories is an indication of increased pressure on surface and ground water resources in 2030, increased reliance on green water and associated production risk in the coming years, and increase in the social cost and negative externalities emerging from generating gray water from agricultural production.

The 2030 Baseline simulation is an indication to the government to target these highest demand sectors when focusing on conserving water in agriculture. However, at the same time, it must also be noted that cereals, fruits and vegetables are projected to increase in the consumption basket of households over time in India (Alae-Carew et al., 2019). Therefore, it is important to consider water saving technologies in addition to demand changes in agriculture.

In the E3-India model, the regional analysis shows the cost of water supply to increase in 2030. The estimated cost of water supply in Haryana, Punjab, and Uttar Pradesh in 2030 is 45,584.8, 107,821.6, and 13,505 (million Rupees, in 2011 prices). In this context, the allocation of water supply subsidy to agriculture as a proportion of the total water supply cost in states needs to be reconsidered when providing price incentives to conserve water in agriculture.

5.3 Scenario Results

The four scenarios developed are based on demand, pricing, and technology changes in the agriculture sector. **The scenario results are in comparison to the 2030 baseline simulation in the model.**

5.3.1 Scenario 1

In the GOVTPROCURE scenario, aggregate demand for wheat and rice is decreased by 15 percent and aggregate demand for coarse cereals is increased by 10 percent in 2030. Using the demand shock, the green, blue, and gray water demand saving/loss for 2030 is estimated and the results are provided below (Table 12).

Table 12: Green, Blue, Gray, and Total water saving/loss (in BCM) in 2030 due to shift in procurement from staple to coarse cereals

Crops	Green water saving BCM (-)/loss (+)	Blue water saving BCM (-)/loss (+)	Gray water saving BCM (-)/loss (+)	Total water saving loss BCM (-)/loss (+)
Paddy	-60.19	-19.51	-9.67	-89.37
Wheat	-39.51	-71.42	-18.07	-128.99
Coarse Cereals	844.22	70.06	58.09	972.37
Water Saving/loss	744.53	-20.86	30.34	754.00

From Table 12, it can be seen that the maximum saving of green water is due to the reduction in paddy demand since any reduction in demand for the rainy-season crop implies less green water use. The green water saving due to a reduction in paddy demand in 2030 is 60.19 BCM which is higher than 39.51 BCM of green water saving due to the reduction in wheat demand.

In contrast, blue water and gray water savings due to the reduction in wheat demand is 71.42 BCM and 18.07 BCM which is the highest for 2030 in the GOVTPROCURE scenario. This reinforces the irrigation and fertilizer intensive nature of wheat production as a primary winter (rabi) season crop. In terms of total water savings, change in wheat demand leads to an estimated water saving of 128.99 BCM, which is more than 89.37 BCM of water saving due to change in the paddy demand.

The GOVTPROCURE scenario results demonstrate a shift in government procurement from paddy and wheat to coarse cereals leads to an overall increase in green water and gray water demand, estimated to be 744.53 BCM and 30.34 BCM respectively. In contrast, the shift in procurement leads to 20.86 BCM saving of blue water in 2030. **The overall water demand in the GOVTPROCURE scenario increases by 754 BCM in comparison to the baseline 2030**.

Other studies such as Shah and Vijayshankar (2021) have also estimated blue water saving due to crop replacement scenarios. The authors estimate the replacement of high water-demanding crops with low water-using ones to the extent of 10 to 50 percent of the cropped area in the kharif season and 25 to 50 percent in the rabi season. The results depict a blue water saving of 70.83 BCM to 90.81 BCM depending upon the extent of crop replacement to low water using crops. In comparison, the blue water saving of 20.86 BCM in the GOVTPROCURE scenario estimated is on the basis of a change in the composition of government procurement, and not due to an explicit crop replacement. A limitation of the Shah & Vijayshankar (2021) study is assuming crop replacement without defining any demand-side or supply-side mechanism to achieve the replacement. The GOVTPROCURE scenario, in contrast, clearly defines a demand-side mechanism of government procurement for a change in crop production and blue water saving.

The results of the GOVTPROCURE scenario demonstrates a shift in procurement from staple to coarse cereals is impactful to save blue water use but increases green and gray water demand in 2030. This implies the need to balance trade-offs between the three categories of water use when considering any agricultural policy altering the cropping pattern and the demand for crops. Factors such as regional blue water stress, precipitation patterns in recent years, and agricultural run-off management need to be taken into account before any national level agricultural policy change.

In order to conserve blue water, the government has implemented the Crop Diversification Programme (CDP) in the original green revolution states of Punjab, Haryana, and

Western Uttar Pradesh as a sub-scheme of the Rashtriya Krishi Vikas Yojana (RKVY) since 2013-14 (GOI, 2022). The objective of the programme is to shift the area under paddy cultivation towards less blue water consuming crops such as oil seeds, pulses, nutri-cereals, cotton, etc. An important path to achieving this is through incentive structures provided under the MSP regime which can affect variation in return over cost across crops. Thus, in this context, the discussion in the GOVTPROCURE scenario results can provide policymakers with a balanced overview of the impact on water use of a crop diversification programme taking into account green and gray water demand in the analysis too.

5.3.2 Scenario 2

In the WATEREFF scenario, two exogenous technology shocks are given to the model. Using these shocks, the total blue water saving for 2030 is estimated and the results are provided below (Table 13).

Table 13: Total Blue water saving (in BCM) in 10 crop varieties due to increase in water use efficiency in 2030

Crops	Total Blue water saving (BCM) (-)
Wheat	- 351.59
Coarse Cereals	- 454.55
Gram	- 1.8
Arhar	- 0.41
Other Pulses	- 6.5
Groundnut	- 31.6
Rapeseed-Mustard	- 17.14
Other oil seeds	- 3.49
Vegetables	- 511.78
Other Food crops	- 66.68
TOTAL	- 1445.54

The WATEREFF scenario results show that if canal irrigation is replaced by alternate high efficiency irrigation systems for the above 10 crops, the country can save 1445.54 BCM of blue water, which is much larger than the blue water saving due to the GOVTPROCURE demand shock. The WATEREFF scenario results are an indication to agricultural policymakers about the importance of investing in efficient water use technologies in the country, in comparison to the discourse focusing mainly on demand side policies (Shah & Vijayshankar, 2021). The maximum blue water savings in the scenario can be seen in vegetables, coarse cereals, and wheat and indicates a positive signal to policymakers as these commodities were high water demand categories in the baseline 2030.

In comparison, other studies have also demonstrated the blue water saving potential of high-efficiency irrigation systems such as drip irrigation for water-intensive crops such as wheat. Results from Chouhan et al. (2015) reveal blue water savings of 28.42 percent due to the adoption of drip irrigation for wheat in the state of Madhya Pradesh. Suryanvanshi et al. (2016) estimated a 57 percent blue water saving in wheat production in Punjab due to the adoption of drip irrigation in comparison to conventional irrigation practices. These studies supplement the results from the WATEREFF high efficiency irrigation scenario demonstrating the blue water saving capacity of drip irrigation.

The regional analysis shows that the largest wheat producing states of Punjab, Haryana, Rajasthan and Uttar Pradesh in northern India along with Madhya Pradesh in central India will see the largest impact of blue water saving due to the WATEREFF scenario. Similarly, Rajasthan, Karnataka, Madhya Pradesh and Maharashtra which are the largest producers of coarse cereals, see the largest decrease in blue water requirement due to the adoption of water efficient irrigation technologies.

However, when considering the increase in efficiency of irrigation technology, it is important to take into account regional disparities in irrigated area. On average, 49.80 percent of the cultivated area in India is irrigated, and the rest is rain-fed agriculture (GOI, 2022). In terms of irrigation, widespread regional disparities exist. Jharkhand has 7 percent of its agricultural area irrigated whereas Punjab has 98.70 percent of its area under irrigation. Major agricultural states such as Uttar Pradesh, Haryana, and Madhya Pradesh have 76.10, 88.90, and 50.50 percent of the respective agricultural area irrigated (Dhawan, 2017). Therefore, it is regions which have a large percent of the cropped area under irrigation management (such as Punjab and Haryana) which can benefit from adoption of alternate water-efficient technologies.

The results of the below table (Table 14) show that if irrigation canals are modernized and moved to a lined canal system then the estimated blue water saving in 2030 is 588.06 BCM.

Table 14: Total Blue water saving (BCM) in 11 crop varieties due to conveyance modernization in 2030

Crops	Total Blue water saving (BCM) (-)
Paddy	- 36.4
Wheat	- 220.55
Coarse Cereals	- 285.14
Gram	- 1.12
Arhar	- 0.24
Other Pulses	- 4.09
Groundnut	- 19.81
Rapeseed & Mustard	- 10.74
Other oil seeds	- 2.13
Kapas, jute, mesta	- 0.52
Sugarcane	- 7.32
TOTAL	- 588.06

The blue water saving estimated in this scenario is less than the water saving due to adoption of high efficiency irrigation systems but more than the GOVTPROCURE demand shock, indicating the importance of upgrading technology in water management. Here again, the largest wheat and coarse cereals producing states see the largest blue water saving impact. The estimated total blue water saving in wheat due to conveyance modernization of irrigation canals is 220.55 BCM. In comparison, the blue water saving for paddy in this scenario is only 36.4 BCM. Coarse cereals as a group category save 285.14 BCM. Other crops which save blue water from upgrading the canal irrigation systems are: groundnut, rapeseed and mustard, and sugarcane saving 19.81 BCM, 10.74 BCM, and 7.32 BCM of blue water respectively.

It is important to note states such as Uttar Pradesh, Punjab, and Haryana, which already have canal irrigation infrastructure in place can benefit from the WATEREFF canal modernization scenario. Based on this scenario, national and state governments can develop canal modernization polices to improve water delivery and reduce conveyance losses in agriculture.

Along with the modernization of canals, complementary institutional reforms are also needed in irrigation management. Many large-scale canal irrigation systems perform below their potential due to inadequate water resource management and maintenance (Meinzen-Dick, 2007). It is this underperformance of irrigation system which has led to the creation of water user associations (WUAs) across regions which are farmer led organizations to manage allocation, distribution, and management of water at the local level. Meinzen-Dick (2007) demonstrates the poor collection of canal user fees is a major factor leading to poor maintenance of canals. The management and collection of user fees by a farmer-based, participatory organization in which farmers organize themselves to manage the village's irrigation systems can facilitate economically viable upgrading and maintenance of irrigation systems. Centralized agencies are unable to measure the amount each farmer consumes, to exclude those who do not pay, and asses the value of water in production. WUAs, therefore, have a relative advantage due to greater local knowledge of members using the irrigation services (Subramaniam et al., 1997).

5.3.3 Scenario 3

In the GENOMPADD scenario, the total water saving in 2030 is estimated due to the adoption of a genomic water saving variety of rice (HRD Rice). Using this technology shock, the total green, blue, and gray water saving for 2030 is estimated and the results are provided below (Table 15).

Table 15: Green, Blue, Gray, and Total water saving (in BCM) due to adoption of HRD rice in 2030

Crops	Green Water Saving (-) BCM	Blue Water Saving (-) BCM	Gray Water Saving (-) BCM	Total Water Saving (-) BCM
HRD Paddy	-131.37	-42.58	-21.13	-195.07

The results show that the new genomic variety of rice can save 131.37 BCM of green water, 42.58 BCM of blue water, and 21.13 BCM of gray water in 2030 if adopted in the Indian context and replaces the conventional rice variety grown.

Regional analysis demonstrates that the largest impact on water consumption due to the adoption of HRD rice on states such as Punjab, Haryana, West Bengal, and Uttar Pradesh which are the largest producers of paddy. It is seen from the GENOMPADD scenario results, saving in green water is the highest and estimated to be 131.37 BCM. This is followed by a blue water saving of 42.58 BCM. The reduction in green water consumption for paddy in this scenario can reduce financial risk for farmers during drought years and reduce dependence on the rainy season for crop production.

However, a major challenge of adopting water saving new genomic varieties of crops across the country can be the reluctance of farmers to change from the conventional seed varieties used. In this context, agricultural extension services such as the establishment of Krishi Vigyan Kendras (KVKs) can help test and demonstrate the benefits of on-farm technology to farmers (Meena et al., 2013). These micro-level agricultural institutions are equally important and complementary to any national level strategy to adopt and scale up water-saving seed varieties.

In this context, studies have evaluated farmers' valuation of water saving rice varieties tolerant to droughts and floods. In a discrete choice experiment in Odisha, Arora et al. (2019) found farmers perceive the threat of drought and are willing to pay for protection against drought risk. Further, only farmers in flood-prone areas are willing to pay for rice that can withstand being submerged for prolonged periods. The results indicate all farmers, even those not residing in designated drought-prone areas, perceive susceptibility to droughts, highlighting the importance of drought resistance and water-saving seed varieties. Ward et al. (2014) examined farmers' preferences using primary data from Bihar and the results suggest farmers value reductions in yield variability offered by drought tolerant (DT) paddy, but are willing to pay even more for seeds that offer yield advantages under normal conditions. Therefore, it is important to consider yield growth and its impact on farm income too, when adopting new water-saving and drought tolerant crop varieties.

5.3.4 Scenario 4

In the IRRSUBSD scenario, the direct and total blue water saving is estimated due to a 30 percent increase in the average cost of irrigation allocated to crop varieties in the model. Using the policy shock, the direct and total water saving in 2030 is estimated and the results are provided below (Table 16).

Table 16: Direct and Total water saving (in BCM) due to an increase in the average cost of irrigation by 30 percent

Crops	Increase in cost of Irrigation water (Lakh Rupees)	Direct Water Saving (-) (BCM)	Total Water Saving (-)(BCM)
Paddy	225264.42	-11.78	-12.13
Wheat	128226.33	-8.60	-8.95
Coarse Cereals	58004.75	-30.63	-30.98
Gram	24286.63	-1.16	-1.51
Arhar	14617.31	-0.45	-0.80
Other Pulses	33617.92	-1.55	-1.90
Groundnut	29455.62	-1.29	-1.64
Rapeseed and Mustard	21614.56	-0.90	-1.25
Other oil seeds	53615.39	-1.21	-1.56
Kapas, Jute, and mesta	75563.5	-7.41	-7.76
Sugarcane	77955.43	-3.82	-4.17
Coconut	21317.73	-1.59	-1.94

Tobacco, tea, coffee, rubber	37201.25	0	-0.35
Fruits	186841.29	-21.42	-21.77
Vegetables	2570797.44	-5.87	-6.22
Other Food Crops	341108.74	-1.02	-1.37
TOTAL	1585788.31	-98.70	-104.30

The results show that a reduction in irrigation subsidy reduces total blue water demand by 104.3 BCM. Fruits, Coarse Cereals, and Vegetables are crops with the most water saving. The highest water saving is for Coarse Cereals with an estimated saving of 30.98 BCM, followed by Fruits with a saving of 21.77 BCM.

Staple crops such as paddy and wheat have historically been heavily subsidized (Gulati and Sharma, 1995). In this context, a reduction in input subsidy due to the IRRSUBSD scenario is relatively not impactful to save blue water in comparison to other crops such as coarse cereals. A significant reduction in input and output (Minimum Support Price) subsidies is required for farmers to move away from the rice-wheat cropping pattern to save blue water resources. Increasing water supply and irrigation charges is a policy option which can encourage farmers to prudently use blue water and consider growing less blue water-intensive crops.

In addition to providing incentives for conserving water, increasing irrigation charges can help state irrigation departments with increasing economic returns to irrigation investment. Low water charges have remained low in many states for decades. Post-independence, due to the irrigation subsidy, state irrigation departments have been unable to recover operation and maintenance costs, which further affects budget allocated to irrigation projects and command area development, i.e., new acreage under assured water supply (Shah, 2011). It is therefore important to increase irrigation water charges to make irrigation projects economically feasible, and provide incentives to conserve water, especially in water-scarce states such as Punjab, Haryana, and Uttar Pradesh.

Although, the initial imposition of irrigation subsidies was to reduce cost of production, in recent years, these subsidies have led to negative externalities in the form of unsustainable water withdrawals in agriculture. Since irrigation subsidies impact the cost of food and farmers' income, thus any reform of subsidies is both far-reaching and complex to reform (Hellegers et al., 2021). Agricultural policymakers, in order to balance multiple objectives, need to consider alternate measures to address farmers' welfare and cost of production while reducing perverse incentives for excessive water use and withdrawals.

5.4 Discussion

The change in green, blue, and gray water estimated in the scenarios gives policymakers a platform to design policies to save water and understand the trade-offs between the three categories. In this context, any agricultural policy change focusing on saving water should take consider four factors.

Firstly, the cropping season is an important consideration in agricultural policymaking. There are two cropping seasons in India, *Kharif* is the rainy season where crops are grown from June to October and *Rabi* is the dryland season from October to April. Even though the Economic Survey 2021-22 recommends a crop diversification policy, it is important to note, any change in cropping pattern (such as staple to coarse cereals) can imply production to move from rabi to kharif season. This could lead to other challenges of erratic rainfall and climate change (Kayatz et al., 2019). Given the stress on freshwater resources in the country, saving blue water is of utmost importance, especially in water-stressed regions. However, any transition of the cropping pattern from blue to green water use impacts direct production risk of farmers. Production risk stems from uncertain natural growth processes for crops with typical sources of these risks related to changes in temperature and precipitation (Komarek, Pinto, & Smith, 2020). Hence, policy trade-offs between blue and green water use needs to be accounted for in the context of precipitation uncertainty arising due to Climate Change. Along with these trade-offs, policies directed to change the cropping pattern to conserve water should also consider impacts on food and nutritional security, climate resilience of crops, and availability of agricultural extension services.

Secondly, when designing policies to change the cropping pattern, it is important to focus on water management from a regional perspective. Rice and wheat grown in Punjab and Haryana are not suitable for the local geographical region as the water tables are declining rapidly (Gulati and Banerjee, 2016). These crops can be grown in other regions where the local water tables are not stressed. The three states with the highest irrigation draft in India are: West Bengal, Uttar Pradesh, and Uttarakhand (WRIS-India, 2021). West Bengal is a major rice producer, Uttar Pradesh produces a rice-wheat/oilseeds cropping combination, and Uttarakhand produces rice (high quality *Basmati* rice) and other crops such as maize and pulses (Drishti, 2021). This association between rice producing states and irrigation draft demonstrates the need for regional adoption of blue water-saving policies. Production risk can also differ in regions with different geographic and socio-economic characteristics. Shah et al. (2021) discuss regional implications of blue and green water conservation and its impact on production risk of farmers. The authors analysed the *Jalyukt Shivar Abhiyan*, a water-conservation campaign in the state of Maharashtra. Conserving soil moisture (green water) and blue water can protect rain dependent agriculture from precipitation variability. However, such an integrative water conservation campaign impacts capture, equity, and sustainability for agricultural risk reduction in drought-prone villages. The study found that the campaign excluded residents who did not possess 'endowments' and 'entitlements' needed to acquire benefits with drought relief initiatives. Therefore, any water conservation policy at a regional level to reduce the production risk of farmers needs to be widespread, accessible, and long term. In addition, there is a need to harmonize regional level and national level water saving policies to develop a cropping pattern which is sustainable and meets the food and nutritional requirements of the country.

Thirdly, with any policy designed to save blue water (in particular, groundwater) it is important to take into account the negative association between power tariffs and groundwater withdrawals (Sidhu, Kandlikar, and Ramankutty, 2020). Electricity for irrigation (such as pumping of groundwater) is highly subsidized and has led to the over pumping of groundwater from aquifers, especially in water scarce regions in the north-western parts of the country. These subsidies were created to improve farmers' welfare in post-Independence India. However, as the water table declines, more electricity is required to pump groundwater exacerbating the problem. Thus, along with macro-demand side policies the government needs to do away with perverse incentives in irrigation and agriculture that leads to exploitation of groundwater tables. In this context, authors have recommended a switch from price policy (subsidy) to an income policy to improve farmers' welfare. Gulati and Banerjee (2016) argue switching from price subsidies to direct benefit transfers (DBT) to the accounts of farmers on a per-hectare basis can be efficient and equitable. If water charges are levied such that the full operation and maintainace costs are recovered, cash can be transferred to the beneficiary account on a per-hectare basis. This can enable the farmer to pay for the increased water charges. The increased charges can incentivize efficient use of both surface and groundwater for irrigation. The DBT policy addresses both, the issue of farmers' welfare and income as well as sustainable use of water on farms. However, before any increment in water charges, the national and state government should ensure proper irrigation infrastructure and service delivery in order for farmers to be willing to pay more for water supply and irrigation to farms.

Fourthly, agricultural policy, in addition to demand-side and price policy changes, should consider adoption of green, blue, and gray water saving technologies in agriculture. The Economic Survey 2021-22 states that increased coverage under micro irrigation can be an effective method of blue water conservation (GOI, 2022). The survey recommends promoting micro-irrigation through Drip and Sprinkler irrigation under the Pradhan Mantri Krishi Sinchayee Yojana - Per Drop More Crop scheme (PMKSY-PDMC). Till 2021, under the PMKSY-PDMC, a total sown area of 59.37 lakh ha has been covered under micro irrigation from 2015-16, indicating the importance of water efficient technologies in agricultural policy. The WATEREFF and GENOMPADD scenarios demonstrate the need for the government to invest in research and development (R & D) to reduce blue water withdrawal and consumption in agriculture. It is shown that every rupee spent on agricultural research and development yields better returns compared to returns on money spent on subsidies or other expenditure on inputs (GOI, 2022). Therefore, the increase in agriculture R & D (such as investment in new irrigation technologies, water saving crop varieties) has the potential to reduce water use as well as increase agricultural productivity to boost farmers' income. For example, policies such as the Jal Shakti Abhiyan which focuses on building rainwater harvesting structures and technology in water-stressed districts to conserve green water are essential water saving supply-side policies (GOI, 2019). In addition, the Jal Jeevan mission initiated by the Government provides the technology and resources for treatment and reuse of gray water for agricultural purposes to reduce water-stress in villages. The policy has a dual objective: minimize generation of graywater and substituting the use of blue water (GOI, 2021). Further, in order to reduce the generation of gray water in agriculture, the Economic Survey 2021-22 recommends promoting the use of alternative fertilizers such as nano urea and organic fertilizer rather than conventional inorganic varieties, contributing to higher nutrient-use efficiency. Thus, adoption of water-saving agricultural technologies are a pre-requisite for sustainable agricultural practices in India in the present decade.

The scenario results indicate the vast potential for water saving from agricultural reforms. Given the increased pressure of water withdrawals from the industrial and services sector, it is of utmost importance to reduce agricultural water withdrawal and consumption by 2030. Demand, technology, and pricing policy agricultural reforms are needed to sustainably manage water use in the country. In this context, in order to achieve the United Nation's Sustainable Development Goal (UN SDG 6) of sustainable management of water resources, the scenario policies developed, and the results provide policymakers with a rubric for implementation of water saving agricultural reform in the 2020 to 2030 decade.

CHAPTER 6: CONCLUSION

6.1 Problem Situation and Research Objectives

India is a water stressed country, the annual per capita availability of water is less than 1700 m^3, which is an indicator of the country's ability to meet freshwater demand. The per capita availability of water is projected to decline to 1340 m^3 in 2025 (Gulati & Banerjee, 2016; GOI, 2018). Since water is a crucial resource for sustaining livelihoods, this decline in per capita availability of freshwater resources in India is worrisome from a policy lens (FAO, 2020). Due to hydrological and geographic constraints, the utilizable water resources in the country, i.e. macro-supply side cannot be increased (CWC, 1993). However, the government in response to the water stress can develop policies and provide incentives to conserve water. Two notable government policies initiated at a national level to conserve water are: *Atal Bhujal Yojana*, an initiative to improve groundwater management through community participation in seven states in the country (GOI, 2019); *Jal Shakti Abhiyan*, an initiative to accelerate water harvesting, conservation, and borewell recharge in 255 water stressed districts across the country (GOI, 2019). These two national-level policies are either from a micro-supply side, i.e. boosting water supply at the local level or from a micro-demand side, i.e. reducing water demand at the local level. In this context, there is no policy to address water stress and demand at the macro-level. Macro-demand side policies reduce the aggregate demand for water through changing production patterns and adopting water saving technology across different economic sectors. Hence, there is a need to develop macro-demand side policies to address water stress in India.

A major user of water, in particular freshwater in India is the agriculture sector which uses 78 percent of the country's freshwater resources (Gulati and Banerjee, 2016). Therefore, saving water in the agriculture sector is of utmost importance to address water stress. Given the current freshwater (or blue water) intensive cropping pattern in India, there is scope for saving water in the country through the adoption of an alternate cropping pattern and new irrigation technologies. In the context of Climate Change which leads to uneven rainfall patterns, and non-point source pollution due to agriculture, in addition to estimating blue water saving, there is a need to estimate green water, i.e., the amount of rainwater consumed, and gray water saving, i.e. the volume of freshwater required to assimilate a load of pollutants in agriculture based on existing water quality standards (Mekonnen and Hoekestra, 2011). It is important to study water consumption in agriculture based on the three water categories (green, blue, and gray water) to conserve the country's blue water resources, increase the adaptive capacity of agriculture to changing rainfall patterns, and reduce wastewater release from agriculture.

In this context, the objective of the study is to estimate total water demand with changing agri-food policies and agricultural technology. In particular, the study has the following research objectives:

1. Estimate total water demand in agriculture for 2015 and 2030
2. Estimate the direct and indirect impact on total water demand of domestic and exported agricultural commodities for 2015 and 2030
3. Estimate green, blue, and gray water demand for agricultural commodities in 2015 and 2030
4. Evaluate the impact of domestic agri-food policies on demand for water in 2030
5. Evaluate the impact of a change in agricultural technology on demand for water in 2030

6.2 Method

The study uses the 2014-15 Supply-Use (SUT) tables for India and was converted to a balanced Input-Output table (IOTT) for analysis. The Input-Output (IO) framework is an extension of the basic IO model of Leontief (1951). The model primarily deals with the methodology of studying the interrelationships and interdependence among different sectors of the economy. In this framework, the economy is divided into sectors and flows of goods and services among these sectors are recorded to study the relationship among them in a systematic and quantitative manner (Miller and Blair, 2009; Chakraborty and Mukhpadhayay, 2014; Sengupta and Mukhopadhyay, 2016). The IOTT is aggregated into 48 commodities, however, the agriculture sector remains disaggregated with 16 crop sectors in the model. The disaggregated agriculture sector is included because the objective of the study is to estimate green, blue, and gray water consumption in agriculture. The 'water supply' commodity in the model represents the cost of collection, purification, and distribution of water in the economy. However, the 'water supply' commodity in the model does not necessarily represent physical units of water withdrawn by different sectors as the supply of water in certain sectors such as agriculture is heavily subsidized. Therefore, the model has been extended to include a separate 'water' commodity expressed in physical terms and segregated into green, blue, and gray water categories. Based on the 2014-15 IO model and 'water commodity' data, a 2015 Baseline is prepared. Since IO models are static, i.e. the data available is for one fiscal year, in this case 2014-15, therefore, for the preparation of the 2030 Baseline, the study uses the E3-India Model (Pollitt, 2021). E3-India model (Economy, Energy, Emissions) is a macro-econometric model used to simulate the effects of economic and energy policy at the national and sub-national levels within India. This model projects sectoral output growth rate from 2015 to 2030. Based on this sectoral output growth rate data, an estimate of the total output is developed for 38 sectors in the E3-India model. We then distribute the sectoral output estimates for 2030 across the 48 sectors in the national IO model. In addition, the E3-India model helps derive the regional implications from the national level results. These include analysing impacts on water-stressed states (such as Punjab, Haryana, Uttar Pradesh, and Maharashtra) of change in government agri-food and water policies. Further, the scenario simulations developed are compared to the 2030 baseline to analyze the impact on water saving.

6.3 Results and Scenarios

The four scenarios developed in the model analyze the impact on water demand in 2030 due to changes in agricultural policy and technology. The first scenario simulates a shift in government procurement from staple cereals such as wheat and rice to coarse cereals. Given that wheat is primarily grown in the dryland (rabi) season, the largest saving in blue water observed is due to a reduction in the demand for wheat. In comparison, the largest green water saving is due to a reduction in the demand for rice which is grown both in the kharif and rabi seasons. The increase in demand for coarse cereals leads to a corresponding increase in green, blue, and gray water demand. The results indicate an increase in total green and total gray water demand, and a reduction in total blue water demand, with an overall increase in total water demand. The scenario estimates a total blue water saving of 20.86 BCM and a total water loss of 754 BCM. This implies the need to balance trade-offs between the three categories of water use in any change in agricultural policy. A water-stressed region (such as Punjab and Haryana) may benefit from a shift in government procurement to coarse cereals to save blue water. However, at the national level, the increased production risk and negative health externalities emerging from a corresponding increase in green and gray water demand must be taken into consideration. Factors such as regional blue water stress, precipitation patterns in recent years, and agricultural run-off management need to be taken into account before any national level agricultural policy change.

The second scenario simulates a change in irrigation technology with the adoption of higher efficient water saving techniques, and the conveyance modernization of irrigation canals. An increase in irrigation water-use efficiency for the production of wheat leads to a blue water saving of 454.55 BCM, the highest for any single-crop category. In terms of group categories, the largest blue water saving due to high-efficiency irrigation is observed for vegetables and is estimated to be 511.78 BCM highlighting the emerging importance of horticulture in framing agricultural policy. Similarly, in the conveyance modernization scenario, the blue water saving estimated is highest for wheat as a single-crop category and is estimated to be 220.55 BCM. In terms of group categories, coarse cereals have the highest blue water saving due to conveyance modernization and are estimated to be 285.14 BCM. The results indicate total blue water saving due to the technology shocks is much higher than the government procurement demand shock. The high-efficiency irrigation scenario estimates a total blue water saving of 1,445.54 BCM, and the conveyance modernization scenario estimates a saving 588.06 BCM. Before any comprehensive national level policy is framed, it is important to focus on command area development, i.e., increased irrigation coverage, to build baseline irrigation infrastructure, and then subsequently adopt water saving irrigation technologies. In addition, complementary institutions such as water user associations are needed at the local level for better and more prudent management and maintenance of blue water resource use and distribution.

The third scenario simulates an adoption of a genomic water saving variety of rice (HRD rice). The results indicate a saving of 131.37 BCM of green water, 42.58 BCM of blue water, 21.13 BCM of gray water if the genomic variety replaces the conventional rice varieties grown across the nation. Regional analysis demonstrates rice producing states such as Punjab, West-Bengal, and Uttar Pradesh save the most blue water in this scenario. It is important to note any national level adoption of new genomic varieties requires complementary micro-level agricultural extension services (such as Krishi Vigyan Kendras) to help demonstrate to farmers the economic and environmental benefit of these varieties. In this context, studies have demonstrated the willingness of farmers to pay more for drought tolerant and water saving varieties highlighting the importance of price incentives to adopt these varieties on a national scale (Arora et al., 2019; Ward et al., 2014). The scenario demonstrates the importance of investing in agricultural research and development in the country to produce drought tolerant and water saving crop varieties.

The fourth scenario simulates a reduction in irrigation subsidy leading to an increase in the average cost of irrigation. The results indicate blue water saving for all crop varieties, but the extent of the saving differs for each variety. The highest blue water saving estimated is 30.98 BCM for the group crop category coarse cereals, followed by 21.77 BCM for fruits. Historically heavily subsidized varieties such as rice and wheat witness less blue water saving in comparison to other crops since subsidies on the output-side in the form of minimum support prices (MSPs) are still prevalent for these varieties (Gulati & Sharma, 1995; Gulati & Banerjee, 2016). It is seen that apart from saving blue water, winding down irrigation subsidies can increase economic returns to irrigation investment, and hence improve irrigation performance and management. Since agricultural subsidies are usually put in place to increase farmers' income, any reduction in these subsidies can be complex to reform (Hellegers et al., 2021). Therefore, in order to address the dual objectives of farmers' income and water stress in agriculture, an alternate mechanism of addressing the welfare needs to be considered which does not exacerbate the problem of excessive water withdrawals.

6.4 Discussion

The study emphasizes three pathways to saving water in India for the 2020-2030 decade. Firstly, demand side management should be region specific focusing on water stressed states such as Punjab and Haryana. The Crop Diversification Programme (CDP) under the Rashtriya Krishi Vikas Yojana (RKVY) implemented in the original green revolution states of Punjab, Haryana, and Western Uttar Pradesh holds potential to save blue water in water stressed regions. However, any national level strategy altering the cropping pattern should consider trade-offs between blue, green, and gray water use. A shift in procurement from staple to coarse cereals in the GOVTPROCURE scenario leads to a decrease in total blue water consumption but an increase in total green and gray water consumption. The shift in cropping patterns leads to a higher dependence on rainfall and associated production risk for farmers due to climate change and increased non-point source pollution from agriculture.

Secondly, the study highlights the importance and potential of water-saving technologies in agriculture. High-efficient irrigation techniques, conveyance modernization of canals, and genomic varieties of crops can reduce blue water consumption and withdrawal in agriculture. In this context, the promotion of drip and sprinkler irrigation under the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) holds great potential to save blue water use. However, the implementation of these technologies depends on the adoption of complementary institutions such as the availability of agricultural extension services and the creation of Water User Associations (WUAs). The development of extension services such as Krishi Vigyan Kendras across the country can help in scaling up the adoption of new water-saving crop varieties. It is demonstrated that management and collection of water user fees by a farmer based participatory organization improves irrigation performance and maintenance of canals. A decentralized approach leads to greater knowledge of members using the irrigation services, and hence better supervision and management.

Thirdly, the importance of 'pricing water' and removing irrigation subsidies are highlighted to provide incentives for judicious use of blue water resources. The pricing policy complements irrigation performance and management through better economic returns. A major area of reform is state subsidies for electricity and the associated marginal cost of pumping groundwater in agriculture. Electricity for groundwater irrigation is highly subsidized leading to overpumping of groundwater from aquifers. In this context, the study recommends switching from price subsidies to direct benefit transfers (DBT) to the accounts of farmers on a per hectare basis. The DBT policy enables the farmer to pay for increased water charges incentivizing efficient use of blue water without reducing farmer welfare or income.

In conclusion, policymakers should consider a mix of demand, technology, and pricing policy to reduce water withdrawals and consumption in agriculture in the 2020 to 2030 decade. These policies should be region specific and consider trade-offs if implemented at the national level. In this context, the role of complementary institutions such as participatory irrigation management, agricultural extension services, and watershed development should not be neglected for sustainable use of water in agriculture.

6.5 Limitations of the study

The model used in the study was the 2014-15 input-output (IO) model of the Indian Economy. The industrial structure of the economy can change from 2015 to 2030. The scenario simulations assume the 2014-15 industrial structure. Using the 2014-15 IO model, may not capture the newest technology coefficients between industrial sectors, and the changes in the economy can impact the extent of water demand. The main limitation in the study relates to the unavailability of green and gray water consumption data for industry and service sectors. Reliable estimates of blue water consumption data are included for agriculture, industry, and services sectors in the model, however, there is no reliable source of green and gray water consumption for industrial and service sectors. The study doesn't estimate the cost of adoption of new water saving technologies (such as drip & sprinkler irrigation, and genomic variety of rice) at a national and regional level which can be a consideration in agricultural policymaking. Lastly, there is no disaggregated data for group crop categories, namely, coarse cereals, fruits, and vegetables in the 2014-15 IOTT model. Thus, total green, blue, and gray water consumption data is not estimated for individual categories such as maize, sorghum, millets, barley; bananas, apples, oranges, pineapples; potatoes, brinjal, cauliflower, etc., instead total water estimates are available for the corresponding group categories.

6.6 Future Research

Future studies on the topic can account for water use in regional specific IOTT models which can provide policy focus on the idiosyncrasies of particular states and regions. For example, a region specific IOTT model for the state of Maharashtra can give better insight into the state-wide economic and environmental impacts of reducing sugarcane production. Further, sophisticated hydrological models which take into account the interactions between green, blue, and gray water can give better insight into water consumption in agriculture, and its possible impacts on the regional hydrological cycle. Studies on water saving due to treatment of gray water and re-use in agriculture are another area of future research. A cost-benefit analysis of the adoption of new irrigation techniques is also needed in the future to justify irrigation reform in agriculture.

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APPENDIX 1: Aggregation Scheme

Aggregated commodity	Commodities
Cash crops	Kapas (10); jute, hemp, and mesta (11)
Tobacco & beverages	Tobacco (14), Tea (15), Coffee (16), Rubber (17)
Livestock	Milk (21), Wool (22), Egg & Poultry (23), Other Livestock products (24)
Forestry & logging	Industry wood (25) , Firewood (26), other forestry products (27)
Fishing & aquaculture	Inland fish (28), Marine fish (29)
Coal, natural gas, & petroleum	Coal and Lignite (30), Natural Gas (31), and Crude Petroleum (32)
Non- ferrous metal ores	Manganese ore (34), Bauxite (35), Copper Ore (36), Other Metallic Minerals (37)
Other mining	Limestone (38), Mica (39), other non metallic minerals (40)
Processed food	Processed poultry meat & poultry meat products (41), Processed other meat & meat products (42), Processed fish & fish products

	(43), Processed fruits and processed vegetables (44)
Food products	Dairy products (45), Edible oils and fats (46), Grain mill products, starch and starch products (47), Sugar (48), Bread & Bakery products (49), Misc. food products (50), Tobacco products (55)
Other Beverages	Alcoholic beverages (51), non- alcoholic beverages (52), tea processed (53), coffee processed (54)
Textiles	Cotton yarn and cotton textiles (56), Synthetic yarn and synthetic textiles (57), Wool yarn and woolen textiles (58), Silk yarn and silk textiles (59), Carpet weaving (60), Ready made garments (61), Misc. textile products (62)
Leather	Leather footwear (63), Leather and leather products except footwear (64)
Wood & furniture	Wood and wood products except furniture (65), Paper, paper products and newsprint (66), Publishing, printing, and allied activities (67), Furniture & fixtures (68)
Rubber & Plastic products	Rubber products (69), plastic products (70)

Petroleum & coal tar products	Petroleum products (71), Coal tar products (72)
Chemicals	Inorganic (73), organic chemicals (74)
Fertilizers & pesticides	Fertilizers (75), Pesticides (76)
Synthetic chemicals	Paints, varnishes, and lacquers (77), Drugs and medicine (78), Soaps, cosmetics, and glycerin (79), Synthetic fibres, resin (80), Other chemicals and chemical products (81)
Cement & other products	Cement (82), Non- metallic mineral products (83)
Iron & steel alloys	Iron and steel ferro alloys (84), Iron & steel casting and foraging (85), Iron and steel foundries (86)
Non– ferrous metals and hardware	Non ferrous basic metals (including alloys) (87), Hand tools, hardware (88), Misc. metal products (89), Tractors and other agricultural implements (90)
Industrial machinery	Industrial machinery for food and textile industry (91), Indistrial machinery (except food & textiles) (92)
Electrical machinery	Machine tools (93), Other non-electrical machinery (94), Electrical industrial

	machinery (95), Other electrical machinery (100)
Electrical equipment	Electrical cables (96), Batteries (97), Electrical appliances (98), Coomunication equipment (99)
Precision equipment	Electronic equipment including T.V (101), Medical precision, optical instrument (102), Watches and clocks (103), Gems & jewellery (111)
Transport equipment	Ships and boats (104), Rail equipment (105), Motor vehicles (106), Motor cycles and scooters (107), Bicycles, cycle-rickshaw (108), Aircrafts & spacecrafts (109), other transport equipment (110)
Construction	Misc. manufacturing (112), Construction and construction services (113)
Electricity & Gas	Electricity (114), Gas (115)
Transport Services	Repair & Maintainace of motor vehicles (118), Railway transport (120), Land transport (121), Air transport (122), Water Transport (123), Supportive and auxillary transport activities (124)

Storage and renting of capital	Storrage and warehousing (125), Ownership of dwellings (129), and Renting of machinery and equipment (131)
Services	Communication services (126), Financial services (127), Insurance services (128)
Other Services	Trade (117), Hotels & Restaurant (119), Real estate services (130), Research & Development Services (132), Legal Services (133), Other Business Services (134), Computer related services (135), Public administration and defence (136), Education services (137), Human health and social care services (138), Community, social, and personal services (139), Recreation, entertainment, and radio & TV broadcasting and other services (140)

APPENDIX 2: List of Agricultural Commodities

Serial Number	Agricultural Commodity
1	Paddy
2	Wheat
3	Coarse Cereals
4	Gram
5	Arhar
6	Other Pulses
7	Groundnut
8	Rapeseed and Mustard
9	Other Oil Seeds
10	Cash crops
11	Sugarcane
12	Coconut
13	Tobacco & Beverages
14	Fruits
15	Vegetables
16	Other food crops