Mitigation of Groundwater Depletion in India

MPA/ID Second Year Policy Analysis

Picture: Villagers gather to collect water from a well that was filled by a tanker in Kasara, Maharashtra
Cover picture credit: © Indranil Mukherjee, Source Business Standard

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Executive summary

India is the largest consumer of groundwater, utilizing more than a quarter of global annual groundwater available. Average annual per capita availability of water in India was 1486 cubic meters in 2021, (water stressed i.e., less than 1700 Cubic meters per capita) and is projected to decline to 1367 cubic meters by 2031[1] (inching closer to the "water scarcity" i.e., less than 1000 cubic meters). This depletion poses significant threats to India's food security, socio-economic welfare, and economic growth, ultimately impacting global food stability.

While agriculture is the most severely affected sectors, ironically it is also the single biggest factor driving groundwater demand. Farmers form 50% of the nation's workforce but are among the lowest-income groups, necessitating government to prioritize their' socio-economic welfare in tackling groundwater depletion.

A causal analysis exposes distorted markets and lack of incentives for water conservation compelling farmers to excessively rely on groundwater. Key Findings identified are: 1. Lucrative pricing prompts a shift towards water-intensive crops like rice, wheat, and sugarcane, overshadowing dryland alternatives like ragi and jowar. 2. The tragedy of the commons problem in collective use of groundwater exacerbated with politically driven incentives such as electricity subsidies, hinders pro-conservation behaviour of individual farmers. and 3. Logistical hurdles, notably the scarcity of affordable skilled labor, pose a major obstacle to embracing water-efficient agricultural practices.

Potentially, the answers lie in correcting some of these bottlenecks, to allow the market forces to play out in the interest of farmers, to achieve a win-win situation. This SYPA proposes a two-pronged strategy: one targeting markets and the other focusing on the community, guided by Eleanor Ostrom's collective action principles:

- Recommendation 1: Deepen and widen the market while driving-up demand for millets and dryland crops and supporting investments in building value chains for them.
- Recommendation 2: Facilitate and scale-up 'community driven & governed' efforts toward long term groundwater conservation efforts by farmers to build socially supported systems with potential for self-limiting groundwater use and collective groundwater recharge.

[1] Ministry of Jal Shakti, India. "Per Capita Water Availability." Press Information Bureau. [Online] Available at: https://www.pib.gov.in/PressReleasePage.aspx?PRID=1882796

I. Problem Statement

World bank estimates that ***accelerating groundwater depletion threatens 63% of India's districts risking at least 25% of India's agriculture****.*

Since "more than 60% of irrigated agriculture and 85% of drinking water supplies are dependent on ground water[2]", severe ***depletion jeopardizes livelihoods of half-a-billion people.***

In fact, ***NITI Ayog[3] projects that by 2030, demand for fresh water will be double the supply impacting 6% of GDP***

II. Motivation & Background

2.1. Problem Motivation

India is the most populous country in the world with a population of 1.48 billion of which 47% are directly engaged on agriculture. India is the world's largest user of groundwater, accounting for about 25% of the total global withdrawal. India's groundwater consumption is about 39% of the country's total usable water resources. Compared to major world countries, India has a high degree of extraction of groundwater[1].

Chart1: Ground water consumption trends by various countries

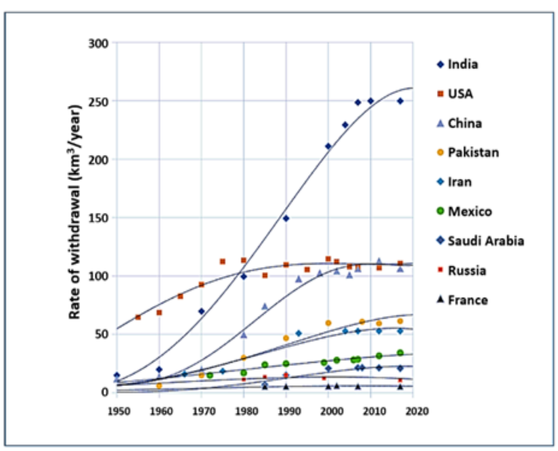
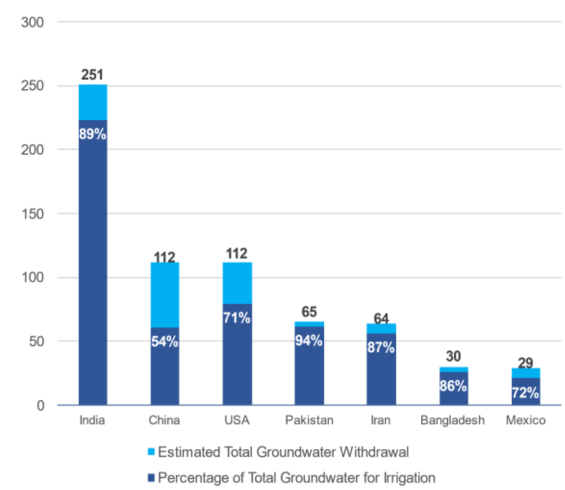


Chart2: Estimated total groundwater withdrawal (km3) and percentage used for Irrigation (2010)



Data Source: Custodio, E., Thematic Paper 1; after Margat and Van der Gun, 2013

[2] India Groundwater: a Valuable but Diminishing Resource, world Bank 2012, https://www.worldbank.org/en/news/feature/2012/03/06/india-groundwater-critical-diminishing

[3] National Institution for Transforming India (NITI Ayog) serves as the apex public policy think tank of the Government of India, HTTPs://www.niti.gov.in/

With 2% of total land mass and only 4 % of global water resources, India supports 18% of human population and 15% livestock, making it one of the most water-stressed countries in the world. India is the largest consumer of groundwater, consuming more than US and China together.

India's average annual per capita availability of water was 1486 cubic meters in 2021, categorizing it as "water stressed" (less than 1700[4] Cubic meters per capita). Projections indicate a further decline to 1367 cubic meters by 2031[5], inching closer to the "water scarcity" threshold (less than 1000 cubic meters).

The FAO data on percentage of area irrigated with groundwater shows how large parts of north-western and southern India are almost 100% irrigated by groundwater. Since the 1960s, ar]ea irrigated by tube wells surpassed all other modes of irrigation indicating the dominance of groundwater for irrigational purposes.

Chart 3: Percentage of area irrigated with ground water

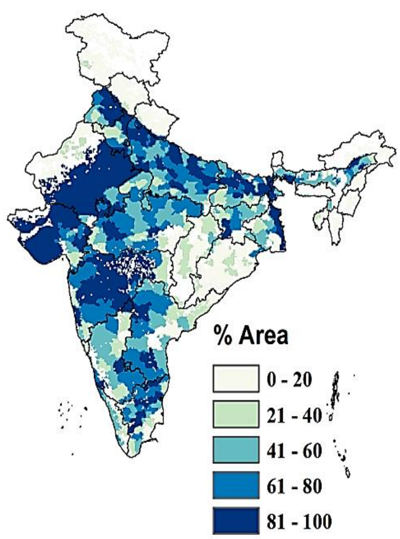
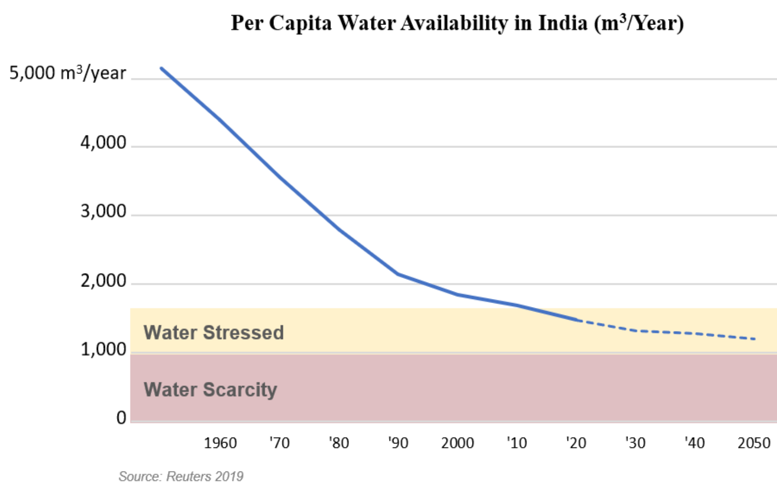


Chart 4: Time trend of different sources of water for irrigation



Tumbling per-capita water availability is accelerated by 'dying' aquifers due to over-extraction accelerated by global warming and increasing population. Studies by Reuters (2019) reveal a **4-fold decrease in per-capita** water availability in past 5 decades.

[4] Water scarcity | International Decade for Action 'Water for Life' 2005-2015 (un.org)
[5] Per Capita Water Availability, Ministry of Jal Shakti, India, Press Information Bureau (pib.gov.in)

2.2. Comparison

India and its neighbouring countries face common issues of excessive extraction, inadequate management, and growing demand leading to Groundwater depletion. They share common non-modern agricultural practices and low socio-economic conditions which further compound these challenges. A preliminary comparative study reveals parallel concerns regarding over-extraction of groundwater.

2.1.1. Over-extraction for Agriculture and Other Purposes:

- India: Groundwater extraction for agriculture is substantial, with estimates indicating that around 89% of groundwater is used for irrigation (Shah, T., et al2000). Over 60% of groundwater blocks are categorized as "critical" or "over-exploited" by the Central Ground Water Board (CGWB, 2022).
- Pakistan: Over 95% of the water extracted from the Indus Basin is utilized for agriculture, contributing to groundwater depletion (Shah, T., et al. 2000). Indus Basin depletion reaches 53 BCM annually, with some areas experiencing land subsidence (IWMI, 2019).
- Bangladesh: Agriculture heavily relies on groundwater, accounting for approximately 90% of total water use (Hoque, MA, et al. 2017). Groundwater extraction exceeds recharge by 1.2 billion cubic meters (BCM) annually (World Bank, 2020).

2.1.2. Inadequate Water Management Practices:

- India: Inefficient irrigation practices contribute to groundwater depletion, with studies suggesting that only about 35-40% of the water applied to crops is beneficially used (Shah, T., et al 2000).
- Bangladesh: Irrigation efficiency is only 38%, resulting in significant wastage (FAO, 2020).
- Pakistan: Canal conveyance losses in Indus Basin irrigation system reach 30-40% (World Bank, 2010). This leads to over extraction of groundwater to meeting irrigation needs. (IWMI, 2019).

2.1.3. Increasing Demand Due to Population Growth, Urbanization, and Industrialization:

- India: Population to surpass 1.5 billion by 2030, with water demand projected to grow by 29% (NITI Aayog, 2022).

- Bangladesh: Population projected to reach 220 million by 2050, increasing water demand by 25% (World Bank, 2020).
- Pakistan: Industrial water demand expected to double by 2025, exacerbating competition with agriculture (ADB, 2016).

2.3. What are the implications of continued groundwater depletion

India is feeding its population by over-drafting of groundwater from aquifers and may lose its capacity of food production in the coming decades. Further dependence on non-renewable groundwater to meet food and water supply will cause economic, environmental, and social & political challenges with global implications. (Refer appendix 11.4 for a summary table).

2.3.1. **Food security and Global food supply chains: Water-intensive and multi-cycle crops** such as Rice and Wheat constitute 50% of calories consumed. The food security India achieved since the green revolution, is due to the increase in cropping intensity (crop cycles per year), leveraging cropping in the dry winters.

2.3.2. **Reduced cropping intensity is caused by reduced availability of water as a result of** groundwater depletion is projected to decrease the yield of staple crops such as rice and wheat by 20% by mid-century according to Nishan Bhattarai, et al27.

Meha Jain et al from University of Michigan in their 2021 publication conclude that "given current depletion trends, cropping intensity may decrease by 20% nationwide and by 68% in groundwater-depleted regions" [6] by 2025.

2.3.3. **Global Impact:** Impact on India's food security and agricultural production *has significant global impact since India is the largest exporter of rice and second largest producer of agricultural produce.*

2.3.4. **Water security:** ***As per Central Ground Water Authority (CGWA), 85% of rural and*** 50% of urban drinking water supplies are dependent on groundwater. If current trend continues, **100 million residents** (of 21 large cities) face **zero water threat** in a decade.

2.3.5. **Environmental impacts:** Desertification is the biggest environmental concern arising *out* of destruction of 'water cycle' due to over extraction of groundwater, a very valuable

[6] "Groundwater depletion will reduce cropping intensity in India", Meha Jain etal, PMCID: PMC7904249, 2019

natural resource accumulated over several millennia. As groundwater levels reduce, the resultant significant geological alterations cause adjacent soil to lose moisture.

As this continues over longer periods of time, soil becomes vulnerable to erosion and loses the capacity to retain rainwater in future. **Threat of desertification looms over 14% of water-stressed districts by 2050**

2.3.6. **Economic risks and Livelihood impacts:** NITI Ayog, in its 2018 report, predicts 6% GDP *impact by 2030 due to groundwater depletion. 'Water risk'* is increasingly becoming a 'systemic and material' dimension. As per the World Bank, "*Poverty rates are 9%* higher in districts with severe depletion (water table depletion more than 8 meters)".

The United Nations World Water Development Report 2022 highlights that as groundwater level deepens, the cost of construction and pumping increases to prohibitive levels, excluding the poor from accessing this precious resource. As water levels fall deeper, the common pool problem worsens and disproportionately impacts small farmers despite subsidized electricity.

2.3.7. **Political & Internal security impacts:** Groundwater depletion leads to increased demand for surface water. More than 10 Indian states are already involved decade-long inter-state water disputes over sharing the waters of rivers. Many of them have even escalated into violent clashes endangering internal security. Increasing demand for surface water from rivers is posing a serious challenge as a Politically sensitive matter with serious internal security implications.

2.4. Why is India so dependent on Groundwater?

Acute water scarcity lies at the root of India's dependence on groundwater and is further exacerbated by mounting socio-political pressures and populist policy measures.

- **Demographic and hydrological reasons:** Scarcity of water in India is complicated manyfold due to the high population density. According to the World Bank, "India has 18 percent of the world's population, but only 4 percent of its water resources, making it among the most water-stressed[7]" countries in the world.

[7] "How is India addressing its water needs?", The World Bank, 2023, https://www.worldbank.org/en/country/india/brief/world-water-day-2022-how-india-is-addressing-its-water-needs

- **Historical reasons for the** exponential increase in groundwater-based irrigation since Green Revolution: Post independence in 1947, Indian farmers found a great opportunity for "instant irrigation" due to modern techniques of pumping out groundwater. The national impetus on achieving food security through the "green revolution" led to 150% increase in the total area irrigated by wells since1956.

- **Legal/administrative/Policy failures:** Groundwater governance in India has not evolved at the pace at which extraction grew, leaving a policy vacuum. The colonial era Indian Easement Act of 1882 gave landowners the rights to manage, control and use unlimited groundwater in their land, and this system of private rights has continued till date. As a result, groundwater is regarded as private property in India, as is the case in Pakistan, Philippines and in most states of the USA. As a result, the right to groundwater is tied to land ownership, making it difficult to regulate.

  Subsequent measures to adjudicate on groundwater have been sporadic, often driven by court rulings on a case-by-case basis. The Central Ground Water Authority has largely advisory role and lacks teeth in passing strict measures. State boards suffer from lack of personnel and monitoring capacity and are driven by socio-political pressures. Hence, the state policies are focused more on industrial extraction, largely overlooking extraction for domestic and irrigational purposes.

- **Populist policies: Free or subsidized electricity** for farming encourages irrational groundwater extraction. Most states in India provide free or highly subsidized electricity to farmers. which is used for irrigation. *"Groundwater based irrigation, accounts for as much as 40–60% of total electricity use across states"*

  a. ***Tragedy of Commons:*** Farmer does not grow water efficient crops thinking other farmers around will not
  b. ***Politician's (Prisoner's) dilemma:*** If one politician doesn't promise free electricity, her competitor will – free electricity wins votes!

- **Unplanned, explosive urbanization:** Destruction of surface water bodies, rivulets, local aquifers, and their catchment areas results in urban dependence on groundwater.

2.5. Is India's dependence on groundwater sustainable

The accelerated depletion of groundwater represents one of the most significant sustainability challenges confronting India. The number of borewells has increased to 20 million now from 1 million five decades ago. Every year, India extracts 2/3rd of its available annual groundwater resources. With 7% growth in population, water demand will double the supply by 2030. With a fall of 0.5 meter in groundwater table every year in most districts, 20% districts have observed a fall of 8 meters in the past decade itself. In fact, the Central Ground Water Authority (CGWA) quoting a World bank report[8] notes that 5% of aquifers which have reached the point of no return are in critical state and 14% are near critical.

2.6. Literature Review

Existing literature on groundwater extraction in India and the world revolves around important themes such as **regional and global patterns of groundwater abstraction**, **role of globalization, and governance options available.**

Regional and global patterns:

The UN World water development report 2022, which focusses on making groundwater, the "invisible visible" states that 99% of the Earth's running freshwater is groundwater but it is poorly understood and mismanaged as it is invisible.

India ranks first among countries all over the globe, accounting for close to 26% of all the groundwater extracted according to The United Nations World Water Development Report[32] 2022. It surpasses the extraction by USA and China (which rank 2nd and 3rd) combined together, indicating an alarming trend. The degree and purposes of water extraction in India is comparable to its neighbours Pakistan and Bangladesh, all of which use more than 80% of the extracted groundwater for agriculture. Overall, Asia accounts for the highest groundwater extraction amongst all continents, possibly due to its high population density.

Among agricultural uses, rice, wheat, maize, sugarcane, cotton and fodder are principal crops requiring groundwater extraction. They are also heavily traded, thus contributing to unsustainable water footprint due to intensive exports. Major countries that account for about 70% of the

[8] Shiferaw, Bekele. "Addressing groundwater depletion: Lessons from India, the world's largest user of groundwater." World Bank. [Online] Available at: https://ieg.worldbankgroup.org/blog/addressing-groundwater-depletion-lessons-india-worlds-largest-user-groundwater

unsustainable water footprint are China, India, Iran, Pakistan and the USA. Climate change is expected to exacerbate the impact of groundwater depletion, reducing up to 20% yield of rice and wheat by 2050.

Role of globalization:

Export of water: Virtual Water Trade (VWT): Countries which can afford it, are choosing to outsource water intensive activities to other countries with a view to conserve domestic water resources. Such activities include industrial production of chemicals and dyes, agriculture, meat and leather. Unfortunately developing countries find it difficult to face this international pressure, especially translate to mounting pressures from domestic exporters in response to rising international prices for water intensive goods[9].

India and its neighbour Pakistan face a grim situation of being energy and water deficient while they are also leading exporters of water-intensive crops such as rice. In effect, they are exporting water and energy, given the huge amounts of electricity being used up to pump all the water from the ground, to grow grains that ae exported[10]. Therefore, scientists believe that international food trade is a significant factor to be blamed for global groundwater depletion[11].

Instruments of groundwater governance:

Legal regimes for groundwater governance show two significant trends. Public ownership or government ownership is the predominant norm across most countries in the world, requiring permits, licenses or other administrative entitlements for extraction. Such entitlements are time bound and specify volumes and rates of extraction, thus regulating extraction. However, in countries with dense population such as India, Pakistan, Philippines etc, groundwater rights are tied to landownership, hence complicating the regulatory options available for governments. Pricing of water is a widely debated topic which has found little political support.

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[9] India's water is being exported as agri-exports; is there a solution, [Online] Available at: https://www.downtoearth.org.in/blog/agriculture/india-s-water-is-being-exported-as-agri-exports-is-there-a-solution-77966

[10] Pakistan World's Top Groundwater Exporter, India Ranks Third, [Online] Available at: https://thewire.in/agriculture/pakistan-worlds-top-groundwater-exporter-india-third

[11] As global groundwater disappears, rice, wheat and other international crops may start to vanish, [Online] Available at: https://www.pbs.org/newshour/science/global-groundwater-disappears-rice-wheat-international-crops-may-start-vanish

Water is a state subject under the constitution of India. Therefore, states have the power to pass legislations to regulate and develop groundwater, which means a single national legislation regulating use of groundwater is not a politically feasible option.

In recent years, community based management of groundwater is an idea that has been gathering weight due to the elements of local ownership, flexibility in decision making and effective monitoring, which overcome some of the limitations that large-scale top down regulation by governments can face.

2.7. Policy question

Given the severe future impacts of dire groundwater depletion in India, ***the key problem this SYPA aims to address is 'How to mitigate groundwater depletion in India'*** given the constraints in Government's fiscal & regulatory space and political dynamics ensuring farmers' socio-economic welfare and future water security.

III. Groundwater Stakeholder mapping

The key stakeholders in the ground water sector in India are:

3.1. Non- Governmental Entities

3.1.1. Water Consumers

i. **Farmers:** Farmers are the single most dominant "consumer" group contributing to groundwater demand in India. Understanding their priorities and constraints is essential in assessing the extent of elasticity of demand for groundwater in different regions of the country to design interventions.

ii. **Domestic consumers of water (rural and urban):** Domestic consumers of groundwater include households and apartment complexes that consume groundwater either directly from borewells onsite or from private water suppliers who extract groundwater.

iii. **Others:** Industries and real estate construction companies: Industries and real estate companies contribute to groundwater demand through direct extraction onsite or as customers to private sector water supply companies.

iv. **Private sector water supplier companies:** Such companies carry permits to extract groundwater and sell it in the market to clients including households, industrial and construction activities.

3.1.2. Competing Consumers

v. **Neighbouring states** with treaties for sharing river water: Most states involved in interstate river water treaties have information sharing systems to understand each other's water needs and hence become stakeholders affected by variation in groundwater and consequentially surface water demand in each other's territory.

3.1.3. Other Stakeholders:

vi. **Political parties:** water is a very politically sensitive issue. Especially Given farmers form a dominant vote bank in most regions across the country, political parties place high importance for farmer's demands that has resulted in populist policies such as free/highly subsidized electricity that drives increased groundwater extraction.

vii. **NGOs working in the water sector**: NGOs play a key role in building awareness among the consumers of groundwater and on encouraging groundwater friendly and conservation behaviors among the public. They are often engaged by the government to publicize government policies among people in remote areas.

viii. **Legal personnel** who adjudicate on laws governing land and water rights: Legal personnel are able to come up with feasible solutions to the Current vacuum on non-alienation of land rights from groundwater rights that has made regulation of groundwater difficult.

3.2. Governmental entities

3.2.1. National and State government

i. **Policymakers and Implementing departments or Ministries of**

- **Groundwater and Surface water resources:** This is the chief governance body on groundwater that designs and implements national policies on groundwater extraction, drilling of borewells, quality measures etc., provides regulatory services and oversight and is responsible for coordination across other government agencies, departments, and private sector.
- **Agriculture:** Design and implement policies for agriculture and farmers' welfare, including setting minimum support prices for specific agricultural produce.
- **Electricity:** Design and implement policies for generation, transmission and supply of electricity including policies on tariffs and subsidies in the electricity sector.

3.2.2. Local Bodies / Local Governments

ii. **Gram Panchayats**: Gram Panchayats (GP) are the local governance bodies at the village level. Each Gram Panchayat consists of a group of up to 10-15 villages.

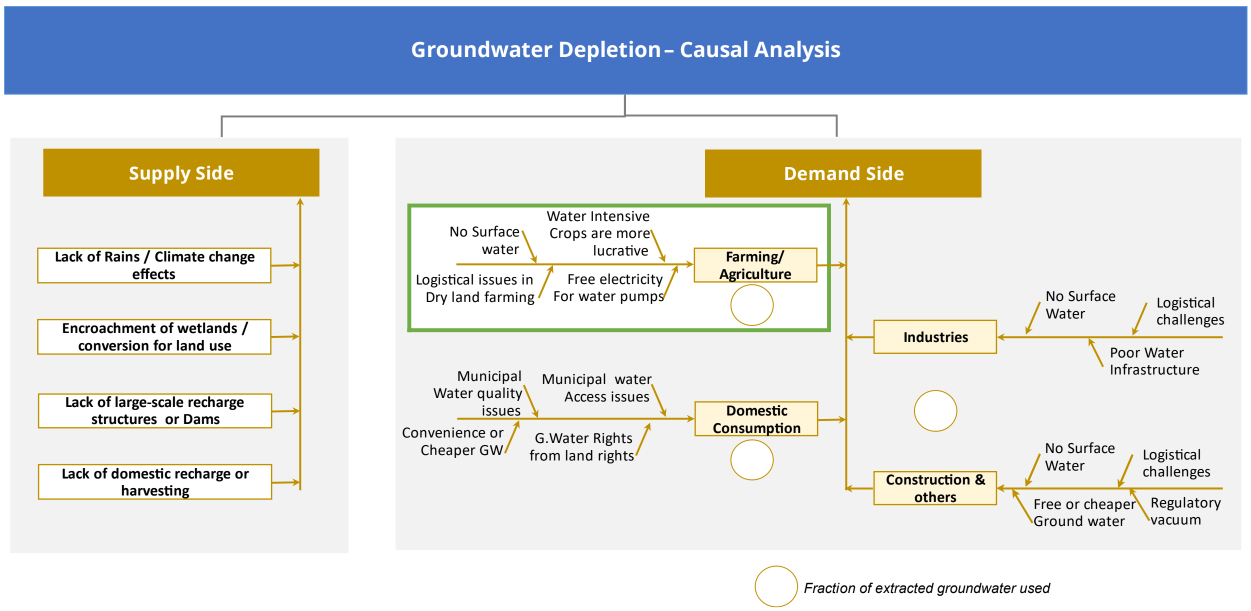
iii. **Water management staff:** GPs hire water management staff for operating the municipal water supply system. Their jobs are temporary in nature and salaries are paid by the GPs.

3.3. International Financial Institutions

Provide Financial and technical support to important projects for conservation of groundwater. The World bank is currently supporting India's national groundwater conservation program "Atal Bhujal Yojana" which runs in 7 states.

IV. Problem Diagnostic & Empirical strategy

The figure below summarizes the key factors and sub-factors affecting ground water depletion in India, organized by groundwater supply-side and demand-side issues.



4.1. Demand Side factors

Four major factors drive the demand for groundwater, which in turn result in high level of groundwater extraction. Interview with academic experts and NGOs confirms the findings from literature research reveals that agricultural demand is the single most dominant driver of groundwater demand in India. 89% of groundwater extracted in India used for agricultural purposes alone[12].

4.1.1. **Agricultural demand (89%):** Agricultural groundwater demand is driven by multiple sub-*factors:*

i. Water intensive crops are more lucrative: Water intensive crops such as rice, wheat and sugarcane fetch higher prices than water efficient crops such as millets, and are therefore cultivated more by farmers driving high demand for groundwater.

ii. Free or Subsidized electricity, as a politically motivated incentive drives high extraction of groundwater.

iii. Logistical challenges in dryland/Water efficient modes of farming make them less favourable than water intensive agricultural practices, driving the demand for groundwater.

[12] "India's Water Crisis: Causes and Cures". The National Bureau of Asian Research (NBR). Archived from the original on 4 April 2020. Retrieved 3 April 2020.

iv. Scarcity of Surface/rainwater drives farmers to draw groundwater to sustain crops, driving demand for groundwater.

4.1.2. **Domestic consumption (9%):** *Domestic consumers are the next highest consumers of* groundwater, though the volume of groundwater extracted for groundwater is 9%, much lesser than that for agriculture. Domestic consumption of groundwater is driven by the following reasons:

i. Lack of access to Municipal water supply (low coverage under municipal water network)

ii. Low quality of municipal water and allied issues of frequency and quantity

iii. Convenience and cost benefit of groundwater

iv. Status of Right to groundwater being tied to land ownership

4.1.3. **Industrial, Construction and others (2%):** Usage of groundwater for industrial, construction and other purposes put together is currently the least proportion, about 2% of the extracted water. Significant factors affecting groundwater withdrawal for these purposes are:

i. Lack of availability / access to surface water and quality of water infrastructure

ii. Logistical challenges in transportation and storage of water

iii. Status of regulation of groundwater vs surface water

iv. Price difference between surface and ground water

4.2.Supply Side factors

There are three major supply-side factors for groundwater depletion.

i. **Lack of Rains / Climate change effects:** In most parts of India, agriculture is dependent on monsoons which have been irregular and unpredictable, leading to cycles of drought and floods. Climate change has exacerbated the woes. Groundwater fills the gap, as a more predictable source of irrigation.

ii. **Encroachment of wetlands / conversion for land use**: Large wells and tanks, and smaller streams which historically acted as good sinks for percolation and fed local rivers are disappearing especially around urban areas, due to illegal encroachments or conversion to buildings/civilian amenities.

iii. **Lack of effective recharge** through check dams and domestic rainwater harvesting: Checkdams on smaller river-streams and domestic rainwater harvesting systems have the potential to improve local groundwater levels to balance moderate increase in demand.

In most arid regions, recharge potential is low while demand is high. Also, lack of scientific data on rainfall, surface flow and percolation levels, efficiency of recharge etc is a significant barrier to scaling up rainwater harvesting[13].

- Previous research has shown that supply side factors are unable to significantly impact groundwater levels unless the enormity of demand side pressures is reduced[14]. Hence the primary focus of this SYPA will be to address the demand side factors which contribute in disproportionately high scales to the problem of groundwater depletion.
- However, it will explore the potential of community-based measures to improve groundwater levels locally by addressing the supply-side factors 2 and 3 (encroachment of wetlands/ conversion for land use, lack of recharge structures such as check dams and domestic recharge or harvesting) which are under human control in the short term.
- Since the scope of this SYPA is on short to medium term solutions, lack of rains/ climate change effects which is a long-term factor with limited direct control of government entities involved in groundwater governance through policy measures is out of scope.

4.3. Significance of agriculture as the predominant causal factor

Interviews with NGOs and water experts as well as with government officials confirm the widely presented fact from existing research, that on a national scale, agriculture remains the most common reason for abstraction and utilization of groundwater. Research also reveals that India's condition echoes a similar pattern in global trends.

UN World Water Development Report[32] 2022 highlights that globally 69% of the total volume of groundwater withdrawn is used in the agricultural sector. It is closely followed by 22% for domestic purposes, and 9% for industrial purposes. However, in Asia, an overwhelming 76% is used for agriculture. Europe is an exception to this trend. The primary use of groundwater in Europe is mainly for domestic purposes. On a deeper analysis between different continents, it is

[13] "Rainwater harvesting in India: some critical issues for basin planning and research" , M.Dinesh Kumar, Shantanu Ghosh. et al

[14] Addressing groundwater depletion: Lessons from India, the world's largest user of groundwater, Bekele Shiferaw, World Bank, https://ieg.worldbankgroup.org/blog/addressing-groundwater-depletion-lessons-india-worlds-largest-user-groundwater

found that Asia uses over 100 km3 more water than the total groundwater withdrawn in the other continents. (See Appendix: 11.3 for more details.)

Based on supporting evidence for domination of agricultural water needs, I would like to primarily focus on agricultural demand for further analysis

Causal Factor - Demand Side	% of Extracted Groundwater Demand
Agriculture and Irrigation	89%
Domestic Consumption	9%
Industry, Construction, and others	2%

4.4. Empirical Strategy

4.4.1. Qualitative analysis approach

Qualitative analysis approach is applied to all the above four sub-factors affecting agricultural demand, to assess the nature and extent to which each drives groundwater depletion. Apart from literature review, interviews conducted with experts and stakeholders, and case studies on specific topics have informed this analysis. It helps in gaining on-ground insights on the priorities and challenges faced by different groups of stakeholders such as consumers of groundwater, administrators and policymakers, that eventually drive their behavioral patterns leading to depletion of groundwater. Qualitative analysis is particularly helpful in fine-tuning the current understanding of the causal factors, and learning from successful interventions through case studies that inform policy decisions.

i. Literature Review

Qualitative analysis through literature review includes survey of previous studies on groundwater depletion in India and regional differences, comparative studies on countries with similar socio-economic and hydrological conditions and identification of necessary data that help in qualitative analysis.

ii. Expert and stakeholder interviews conducted with

- Academics from leading universities researching on groundwater: 1
- NGOs and Water experts working on groundwater conservation: 1

- Senior Government officials, Ministry of Jal Shakti: 2
- Farmer Community leaders: 6
- Executives in agro-industries fertilizer, pesticides, farm equipment: 1

iii. Case studies

- Hivre Bazar, Maharashtra, India:
- Tarun Bharat Sangh, Rajasthan, India

4.4.2. Quantitative analysis approach

With focus on the demand side factors, quantitative analysis was conducted to further examine and explore the nature of impact of the first two subfactors driving agricultural groundwater usage:

- **Water intensive crops are more lucrative than water efficient crops, and**
- **Free or Subsidized electricity as a politically motivated incentive for drawing groundwater**

i. Three **primary data sources** were utilized:

a. Indiastat database:

- Wholesale prices, area of production and quantity of production of rice, wheat, jowar, bajra and ragi from 2002 to 2022 in 5 States of India
- State wise data on consumption of electricity for agricultural purposes from 2002 to 2021

b. Atal Bhujal Yojana: Data on changes in groundwater levels in different regions of India at specific intervals.

c. CIEC Database: Data on lands irrigated by groundwater and those irrigated by surface water irrigation since the 1970s

ii. Sub-factor Analysis:

a. Water intensive crops are more lucrative than water efficient crops:

Two types of analysis of differences in price, area and production trends were conducted, comparing specific parameters for water intensive crops and water efficient crops across 4 regions of the country for a period of 20 years.

- **Time series analysis** trends (2002 to 2022) of water intensive crops vs water efficient crops:
  - Wholesale Price
  - Area of production (‘000 hectares)
  - Production quantity (‘000 tons)
- **Scatter plot/regression** based analysis on correlation between water intensive and water efficient crops
  - Price ratio and production quantity ratio
  - Price ratio and area ratio

For the purpose of comparative study in this SYPA, based on general patterns of consumption, rice was chosen as a water intensive crop for South, South-Eastern and South-Western regions of the country and wheat for the Northern region. Bajra in Northern, ragi in Southern and South-Eastern and jowar in South-Western regions were chosen as water efficient crops.

Wholesale prices of cereals in one representative state in each region was chosen to analyze the price differences. Area of production and quantity of production of both types of cereals during the same duration of study was also conducted.

b. Free or subsidized electricity and politically motivated incentives for drawing groundwater

Three types of analysis were conducted comparing data on electricity consumption for agricultural purposes, with the corresponding groundwater levels and extent of lands irrigated by groundwater vs surface water.

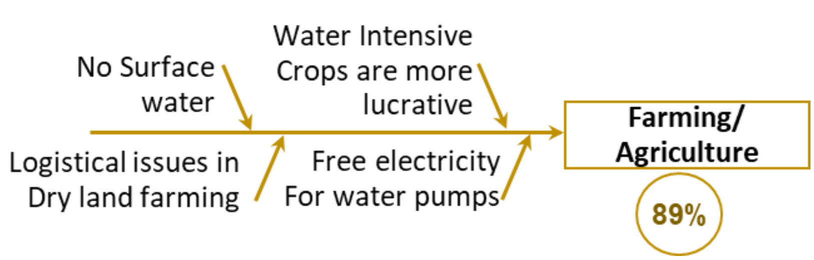
- **Time series analysis at regional level:** Electricity consumption trends for agriculture (2002 to 2022) vs groundwater levels in arid districts
- **Time series analysis at National level:** Comparing area of Groundwater-based and surface water based irrigated lands (1971 to 2019)
- **Cropping patterns before and after free electricity** across 30 villages in Andhra Pradesh

Causal factors	Quantitative analysis	Qualitative analysis
Water Intensive Crops are more lucrative	1. Time series analysis trends (2002 to 2022) of water intensive crops vs water efficient crops: – Wholesale Price – Area of production ('000 hectares) – Production quantity ('000 tons) 2. Scatter plot/regression-based analysis on correlation between water intensive and water efficient crops – price ratio and production quantity ratio – Price ratio and area ratio	1. Expert and stakeholder interviews – Academics from leading universities researching on groundwater – NGOs and Water experts working on groundwater conservation – Senior Government officials – Farmer Community leaders – Executives in agro-industries such as fertilizer, pesticides, farm equipment etc 2. Literature review 3. Case studies
Free/subsidized electricity as a politically motivated incentive for drawing groundwater	1. Regional level analysis: Electricity consumption trends for agriculture (2002 to 2022) vs groundwater levels in arid districts 2. Time series data Comparing area of Groundwater-based and surface water based irrigated lands 3. Cropping patterns before and after free electricity across 30 villages in Andhra Pradesh	
Logistical challenges in Water efficient farming drive water intensive agriculture and crop choice	Qualitative analysis	
Scarcity of Surface/rainwater drives farmers to draw groundwater	Qualitative analysis	

V. Policy solution space

The solution space is determined by

a. Four main casual (sub) factors of the cardinal causal factor of Agriculture



b. **Three types of intervention options based on policy targets**: Market based, Community based and Regulatory interventions

Market based	Measures based on market forces targeting individual's (such as farmer or consumers for example) behaviour by altering incentives
Community based	Measures targeting the community (such as village clusters, farmer cooperatives) behaviours and actions
Regulatory interventions	Measures that change the laws and regulations to induce desired outcomes

VI. Analysis of Results

This section summarises the qualitative and quantitative analysis results for each of the four sub-factors of the main driving factor of Agriculture, with greater emphasis on the first two subfactors.

Sub-Factors	Takeaways
Sub-factor1: Water Intensive Crops are more lucrative	1. Water intensive crops consistently fetched higher wholesale prices than water efficient crops. Government, through PDS procurement acts as a dominant player in determining market prices 2. Wholesale prices of millets such as Ragi and Jowar have increased beyond that of rice and wheat over the last 5 years. 3. Area of cultivation and quantity of production of water intensive crops has shown an increase while that of water efficient crops has remained the same
Sub-factor 2: Free electricity as a politically motivated incentive for abstracting water	4. Consumption of electricity for agriculture shows an increasing trend since 1970s 5. Groundwater levels in arid districts growing rice and wheat show a reducing trend 6. Electricity subsidies is a significant factor that increases groundwater abstraction

	7. Politically motivated incentives for utilization of a collective resource such as groundwater drive tragedy of commons problems among farmers
Sub-factor 3: Logistical issues in Dry land farming	8. Farmers prefer to grow low labour consuming rice instead of labour-intensive water efficient crops 9. Farmers prefer to grow water intensive commercial crops such as sugarcane due to the logistical benefits such as access to sugar factories nearby and driven by incentives
Sub-factor 4: Scarcity of Surface water	10. Loss of conventional surface water resources such as tanks due to drying and encroachment led to increased dependency on groundwater for irrigation

6.1.Subfactor 1: Water intensive crops are more lucrative than water efficient crops, driving high demand for ground-water

6.1.1. Qualitative Analysis

Interviews with farmer community leaders, academicians and NGO experts indicated that there is a definite advantage in growing water intensive crops, in terms of the remuneration to farmers, making them an attractive option. A review of literature reveals that in 1956, India produced more millets (a type of water efficient small-seeded grasses which are used as cereals and grains) than paddy and wheat. In 50 years (2006), area under cultivation of millets had dropped from 36.3 million hectares (MH) to 23.17 MH and area under paddy cultivation increased from 33.14 MH to 44.31 MH. Output of paddy also increased by 125%.

Government procurement: Public Distribution System (PDS), through which Government of India procures selected agricultural products such as cereals, pulses, oilseeds, etc. from farmers in specific regions is a dominant factor influencing market prices for procured crops. Details about the PDS system are provided in Appendix 11.2.

Expert interviews affirm that most of the crops in PDS procurement regions are produced using groundwater despite these being arid regions. To quote from [1] Dr. Naresh Devineni's research[15] "*Rice covers 75% of the net cropped area in the arid regions of North-Western .... Given subsidized electricity and limited access to canal water, most irrigation is from groundwater, accounting for as much as 40–60% of total electricity use in some states*[16]"

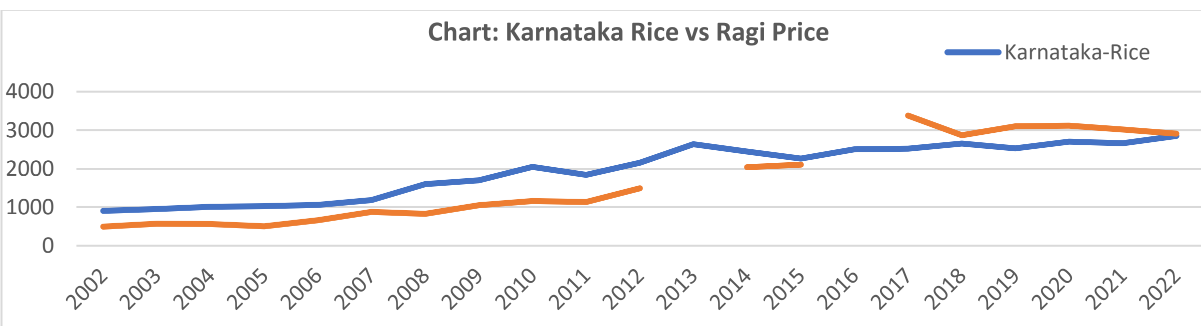
6.1.2. Quantitative analysis

Analysis of 20-year data on state level wholesale prices of grains in different regions of the country supports the consistent price gap between water intensive and water efficient crops, and a brief reversal of trends over the last 5 years, where wholesale prices of millets increased to higher than rice.

Takeaway 1: Water intensive crops consistently fetched higher wholesale prices than water efficient crops. Government, through PDS procurement acts as a dominant player in determining market prices

For most part of the 20 years under study, across all 4 regions of the country, rice and wheat fetched higher wholesale prices than prominent millets/other cereals of that region as reflected in the divergence between the wholesale prices of the water intensive crop and water efficient crop in each state.

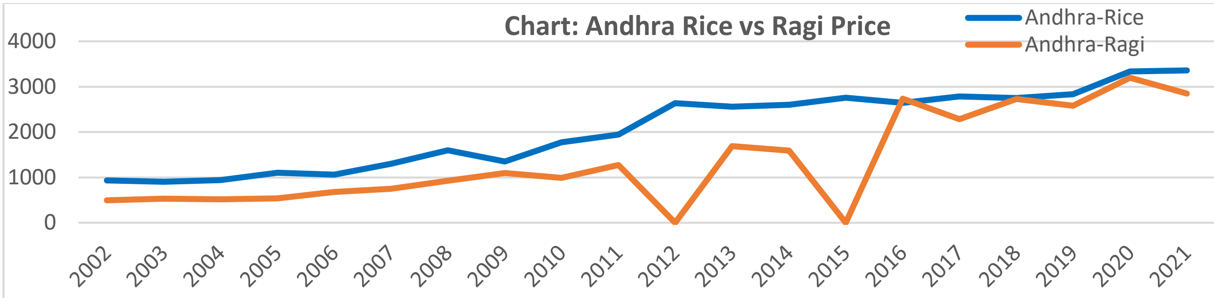
- Comparison of wholesale Price (Rs per Quintal) in Karnataka from 2002 to 2022: Ragi



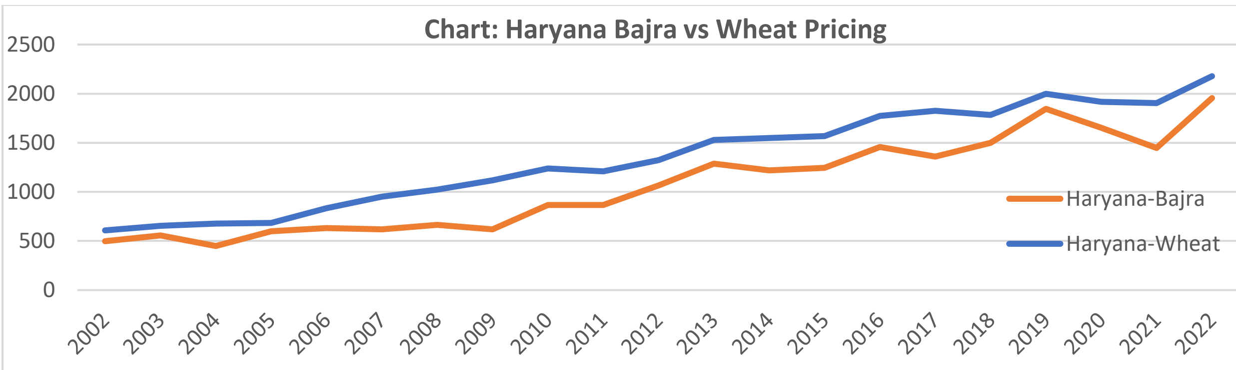
- Comparison of wholesale Price (Rs per Quintal) in Andhra Pradesh from 2002 to 2022:Ragi

[15] Dr. Naresh Devineni & Dr. Shama Perveen. "Securing the future of India's 'Water, energy and food'." October 8th, 2012. Columbia University, United States. Global Water Forum. [Online] Available at: https://www.globalwaterforum.org/2012/10/08/securing-the-future-of-indias-water-energy-and-food/#:~:text=Rice%20accounts%20for%20over%2075,cropped%20area%20in%20Kharif%20season.

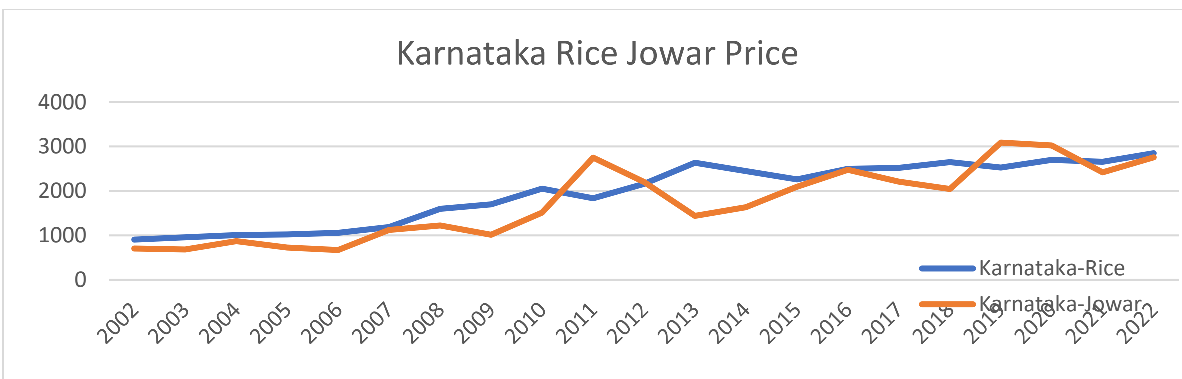
[16] 5.97 lakh hectares converted to non-agri purposes in 10 years, Sep 2016, https://www.deccanherald.com/india/karnataka/597-lakh-hectares-converted-non-2085984



- Comparison of wholesale Price (Rs per Quintal) in Haryana from 2002 to 2022: Bajra



- Comparison of wholesale Price (Rs per Quintal) in Karnataka from 2002 to 2022: Jowar



Charts' source in this section: Author's Analysis. Due to lack of data on prices of Jowar in Maharashtra pre-2012, available data from its neighbouring state Karnataka, which is also a major supplier of jowar to Maharashtra has been analysed.

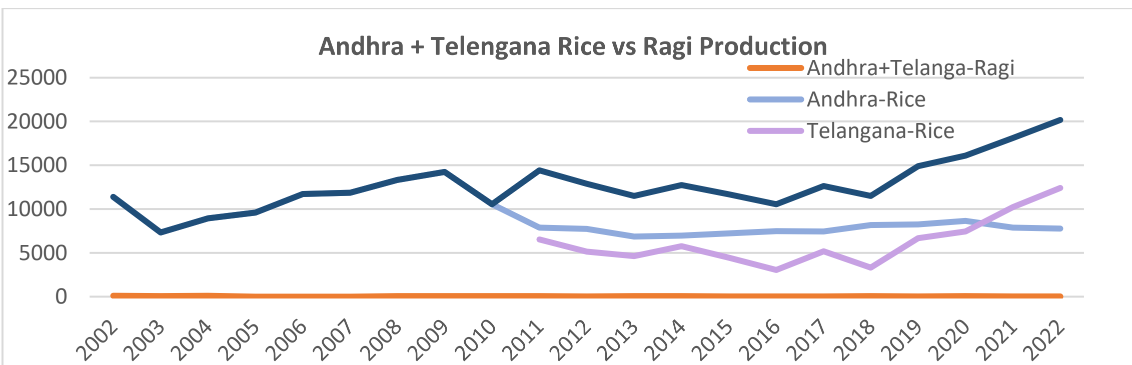
Government, through PDS procurement acts as a dominant player in determining the market prices as described in the previous section on qualitative analysis.

Takeaway 2: Wholesale prices of millets such as Ragi and Jowar have increased beyond that of rice over the last 5 years.

Based on the above presented wholesale price comparison charts, in the last 5-6 years wholesale prices of water efficient crops such as Jowar, Ragi in Karnataka and Andhra Pradesh (including Telangana) have shown an increase above the price of rice. Interviews with farmer leaders and NGO water experts indicated that the probable causes for the increase in prices are limited supply of dryland crops while supply of rice was increasing. Other probable reasons are higher demand from food product companies[17] and health-conscious consumer groups due to recent trends in increased awareness about their nutritional value. The UN declared year 2023 as international year of millets. However, in Haryana, there is no such reversal in prices. Wheat has continued to fetch higher prices than Bajra.

Takeaway 3: Area of cultivation and quantity of production of water intensive crops (rice and wheat) has shown an increase while that of water efficient (Ragi and Jowar) crops has remained the same

- Comparison of Production Quantity ('000 tons) in Andhra Pradesh and Telangana from 2002 to 2022

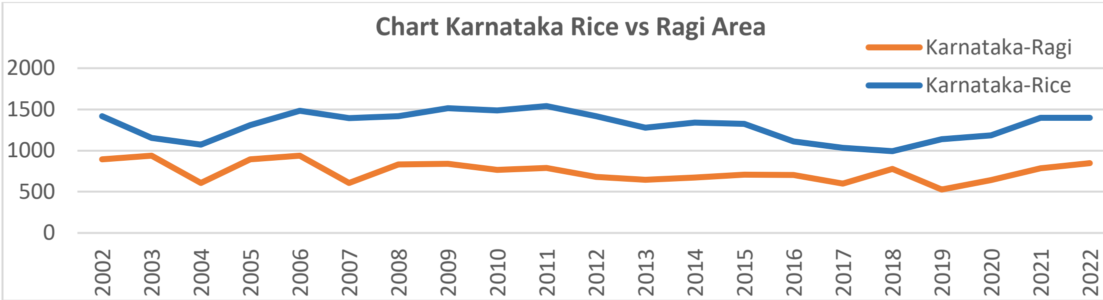


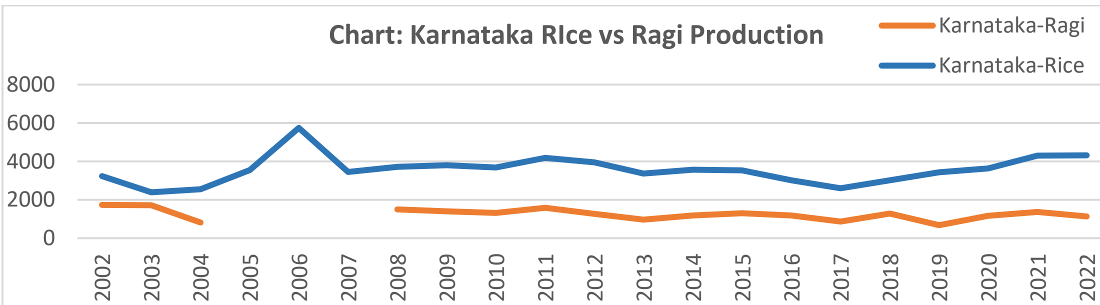
Telangana's spurt in rice production from 2018 onwards

- Post 2018 when the "expensive" uplift irrigation project (Kaleshwaram project) started, rice production accelerated, despite less than 10% water being sourced from irrigation.
- Rice production increased in anticipation of irrigation from Kaleshwaram project.

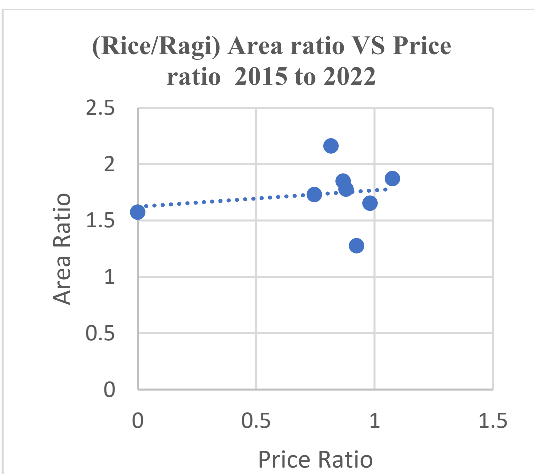
- In Karnataka an analysis from 2002 to 2022 shows significant increase in area and quantity of rice from 2017 to 2022

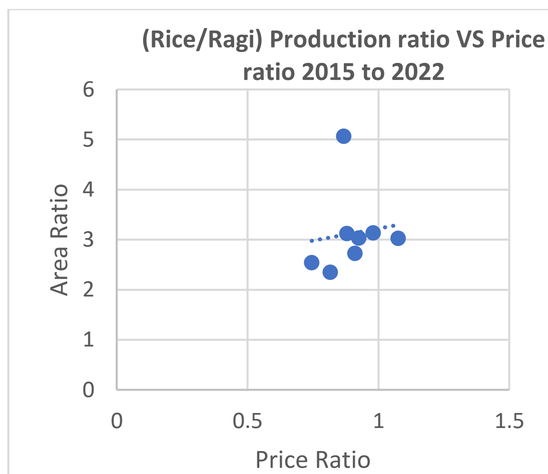
[17]Humble jowar outprices rice and wheat https://timesofindia.indiatimes.com/city/pune/humble-jowar-outprices-rice-and-wheat/articleshow/8085047.cms





- Regression analysis of area ratio and production quantity ratio with Price ratio of rice vs ragi for the years 2017 – 2022 reveals that trends in area and quantity of production of rice relative to ragi follows the price differential.





However, the difference in regression results is not significant for previous years, due to farmers' diversification of crop choices favoring other water intensive crops beyond rice such as arecanut and BT cotton[18]. (Refer to appendix section: 11.5)

[18] '5.97 lakh hectares converted to non-agri purposes in 10 years' https://www.deccanherald.com/india/karnataka/597-lakh-hectares-converted-non-2085984

6.2. Sub-factor 2: Free electricity as a politically motivated incentive for abstracting water

Quantitative analysis:

Takeaway 4: Consumption of electricity for agriculture shows an increasing trend since 1970s

The electricity subsidies can be corelated with increased consumption of groundwater. Steep Growth in Groundwater Irrigated Land Area vs Surface water irrigated area, corresponds to steep growth in Agricultural Electricity consumption.

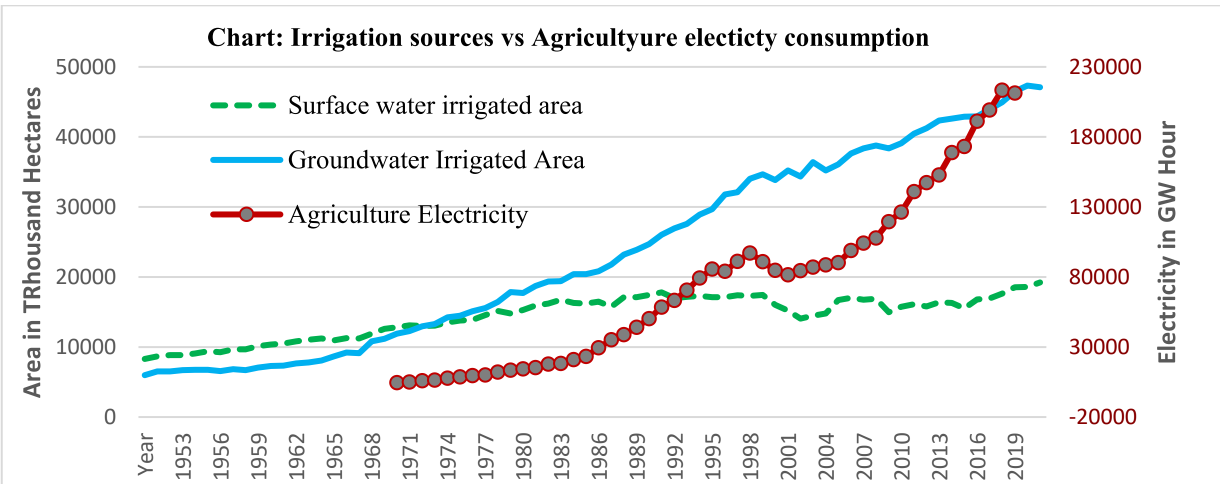


Chart: Shows increasing trend of groundwater-based irrigation corelates with increasing agricultural consumption of electricity.

Takeaway 5: Groundwater levels in arid districts growing rice or wheat show a reducing trend

The analysis of district level groundwater trends for the last 7 years in three arid districts where rice is cultivated in Karnataka state shows decreasing groundwater level across all three districts correlates with increasing agricultural electricity consumption in the state.

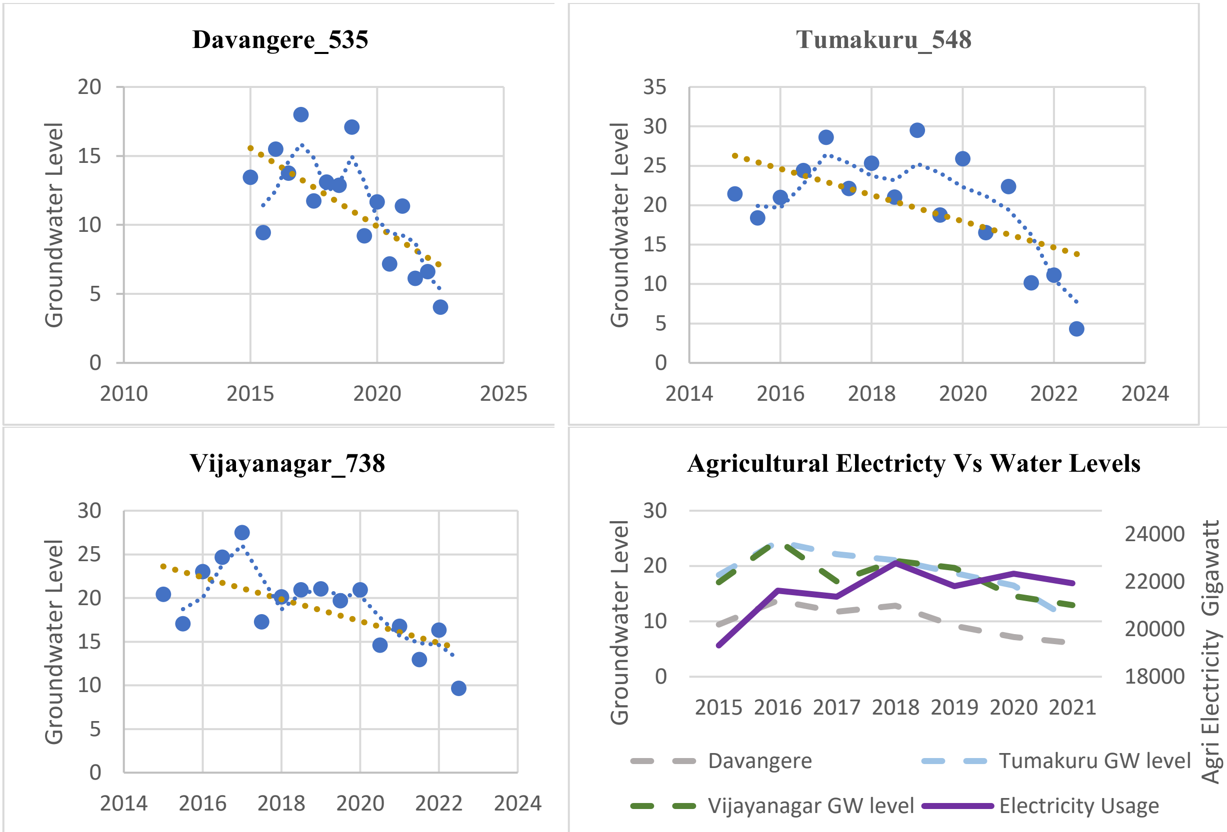


Chart: Shows correlation between increasing electricity use for agriculture and decreasing groundwater levels in the state of Karnataka across 3 arid districts

Takeaway 6: Electricity subsidies is a significant factor that increases groundwater drawal

Analysis of cropping patterns before and after introducing free electricity (Y 2004) in states of Andhra Pradesh and Telangana shows steep shift towards water guzzling high value crops (cotton, soyabean, paddy).

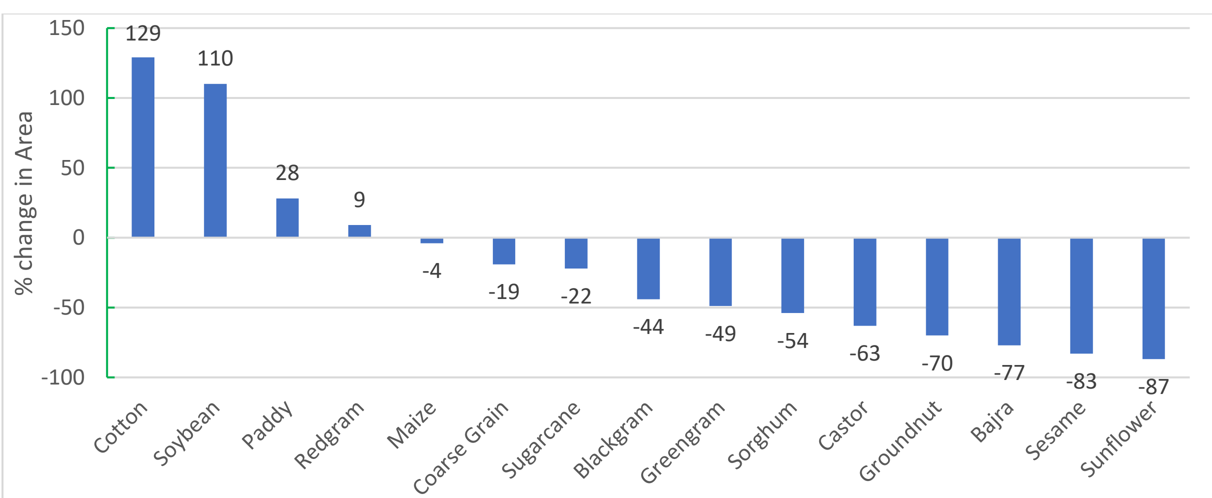


Chart: Shows shift towards water intensive corps after free electricity was introduced for agriculture in the states of Andhra Pradesh and Telangana

Takeaway 7: Politically motivated incentives for utilization of a collective resource such as groundwater drive tragedy of commons problems among farmers

Qualitative analysis: Starting with the green revolution in late 1960s, government provided electricity subsidies to encourage higher production. The trend has continued. Today most Indian states offer subsidies amounting between 85% to 100% of cost of production of electricity and many provide free electricity[19].

As costs of extraction reduce to negligible levels, there is no disincentive to limit groundwater abstraction. This fuels a tragedy of commons problem creating a zero-sum game of competition to abstract more and more water. Research reveals that in comparison to flat rates, a form of subsidy, metered tariffs show potential to encourage judicious consumption[20].

Problem of Tragedy of commons: Interviews with NGO water experts, agroindustry representatives and senior government officials indicate that electricity subsidies play an important role in farmers' crop choices and disincentivize groundwater conservation behavior. Interview with farmer community leaders confirm this fact, while also indicating that as long as electricity subsidies continue, farmers are less likely to unilaterally change their choices of cropping to inculcate water efficiency. Research findings identify subsidized electricity as a main factor contributing to the lack of collective action among farmers to conserve groundwater. An attempt by government of Karnataka to restrict drilling of newer borewells in 2017 led to mushrooming of new borewells all over the state between the date of announcement and date from which the ban would be effective. This indicates the presence of tragedy of commons[21].

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[19] Development and the Environment: The Implications of Agricultural Electricity Subsidies in India, Reena Badiani, 2012, https://journals.sagepub.com/doi/10.1177/1070496512442507

[20] Power tariffs for groundwater irrigation in India: A comparative analysis of the environmental, equity, and economic tradeoffs Balsher Singh sidhu, et al,2020 https://www.groundwatercatalogue.org/sites/default/files/2021-07/Power%20Tariffs%20for%20Groundwater%20Irrigation%20in%20India.pdf

[21] https://journals.sagepub.com/doi/10.1177/0973005220945428

6.3. Sub-factor 3: Logistical challenges in dryland/Water efficient modes of farming make them less favourable than water intensive agricultural practices, driving the demand for ground-water

Takeaway 8: Farmers prefer to grow low labor consuming rice instead of labor-intensive water efficient crops

Qualitative Analysis: Interviews with farmer leader and water experts indicate that growing dryland crops involves prominent logistical challenges such as constraints on technology, mechanization, and costs of labor.

Grains of millets and dryland crops such as sesame are smaller in size compared to rice or wheat. Cost of labor involved in their harvesting, cleaning and processing, which are necessary steps to make them sellable in the market, is high. Farmers therefore prefer to cultivate rice, often termed a "lazy crop" requiring lesser labor[22].

Takeaway 9: Farmers prefer to grow water intensive commercial crops such as sugarcane due to the logistical benefits such as access to sugar factories nearby and driven by incentives.

Qualitative Analysis: Sugarcane is a highly water intensive commercial crop that consumes 1700-2400 mm of water per growth cycle of 11-17 months. Since the 1950s, government offered financial incentives to support various stages of the sugar production value chain including the minimum price for sugarcane (with intentions of supporting farmers who grow sugarcane), subsidizing to sugar factories/mills run by cooperatives and subsidizing the price of sugar to consumers. The longstanding value chain support led to formation of local sugar cooperatives which over time gathered strong political support[23], sustaining farmers' behavior patterns of favoring sugarcane cultivation. As seen in chart below, the share of water used to grow sugarcane is far higher than share of water used for all other crops. Research reveals that adverse impacts on groundwater include reduction in average river basin flow, short-term drying of wells in droughts and reduction of groundwater levels in the long term as hydrological equilibrium changes.

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[22] Telangana government says no to paddy; it's that or nothing, say farmers, VV Balakrishna, https://www.newindianexpress.com/states/telangana/2021/Oct/29/telangana-government-says-no-to-paddy-its-that-or-nothing-say-farmers-2377188.html

[23] Water-food-energy challenges in India: political economy of the sugar industry, Ju Young Lee1 et al, July 2020 https://iopscience.iop.org/article/10.1088/1748-9326/ab9925

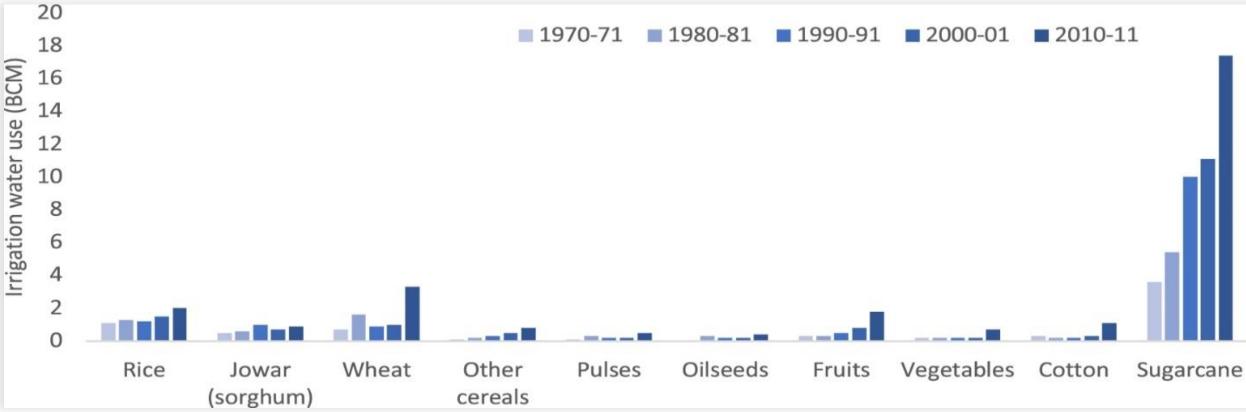


Chart: Irrigation water use by major crops or crop groups in Maharashtra from 1970–71 to 2010–11.

6.4. Sub-factor 4: Scarcity of Surface/rainwater drives farmers to draw groundwater to sustain crops, driving demand for ground-water

Takeaway 10: Loss of conventional surface water resources such as tanks due to drying and encroachment led to increased dependency on groundwater for irrigation

Farmers in arid regions in the deccan plateau historically relied on village tanks or local reservoirs constructed by local communities for small irrigation needs. They helped cultivate water efficient crops like millets. Tanks and streams also served as potent groundwater sinks and were an integral part of rural agriculture. An average tank held sufficient water to irrigate 100 hectares of land.

From 1950 to 2014, the share of tanks[24] in catering to irrigation needs in the country came down from 17% to 2.5%.

Of late, drying up of small streams and encroachment/altered land use of multiple small tanks deprived farmers of potent sources of surface water, driving increased dependency on groundwater. Free/ highly subsidized electricity drives high extraction of groundwater. Unpredictable monsoons and low base flow in rivers further exacerbate the problem endangering water security[25].

[24] Tank rehabilitation in India: Review of experiences and strategies, V Ratna Reddy et al, 2018, https://www.sciencedirect.com/science/article/abs/pii/S0378377418304189

[25] Restoring tank irrigation can strengthen rural climate resilience, Neha Jain et all, 2019 https://india.mongabay.com/2019/01/restoring-tank-irrigation-can-strengthen-rural-climate-resilience/

VII. Recommendations

The key goal is to achieve reduction in demand for groundwater without significantly altering returns to farmers or altering relevant political gains. While doing so, it is also necessary to ensure sustenance of the reduced demand we achieve, since the problem spreads over a long-term horizon. Through a rigorous analysis of data, to arrive at feasible solutions that meet the twin goals to the best extent possible the policy recommendations explored below are based on a multipronged approach involving a broad spectrum of interventions at 3 different levels:

- **Market-based interventions**
- **Community interventions**
- **Regulatory interventions**

7.1.Market-based Interventions

The chief objective here is to use market forces to help farmers reduce usage of groundwater while continuing to derive similar economic benefits from water efficient agriculture, compared to their earlier practices of water intensive agriculture.

R1:	**Deepen and widen the market while driving-up demand for millets and dryland crops and support investments in building value chains for them.**
R2:	**Transition from narrow-spectrum and logistics-constrained PDS procurement towards equitable and diversified procurement model aligned to water and soil conditions**

R1: **Deepen and widen the market while driving-up demand for millets and dryland crops and support investments in building value chains for them.**

Rationale: Two of the key drivers of groundwater demand are (i) lucrativeness of water intensive crops and (ii) the logistical ease/supply chain support in cultivating, processing and selling them. Therefore, the most direct intervention is to use the demand-supply dynamics to ensure comparative price gains to farmers who grow water efficient crops. In doing so, enhancing supply chain facilities to improve their marketability. Millets, a diverse group of small-seeded grasses grown widely around the world, are an excellent option, with promising potential for low water footprint and climate resilience.

Technical Correctness (High)	**Benefits to water levels**: On an average millets such as Ragi, bajra, Jowar, Maize, pearl, kodo millet consume 50% less water than other water intensive cereals such as rice and wheat[26]. Domestic trading and export of millets involves lesser water footprint compared to rice and wheat.
	Food security advantages: With climate change projected to significantly reduce yields of rice and wheat in near future, millets are crucial to fill the gap to maintain food security. Since they can grow in rainfed regions, they have a strategic importance for the country's food security planning.
	Acceptability to consumers: Historically a diverse variety of millets such as ragi, bajra, jowar, pearl millet, etc were the staple food for most people across the parts of the country. Over the last few years, their health benefits are becoming popular, offering a good potential for increasing consumer demand
Administrative Feasibility (High)	Administrative efforts need to be directed at improving awareness among public on a large scale, improving mechanization & supply chain facilities, and provide capacity building support to farmers. These are usually feasible.
Political Supportability (High)	As millets start fetching higher price to farmers, increasing their cultivation in arid regions, pressure on politicians to provide irrigation would proportionally reduce.

R2: Transition from narrow-spectrum and logistics-constrained PDS procurement towards equitable and diversified procurement model aligned to water and soil conditions

Rationale: The objective is to reduce the "distorting" signals being sent out by the dominant demand-side player in the Indian agricultural market and use the same platform to incentivize the "supplier" farmers to make cropping decisions aligned to the local water and soil conditions. Rationalization of PDS procurement both spatially and economically should suit local water, soil and environmental conditions rather than be based on subsidized inputs or groundwater-based

[26] Thin Lei Win. "Swap rice for maize, millet and sorghum to save water and boost nutrition - experts tell India." July 5, 2018. Reuters. [Online] Available at: https://www.reuters.com/article/idUSKBN1JV25D/

cropping. It must be diversified to include more regionally consumed grains rather than only rice and wheat.

Technical Correctness (High)	**Benefits to water levels:** PDS procurement areas typically display highest groundwater consumption. Diversifying procurement locations eases the pressure on groundwater. Diversifying the basket of procurement to include dryland crops such as millets, pulses, oil seeds etc breaks the incentive discrepancy and promotes pro-water efficient crop choices while potentially offering comparative remuneration to farmers.
	Food security advantages: Success of green revolution through cultivating rice and wheat was supported by abundant groundwater. Today, low groundwater in these regions threatens food security. Diversification of crops and easing procurement pressures in water stressed locations improves prospects for food security, diversifying the risks.
	Acceptability to PDS consumers: Dryland crops such as millets are acceptable to consumers as they were part of staple diets historically. Recent trends of many affluent consumers shifting to millet- based diets due to awareness of health benefits of millets creates a positive social signal towards greater acceptability of millets in PDS.
Administrative Feasibility (Low)	**High dependency of farmers on middlemen**: Farmers seldom sell directly to government. They depend on facilitators/agents who buy produce from farmers and sell to government, retaining a large portion of the profit. Interviews with farmer leaders and water experts indicated that despite reforms in PDS, farmers are not likely to receive higher remuneration and price signals may not work.
Political Supportability (Low)	Since government has been procuring grains from specific regions for more than 50 years now, **political interests are deep rooted in these regions**, strongly opposing any changes that reduce their profits.

7.2. Community Level Interventions

The main objective is to create social and institutional support to prevent default of individual farmers from pro-water conservation practices through overcoming the effect of tragedy of commons. It is in line with Eleanor Ostrom's principles of collective action.

R3:	**Facilitate and scale-up 'community driven & governed' efforts toward long term groundwater conservation efforts by farmers to build socially supported systems for self-limiting groundwater use and collective groundwater recharge**

Rationale: In problems that involve a tragedy of commons scenario, as recognized by Eleanor Ostrom's collective action principles, community-level interventions are required to sustain and scale up the gains from individual-level interventions.

While government regulation is a tool to impose disincentives to default, it is a top-down approach and often ineffective due to lack of political support or popular acceptability. Instead, if local communities are empowered to understand, educate and self-govern themselves through a bottom-up approach in their own long-term interests, the chances of success are higher while compliance rates also are higher.

Technical Correctness (High)	**Benefits to water levels:** Community driven initiatives are effective in addressing both improving supply and reducing demand for groundwater. Interview of experts from NGOs reveal that community initiatives historically have shown substantial improvement in water levels
	Farmers' acceptability: Like the success of self-help groups that reduced the cases of moral hazard to loans, (as in Grameen bank) compliance by farmers is high if there are social pressures built into local community managed systems.
Administrative Feasibility (High)	Administrators have a facilitatory role involving technical support, dissemination of relevant hydrogeological data and awareness building. Historically such measures enjoy high credibility and draw favourable response from communities.
Political feasibility	Interviews with water experts and NGOs indicate that locally driven solutions have shown higher political acceptability compared to conventional top-down

(High)	government regulation. Historically they have been effective in enforcing and establishing desired behaviors in problems involving collective use of resources.

7.3. Regulatory Level Interventions

The objective is to gradually phase-out the perverse incentives that promote unsustainable groundwater extraction and pose an impediment to the beneficial effect of crucial forces of market harnessed by earlier described interventions.

It involves using regulatory measures to support the gains from economic tools and community conservation initiatives at the highest level.

R4:	**Work towards a road map for regulatory reforms in phasing out market distorting subsidies on electricity**

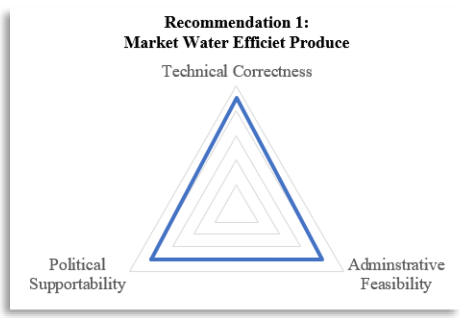
Rationale: In the absence of pricing of groundwater, price of electricity is a powerful lever determining cost of usage of groundwater for agriculture. Addressing subsidies is essential because they otherwise distort market signals, reducing cost to negligible levels, making it attractive to use groundwater to grow lucrative crops.

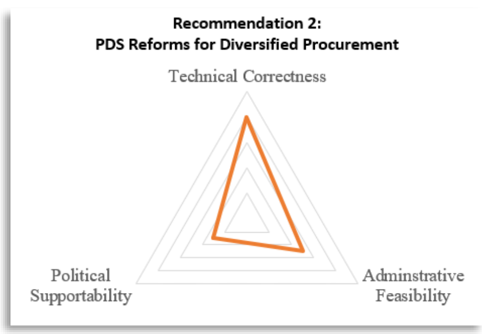
Technical Correctness (High)	**Benefits to water levels:** Electricity being the next most important driver of groundwater extraction, reduction in subsidies is likely to significantly increase cost of extraction and improve groundwater levels.
Administrative Feasibility (Low)	Implementation on field involves installation of electricity meters (currently absent in most states) to start measuring usage. It is likely to face widespread opposition from farmers, potentially escalating to conflicts. This in turn leads to lack of local political support.
Political Supportability (Low)	Free or subsidized electricity has been the most predictable poll promise in elections for more than 50 years. The water-energy nexus is a highly sensitive issue. Diminishing electricity subsidies is likely to face strong resistance and loss of political capital.

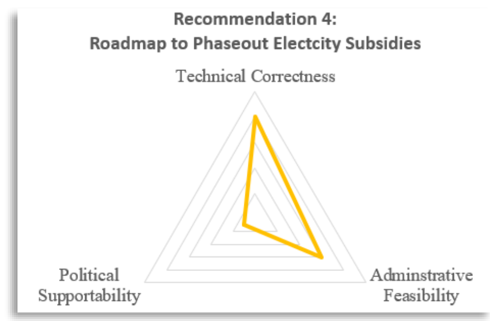
VIII. Selection of feasible Recommendations

Recommendation 1 and 3 are the two key recommendations based on their soundness on the three dimensions of Technical Correctness, Administrative Feasibility and Farmers acceptability.

Recommendations 2 and 3 are least on the political supportability dimension and do not fare well on administrative feasibility dimension.







Hence Recommendation 1 and Recommendation 3 are the selected two key recomemndatiosn for which the implementation roadmap is detailed below.

IX. Roadmap for Recommendations

The most pressing concerns and challenges to implementing both the chosen recommendations were identified and a roadmap designed to address them to the best extent to ensure successful implementation.

R1: **Deepen and widen the market while driving-up demand for millets and dryland crops and support investments in building value chains for them.**

Challenges:

1. Current market for millet-based products is quite shallow. Demand arises mainly from small educated urban communities and not from larger masses.

2. Cultivating millets and making them consumption-ready requires skilled labor and involves more elaborate processing than rice and wheat. Mechanization opportunities are limited and unaffordable by poor farmers.
3. Poor supply chain facilities and short shelf life of processed millets leads to large wastages and low price-realization.

<u>Steps involved:</u>

i. **Initiate Market research and analysis:** Millets are considered a super-food because of their rich nutritional content and low calorific value[27]. Unlike rice and wheat which have higher calorific value, millets play a crucial role in the management of diabetics. While the government has started promoting millet consumption through campaigns, addressing lack of awareness must be done on mission mode. Government must initiate market research and analysis to understand and enhance their appeal to people, promoting wide health benefits of millets to enhance their marketability by the industry.

ii. **Deepen market penetration and product diversification:** In recent years, higher economic sections in urban areas have increased consumption of millets, due to awareness of their nutritional benefits. Along with effective marketing and publicity of benefits of millets it is necessary to develop and sustain demand through product innovation and diversification. Promoting product diversification to bring out ready-to eat products such as breakfast bars, noodles, pasta etc will help prolong the shelf life of millets and tap into different sections of the markets.

iii. **Invest in supply chain strengthening and mechanization support:** Strengthening supply chains is crucial to help overcome the inconsistencies in supply & demand, optimize the distribution capacity and achieve price realization while reducing wastage. Government should take-up focussed supply-chain enhancement measures and make infrastructure investments to improve access to markets for remote farmers.

iv. **Enable and Empower Farmers and capacity building:** Farmers need to be provided capacity building support in cultivation as well as utilizing market opportunities both domestically and internationally. Most farmers hail from poor socio-economic background and

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[27] ANIC Millet Challenge, [online] Available at: https://www.aim.gov.in/anic-millet-challenge.php

might lack knowledge of opportunities, hence dependent on middlemen. Directly empowering farmers with awareness about their rights and the available opportunities helps enable their self-driven economic empowerment.

Cost and financing concerns/ analysis

Promoting millets and driving the market demand necessitates substantial funding for market research, product diversification, supply chain enhancement, and farmer empowerment. While government schemes and public-private partnerships can contribute, financial support targeting small-scale farmers in overcoming challenges of limited mechanization, and market awareness is required to ensure sustainable and inclusive adoption. Broadening the ambit of existing subsidy schemes for mechanization of rice and wheat, to include machinery specialized for millet processing is beneficial. Creating a supportive environment for private investment in food processing industries can provide positive externalities in terms of improvements to supply chains while reducing the impact on budget.

R3:	**Facilitate and scale-up 'community driven & governed' efforts toward long term groundwater conservation efforts by farmers to build socially supported systems for self-limiting groundwater use and collective groundwater recharge**

Challenges:

1. Organization of farmers at grassroots level requires significant effort and resources.
2. The scalability of community organization is a challenge, given the geographical vastness and cultural diversity of the nation.

Steps involved:

i. **Facilitate formation of village-level Local Water User (LWU) groups:** Gram Panchayats, the lowest tier of government catering to needs of rural areas need to be empowered to organize farmers and water users into LWUs. LWUs generate water user plans, based on an objective understanding of local water needs vs availability of annual groundwater in their watershed. They are also responsible for implementation, monitoring and coordination of efforts regarding water plans within the community and between neighboring communities.

ii. **Community- driven rule framework and monitoring mechanisms:** LWUs work out a set of self-driven rules for volume and frequency of water usage and determine a set of graduated sanctions involving a hierarchic stratum of warnings, penalties/fines, prohibitive measures, etc., acceptable to the members. Good administrative empowerment of communities is required to be taken up by facilitating government agencies

iii. **Create strong networks of LWUs with water experts and resource persons:** Such networks benefit through access to reliable high quality hydrogeological data on local groundwater availability and handhold the LWUs in tailoring irrigation plans sustainably.

iv. **Provide interactive platforms for cross-learning between LWUs across the country:** To facilitate smooth scaling up of community initiatives across the country, government should constantly facilitate interaction between LWUS through platforms at regional, state and national level. This is an opportunity to improve cross pollination of ideas between community groups and give due recognition to well-performing LWUs, which can be role models for others.

Case studies of success: The following case studies show past successes in village community driven groundwater conservation efforts. The appendix 11.1 provides more case details of the case summaries presented here.

Hivre Bazaar Case:

Community-driven collective action measures in Hivre Bazaar, a remote village in Maharashtra state, succeeded in reversing its drought ridden condition to achieve high household income levels and reversed the outmigration in a decade. Local government (Gram Panchayat) leadership, supported by government agencies such as the Groundwater Surveys & Development Agency (GSDA) achieved this feat by organizing farmers into a community which drew-up plans and coordinated implementation of valuable groundwater conservation decisions. Highly politically controversial decisions such as ban on borewells, changing from water intensive to water efficient crops during drought years, banning livestock grazing etc were achieved with high levels of compliance. strong community building empowered by quality hydrogeological data-driven planning and synchronization were the keys for their success.

Tarun Bharat Sangh (TBS) Case:

Tarun Bharat Sangh, an NGO succeeded in mobilizing communities across 1058 villages in Rajasthan, India's driest state, to improve groundwater levels by building traditional rainwater harvesting structures called Johads. It involved a vigilant and active village level body (Gram Sabha) supported by members from all strata of society including women and youth in drawing up plans for recharge, implementing them and in monitoring compliance. The initiative achieved miraculous results including reversal of a critically water deficient subdivision into water surplus status, rebirth of a dried up river and increase in per capita income from Rs. 2800 to 6662 and improved land value from Rs.3000 per Beegha in 1994 to Rs. 25,000 per Beegha in 2000.

Cost and financial analysis:

Existing local leadership and village-level structures can be leveraged to minimize the costs associated with the formation of LWU farmer groups. Community participation is also one of the four strategies in Atal Bhujal Yojana, the government's ongoing groundwater management program (in partnership with World Bank). However, it is currently limited to 7 states and needs to be scaled up. The common resources can be utilized with focus on Training and capacity building, ensuring effective functioning of these groups and promoting sustainable water management practices can leverage financial support from government initiatives, grants, and partnerships with NGOs or private entities is crucial for the successful transition toward an equitable and diversified procurement model.

X. Conclusion

Mitigating depletion of groundwater in India, a major food supplier for global markets, will have ramifications beyond the country's own socioeconomic welfare and economic growth prospects, eventually to global food security.

In walking the tightrope between academically correct solutions and larger welfare concerns of the needy, technically sound solutions often take a backseat in the short term, though much relevant for long term planning.

Innovative market-based instruments and community driven approaches to mitigate groundwater depletion offer a reliable alternative and ray of hope in the near future as they leverage the powerful combination of market forces and social dynamics.

XI. Appendix

11.1. Case studies

11.1.1. Hivre Bazar, Maharashtra, India

Hivre Bazaar is a village in arid regions of Maharashtra state is a widely recognized success story in improving farmer incomes and social well-being while improving groundwater levels. Their success involved mainly addressing demand-side factors to reduce consumption of water, while also supplementing such efforts with improving recharge. It is particularly relevant due to the impact of facilitation by the government through its agencies such as Groundwater Surveys & Development Agency (GSDA).

Population: 1400

Area: 975 hectares

Beginning of the initiative: Ideal village scheme: Comprehensive 5-year plan

Sarpanch/ Gram Panchayat head: Popatrao Pawar elected first in 1989

Historical background and hydrogeological status: arid region surrounded by hilly terrain subjected to deforestation several decades back. Long history of droughts causing severe distress and outmigration.

Groundwater related decisions:

- Critical decision advised by Gram Panchayat: prohibit use of bore wells for agricultural irrigation in 1993: benefit: shifted farmer's minds from competition for groundwater towards cooperation to improve supply of groundwater.
- Comprehensive measure towards soil conservation including arresting hill-top soil run off, afforestation and rainwater harvesting
- Other community- driven measures:
    - Prohibition of deforestation and use of axes
    - Ban on grazing of livestock to reduce soil erosion from nibbling of grass
    - Ban on outsiders purchasing land in the village
    - Ban on cultivating sugarcane, a water intensive crop

- Synchronization of agricultural plans with data driven water resource budgeting: The GSDA provided data on water availability after each monsoon, apportioned the water requirements for consumption for human and livestock, and remaining levels are compared with villagers' proposals for cropping. If an imbalance was found, villagers asked to alter plans towards growing more water efficient crops. High rates of compliance observed.

Results:

- Reversal of distress migration. 40 families which left in the 1970s during a drought, returned to the village.
- Substantial increase in land value by manifold in 10-15 years
- Increase in average household income from 830 Rs. to 11,900 Rs per annum per annum
- Families below poverty line reduced from 92 in 1992 to 1 in 2003

Sources:

1. A Hydrogeologic and Socioeconomic Evaluation of Community-based Groundwater Resource Management –The Case of Hivre Bazaar in Maharashtra-India

https://documents1.worldbank.org/curated/en/858661468041409147/pdf/518270BRI0Box31BLIC10GWMATE1CP122HB.pdf

2. Hiware Bazar: A water-led transformation of a village, IDFC Policy Group, 2016

https://hindi.indiawaterportal.org/articles/hiware-bazar-water-led-transformation-village

11.1.2. Tarun Bharat Sangh

Tarun Bharat Sangh, an NGO based in Rajasthan state, successfully mobilized thousands of village residents towards supply-side measures to improve recharge of groundwater in their locality. They succeeded in mobilizing communities in more than 1000 villages in Rajasthan, India's driest state, to improve groundwater levels by building traditional rainwater harvesting structures called Johads. It involved a vigilant and active village level body (Gram Sabha) supported by members from all strata of society including women and youth in drawing up plans for recharge, implementing them and in monitoring compliance. The initiative achieved miraculous results including reversal of a critically water deficient subdivision into water surplus status, rebirth of a dried-up river.

Number of villages involved: 1058

Key focus: supply-side measures to improve groundwater recharge. Johads, a type of earthern dams were constructed in several numbers to retain and recharge groundwater.

Hydrogeological condition: Drought prone arid regions. Before the intervention, many of the villages were classified under "dark zone" where no further groundwater can be drawn.

Community Groundwater measures taken:

- Individuals and members of village-level institutions including women's groups and youth organizations from 1058 villages mobilized. They act as decision making bodies on proposals made by the local informal bodies called Gram Sabha (members representing each household) of each village for implementation.
- Community makes rules and plans on equitable access to management of water as well as on natural resources including forests.
- Actions taken include construction of about 5000 traditional earthen dams as water harvesting structures (Johads), leading to enhanced irrigation potential. This in turn led to optimal utilization of land and livestock, and improved incomes.
- Villagers contribute through funds and labour for constructing Johads, TBS makes contributions for hiring labor and purchasing materials such as cement, iron etc.

Results from 1985 to 2005

- Thanagazi, an administrative subdivision in Alwar district earlier classified as "dark zone" (critically low groundwater levels) turned into "white zone"
- "Rebirth" of a dried-up river Arwari due to groundwater recharge by series of Johads in its catchment area
- Regeneration of 6500 km of land
- increase in per capita income from Rs. 2800 to 6662 and improved land value from Rs.3000 per beegha in 1994 to Rs. 25,000 per Beegha in 2000.

Sources:

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https://www.ceew.in/sites/default/files/water-revitalisation-programme-case-study.pdf

11.2. PDS system

The Food Corporation of India, an agency under the central government, procures essential commodities under the Public Distribution System (PDS). This system began in 1960s.

In India PDS is a dominant force in the agricultural market. Government of India procures agricultural products such as cereals, pulses, oilseeds, etc. from farmers in designated regions all over the country, at a minimum support price. Procurement was primarily done from regions where the green revolution succeeded in increased crop yields to reduce transportation costs. The minimum support price is based on a margin above cost of production, however, in many states, farmers also receive substantial subsidies on inputs such as electricity and fertilizers. (citation: Paper of Upmanu lall) Overall, the combination of subsidies and guaranteed procurement prices is a great incentive economically, especially in a country where farmers frequently face uncertainty due to irregular monsoons and inadequate surface water.

Expert interviews affirm that most of the crops in PDS procurement regions are produced using groundwater despite these being arid regions.

Sources:

1. National Food Security Portal, Department of Food & Public Distribution, Government of India https://nfsa.gov.in/portal/PDS_page
2. Food corporation of India http://fci.gov.in/
3. Solving groundwater depletion in India while achieving food security, Naresh Devineni et al, 2022 https://pubmed.ncbi.nlm.nih.gov/35697734/

11.3. Global Groundwater Consumption

Table 2 Breakdown of 2017 groundwater withdrawal by water use sector and by continent

	Groundwater withdrawal		Volumes by water use sector			Percentages by water use sector		
	(km³/year)	% of world	Agriculture	Domestic	Industry	Agriculture	Domestic	Industry
North America	156	16	97	48	12	62	30	7
South America	27	3	13	9	5	49	32	20
Europe	65	7	24	29	12	36	45	19
Africa	45	5	29	14	2	65	32	4
Asia	657	68	496	107	53	76	16	8
Australia & Oceania	8	1	4	4	0	48	48	3
World	**959**	**100**	**664**	**211**	**84**	**69**	**22**	**9**

Source: Estimates based on Aquastat (n.d.), Eurostat (n.d.), and Margat and Van der Gun (2013).

11.4. Summary of key facts and adverse impacts of groundwater depletion in India

Table: Summary of key facts and adverse impacts of Groundwater depletion in India

Food Security Implications	Water Security Implications	Economic Risks & Livelihood Impacts	Environmental Impacts	Political & Internal Security Impacts
With **60% farming** and dependent on groundwater	**83% of Rural and 45% of urban drinking water** supplies are from groundwater	**Poverty rates are 9% higher** in districts with severe depletion (Water table depletion > 8 meters)	Destruction of surface water bodies, rivulets, local aquifers, and their catchment areas resulting in urban dependence on groundwater	**Increasing Inter-state water disputes (10+ states)** No political returns for water sharing and water regulations
20% to 68% reduction in **cropping intensity** (no. of crop cycles per year) **Global Impact:** India is largest exporter of rice & 2nd largest producer of agri-products	**100 million residents** (of 21 large cities) face **zero water threat** in a decade **4-fold decrease in per-capita** water availability in 5 decades	**6% GDP impact by 2030** 'Water risk' is increasingly becoming a 'systemic and material' dimension	Over-extraction trends accelerated **warming temperatures could triple groundwater loss by 2080**	**Increased dependence on ground water for downstream states**
Water-intensive and multi-cycle **crops** such as Rice and Wheat constitute **50% of calories consumed**	100-fold increase in borewells **drawing more water than recharge capacity**	Investing on **deeper wells** significantly **exacerbates the common pool problem** Small farmers impacted disproportionately despite subsidized electricity	Threat of **desertification of 14% of water-stressed districts by 2050**	Political and farmer opposition to water-diversion scheme irrigating drought-prone areas

11.5. Crop Diversification Trends in Karnataka over the last decade

Declining trend : Cereals & Pulses

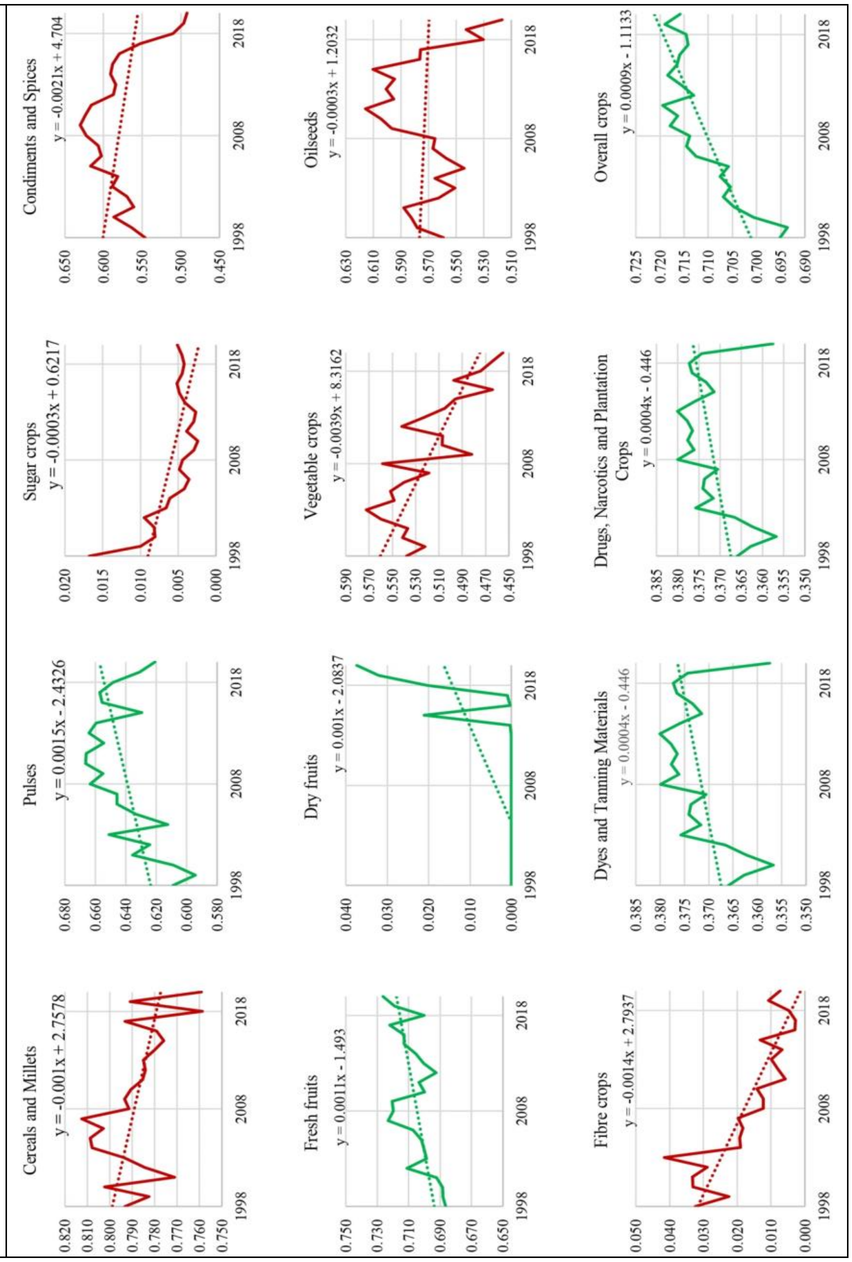
Increasing trend:

- Dying and tanning materials (Arecanut)
- Plantation crops
- fresh fruits
- Pulses

Area trends over last 10 years

- The area under sugarcane crop has increased by 117%
- that of paddy has been decreased by 11%
- Ragi: downward trend by 25%.
- Arecanut and maize has increased by 40% each

The farmers have shown interest in cultivation of arecanut, maize and BT cotton



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