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AGRICULTURAL WATER MANAGEMENT (AWM) TYPOLOGIES

TARGETING LAND-WATER MANAGEMENT INTERVENTIONS TOWARDS IMPROVED WATER PRODUCTIVITY

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EXECUTIVE SUMMARY

In 2019, NITI Aayog estimated that India's GDP by 2050 could be lost by 6% due to water scarcity. Given the growing climate-induced uncertainties and the centrality of water in India's largely agrarian and rural livelihoods, building the resilience of agriculture to climate change is critical. Towards this goal, GIZ India has been implementing the Indo-German project on 'Water Security and Climate Adaptation in Rural India' (WASCA) with the Ministry of Rural Development (MoRD) and the Ministry of Jal Shakti (MoJS) since 2019. Commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ), the project aims to improve water security and rural climate adaptation through better management of rural water resources. The project is operational at national level and in select 10 districts of five states namely Madhya Pradesh, Rajasthan, Tamil Nadu, Uttar Pradesh, and Karnataka. The project's intended outputs include:

Improved convergence of existing planning and financing approaches to strengthen water security

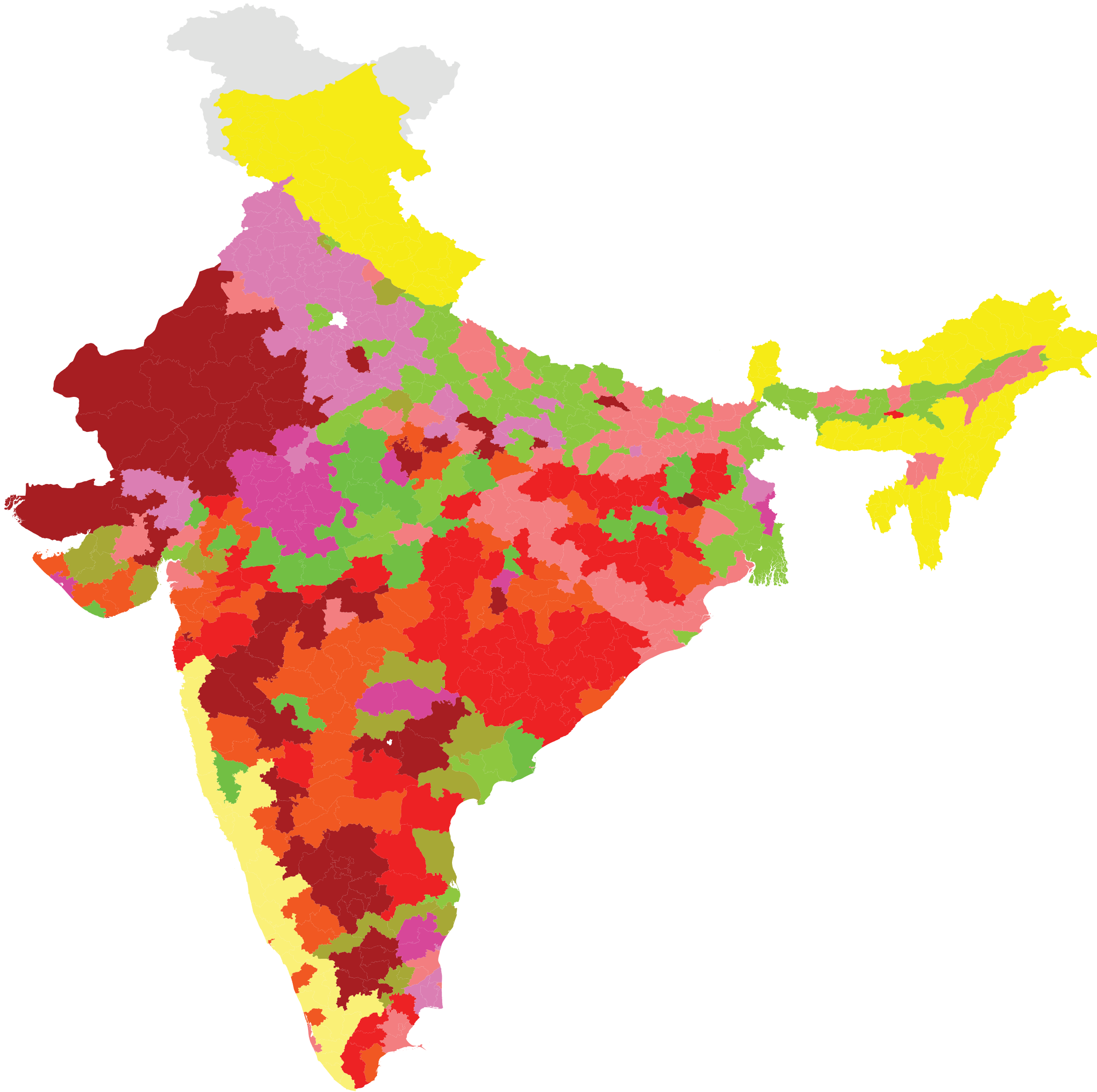
Demonstration of convergent planning, financing, and implementation at local level

Cooperation with the private sector.

International Water Management Institute (IWMI) in knowledge partnership with GIZ India is working to provide support to strengthen WASCA project activities and achieve project intended outputs. Towards this goal, this discussion paper presents national Agricultural Water Management typologies for policy setting, planning, and targeting Land-Water Management Interventions towards improved Water Productivity. With water scarcity and increasing competition from other sectors, increasing water productivity is one of the key pathways to enhance resilience. Thus, achieving Per Drop More Crop i.e., increasing water productivity is among the top priorities of governments globally and more so in India. A range of land-water-vegetation management interventions are widely being promoted and implemented as a part of national and state level government programs and schemes (e.g., Mahatma Gandhi NREGA,) and civil-society and private sector led initiatives. A key criterion for successful planning and achieving desirable outcomes is identifying the best possible suite/package of interventions. This is critical as these land-water- vegetation interventions are contextual and are often associated with trade-offs and synergies among biophysical, environmental, and economic impacts and costs.

This discussion paper presents national scale Agricultural Water Management typologies. The aim of the developed typologies is to identify specific 'development priorities' for each biophysical and socio-hydro-economic context and help frame more effective national policies and programs for achieving per drop more crop. Based on the datasets of yield gap, cropping intensity, water availability and terrain, we classify 657 districts in 12 typologies. These typologies have unique challenges that require different development pathways. Based on developed typologies, we identify and suggest broad intervention strategies that exhibit the maximum potential for achieving Per Drop More Crop while building and enhancing climate resilience. We believe that developed typologies will help policymakers and program designers identify the broad baseline/reference conditions of cluster of districts in terms of agri-water issues. This can be used to capture local diversity for prioritizing and planning management interventions and accordingly prepare typology differentiated national policies and programs.

The selection of suitable (and permissible) activities for a particular typology is guided by the development priorities. In the next volume, with the focus on convergence in MGNREGS, appropriate convergence opportunities at national and state levels for specific development priorities are also identified. These opportunities can be explored for aligning the MGNREGS activities to achieve better outcomes. It is to be noted that the activities and convergence opportunities are neither exhaustive nor prescriptive, but are only indicative. They are organised along with the necessary data to support in planning water security and climate adaptation activities in rural India.



Typology

■	High value diversification districts (Soft rock)
■	High value diversification districts (Hard rock)
■	Demand management districts (Soft rock)
■	Demand management districts (Hard rock)
■	Groundwater development districts
■	Water conservation districts
■	Watershed development districts
■	Water conservation districts (overexploited groundwater)
■	Low Cropping intensity high yield districts
■	Western Himalayas
■	Eastern Himalayas
■	Western Ghats

1. INTRODUCTION

Agriculture accounts for about 70% of total freshwater withdrawals globally, going upto 90% in developing countries (FAO, 2018). With the expected increase in food demand from a higher and wealthier population, estimates suggest that global agricultural demand may increase by upto 50% (Kijne et al., 2009). However, water availability is already constrained in large parts of the world (Kummu et al., 2016; Degefu et al., 2018). Analysis by Kummu et al. (2016) shows that global population under water scarcity increased from 0.24 billion (14% of population) in the 1900s to 3.8 billion (58% of population) in the 2000s. With the increasing competition forwater from other sectors and natural resource degradation, scarcity is expected to exacerbate further. This in conjunction with climate change, which is now a reality is threatening water and food security in large parts of the world. Climate induced extreme risks of floods and droughts account for more than 80% of agriculturallosses (in crop and livestock production) (FAO, 2015) and have reduced the global agriculture total factor productivity by 21% since 1961 (Ortiz-Bobea et al., 2021).

In India with a predominantly agrarian economy supporting over 50% of the Indian workforce and contributing about 17% to national gross domestic product, where monsoon is concentrated in three to four months and about half of the cropland is rainfed, implications can be even worse.

Diversion of freshwater for agriculture in India is likely to reduce due to competing water demands in the near future and some estimates have put it as 72% by 2025, and 65-68%

The adverse impact of climate change on Indian agriculture is expected to reduce annual agricultural incomes on average by 15-18% (MoEF&CCGoI, 2018)

Without any adaptation with the current trend of groundwater depletion, cropping intensity may decrease by 20% in India and by 68% in groundwater-depleted regions of India (Jain et al., 2021)

Building the resilience of agriculture to climate is critical. With water scarcity being one of the key issues, increasing water productivity is one of the key pathways to enhance resilience. Conceptually, Water Productivity (WP) can be related to the physical mass of production (physical water productivity) or the economic value of produce per unit volume of water used (Molden, 1999). Depending upon the scale of analysis and how water used is defined (applied or consumed or depleted), WP is defined in a number of ways (Giordano et al., 2017). With expected higher water variability and water scarcity, it is expected that increasing WP will be critical to meet future agricultural water demands critical for both achieving water and food security. There are large gaps globally and nationally between potential and current levels of WP (Sharma et al., 2018; Foley et al., 2019) reflecting less than efficient use of available water resources. Estimates show that increasing WP in precipitation limited regions alone can increase annual production to provide food for~ 110 million people and can reduce irrigation water consumption equivalent to the water demand of ~ 1.4 billion people (Braumal et al., 2013). Country-level analysis of water productivity of 10 main crops of India by Sharma et al. (2018) show that there is large variation and gap in WP reflecting a vast scope to increase WP. Improvement in WP contributes, directly or indirectly, to 12 and 43 sustainable development goals and targets, respectively (Alam et al., 2021).

Links (primary and secondary) between water productivity and SDGs (source: Alam et al., 2021)

Increasing WP, per drop more crop, are among the top priorities of governments globally and more so in India. A range of land-water-vegetation management interventions, usually termed as Agriculture Water Management (AWM) interventions, are widely being promoted and implemented. These interventions are broadly classified under demand and supply side interventions. Supply-side interventions are focused on creating additional water storage through both in-situ (e.g., soil moisture) and ex-situ (e.g., ponds, aquifier recharge) storage interventions. Whereas demand-side management interventions are focused on more efficient use of available water resources either through efficient irrigation practices (e.g., micro-irrigation) or through broader agronomy measures (e.g., land levelling, crop management, changes in production system) (Sikka et al., 2018; Barron et al. 2009). There are a range of available land-water-vegetation management interventions which have been implemented with benefits widely reported and established for enhancing resilience (Alam et al., 2020; Sikka et al., 2021).

However, the challenge remains in identifying the best possible suite/package of interventions. This is critical as these interventions are contextual and situation specific and may or may not work everywhere (Andrieuet al., 2017). They are associated with trade-offs and synergies among biophysical, environmental, and economic impacts and costs (Sikka et al., 2021; Shirsathet al., 2017). Identifying the best suite of interventions for a location requires assessment of baseline biophysical, agricultural, and socioeconomic factors (Aggarwal et al., 2018, Alam and Sikka, 2019). Considering limited financial resources of government in developing countries, targeting and prioritization of interventions is critical to achieving best outcomes relevant for current as well future climate scenarios (Dunnetet al., 2018). For the targeting and prioritization, a range of decision support systems and tools have been developed and demonstrated broadly consisting of stakeholder participatory approaches, data and modeling-based approaches, and a mix of both (Sikka et al., 2021; Van Wijket al., 2020).

Typology Based Approach

Broadly, typologies is the classification of individual units in a set of categories that are useful for a particular purpose. Specifically, in the domain of agriculture and water, typology is the classification or grouping of entities based on their physical agricultural characteristics. Creating typology helps summarize and represent the baseline characteristics of each group, showcasing how it's different from other groups and subsequently using them to analyze issues and recommending potential interventions. The typology-based approach has been used in a wide array of fields and forms including land use, farmers, lakes, rivers, and health.

2. SCOPE OF REPORT

Water Security and Climate Adaptation in Rural India' (WASCA) is a three-year Indo-German project launched in April 2019 with the key objective of enhancing water resources management with regards to water security and climate adaptation in rural areas through an integrated approach at national, state and local level. The project is commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ) in partnership with the Ministry of Rural Development (MoRD) and Ministry of Jal Shakti (MoJS) in India and implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. The project is operational at the national level and in select areas of five states: Madhya Pradesh, Rajasthan, Tamil Nadu, Uttar Pradesh, and Karnataka (supported by WASCA through a special project 'Technical support to Jalamrutha scheme and Government of Karnataka for water security').

WASCA Project operational states

The project has three key outputs:

Improved convergence of existing planning and financing approaches to strengthen water security

Demonstration of convergent planning, financing and implementation at local level

Cooperation with the private sector

The report focuses on building agricultural water management (in short agri-water) typologies at the national scale for policy setting, planning, and targeting land-water-vegetation management interventions. National scale typologies are developed with the aim to identify broader agri-water situation at the national scale to help frame broader national policies and programs for achieving 'more crop per drop'. In the next volume, typology district scale framework is presented and appropriate convergence opportunities at national and state levels for specific development priorities are also identified. This will be useful since many flagship programs encourage bottom-up planning and quite often the priority setting is done at the district level. Below, the Figure 3 shows the broader conceptual approach and objective of building national and district scale typologies.

Based on the developed typologies, we identify and recommend broad interventions that exhibit the potential for building and enhancing climate resilience through improved water and land management or improved co-management of energy and water resources for delivering Climate-Resilient Water Management (CRWM) outcomes. We have used crop and water related data and parameters for developing typologies.

Conceptual scope and linkage of developed national typologies and district framework

Objectives for developing Agricultural Water Management typologies is to:

1. Help policymakers and program designers to identify the broad baseline/reference conditions of cluster of districts in terms of agri-water issues
2. Create typologies to generalize responses at national scale that can be used to prepare typology differentiated national policies and program
3. Capture local diversity for prioritizing and planning management interventions
4. Plan implementable interventions at the district level

3. METHODOLOGY AND DATA

Typologies are developed with the objective of identifying interventions for achieving 'per drop more crop'. This is more concretely defined as "increasing district level agricultural water productivity, within the limits of current renewable annual water availability of the district." District Agricultural WP is defined as

$$WP = \frac{\text{Crop Production}}{\text{Utilizable Annual Renewable Water}^{1}}$$

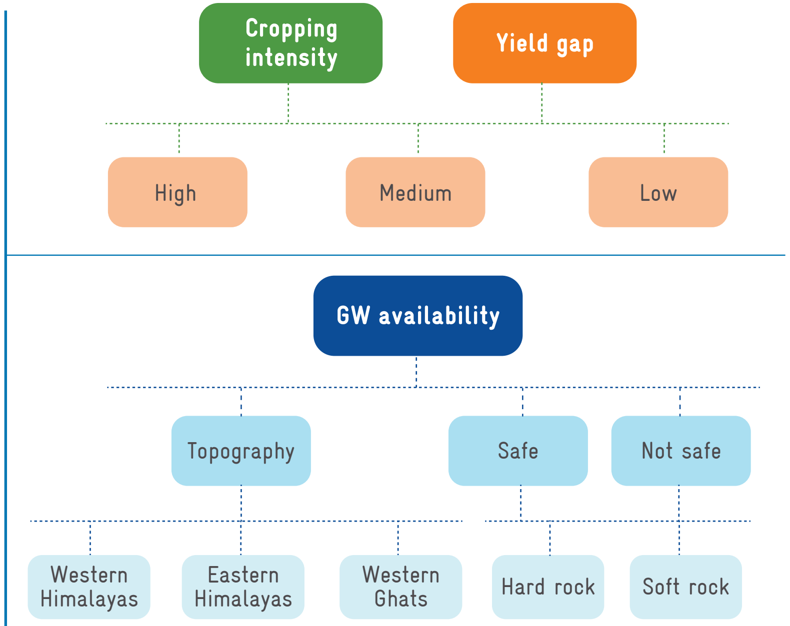
Crop production is the sum of cultivated area of all crops multiplied by their respective crop yields. We define utilizable annual renewable water as the average utilizable annual rainfall in the form of groundwater and surface water resources. Available water can be increased by adding more facilities to divert and store water up to an economic limit of potentially available water (Molden, 1999). Considering equation 1, there are mainly three main pathways for increasing district agricultural water productivity:

a. Increase crop production by increasing crop area.

b. Increase production by closing yield gap (i.e., increasing productivity)

c. Decrease water use without compromising on yield .i.e., efficient use of water

We propose that increasing production should take place within the currently available renewable water resources of the district. To create typologies and identify broad development strategies through land-water-vegetation interventions, we combined four datasets.



Conceptual workflow for typologies creation

Cropping intensity classified into three categories (High, low and moderate)

Yield gap classified into three categories (High, low and moderate)

Groundwater availability classified into three district categories: 1) Safe, 2) Overexploited and 3) Hilly. Safe and overexploited districts are classified based on Central Groundwater Board (CGWB) and hilly districts based on topography

Groundwater/aquifer type classified into soft and hard rock aquifers

[1]Utilizable part of rainfall is the effective rainfall after accounting for runoff and other losses and committed uses that cannot be harnessed for agriculture use through soil moisture, surface and groundwater resources.

Cropping Intensity

The net sown area in India has remained unchanged over the past five decades and is hovering around 140 M ha since the early 1970s, while the gross cropped area over the same period has risen with the cropping intensity growing from 119 percent to 140 percent. This also suggests that increase in production will come from increased cropping intensity and irrigation. Thus, we propose that increase in the gross cropped area will come from increase in cropping intensity, rather than an increase in net sown area. For this, we estimate the potential to increase cropping intensity (gross cropped area/net sown area) of each district. We classify cropping intensity into three categories: High (>= 160 %), 130 % < Medium <160%, Low<= 130 %. For classifying categories, we use expert judgment. We use the latest data (2018-19) of district land use statistics fromthe Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Govt. of India, New Delhi[2].

Yield Gap

Yield gap (in %) of a district (YG_D) is estimated by takingthe yield gap of each crop weighted by its crop area in the district (Equation 2). Yield gap of the crop is estimated as the difference in district crop yield from the 90th percentile yield of the respective crop in India. We classify the yield gap into three categories: Low<= 20% yield gap (high yield), High> 40% yield gap (low yield), 20% < Medium < 40% (medium yield). We use average data of three years (2017-2019) from crop production statistics, Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Govt. of India, New Delhi[3].

$$\mathrm{YG}_D=\sum_{i=1}^{n} (Y_{c(i)}-Y_{c(i)(90)})*(\frac{A_{c(i)}}{A_D}) \quad \text{------ Equation 2}$$

Where YG_D is the district average yield gap, $Y_{c(i)}$ is the yield of crop ith crop (c) in the district, $Y_{cli)(90)}$ is the 90th percentile yield of ith crop (c) in India, $A_{C(i)}$ is the area of ith crop (c) in the district and A_D is the total area of all cropsin the district.

[2]https://aps.dac.gov.in/LUS/Public/Reports.aspx
[3]https://aps.dac.gov.in/APY/Public_Report1.aspx

Water Availability

We define the current stage of water availability of districts based on the current stage of groundwater uses in the district. This is as groundwater is source of drinking water for nearly 90% of rural domestic water use and 70% of water used in agriculture is pumped from aquifers (MoWR, RD & GR, GoI, 2017). Also, there is limited data at the district on surface water resource availability and use. We assume that surface water resources are annually renewed and used. Thus, current stage of groundwater development accounts for the available water resources (including rainwater and surface water) in the district.

District groundwater resource development is classified into two categories (Safe and Not safe) using threshold of 70%. The groundwater resources are deemed not safe if current groundwater use is more than 70% of long-term annual groundwater recharge. This is the criteria employed by Central Groundwater Board (CGWB) (MoWR, RD & GR, GoI, 2017) for categorizing districts under safe category.

Aquifer Type

Type of underlying aquifers is critical to identify appropriate context specific interventions. Overall, in India aquifers have been classified into 14 Principal Aquifer Systems based on their broad hydrogeological properties. These have been further classified into 42 Major Aquifers depending on their distinctive hydrological characteristics and their spatial distribution (MoWR, RD & GR, GoI, 2017). These detailed aquifer types and maps offer the required detail for designing local specific solutions.

However, at the national scale, for this report we use a broader classification of aquifers into three groups based on characteristically different hydraulics of ground water (CGWB):

- **Soft (alluvial) rock aquifers:** These are the porous formations. They can be classified in to Unconsolidated and Semi – consolidated formations. Unconsolidated formations (e.g., alluvial sediments of river basins, coastal and deltaic tracts) are the most productive aquifers with potential to support extensive development. Similarly, semi-consolidated formations (e.g., Gondwanas, sandstones) are relatively less productive but give rise to free-flowing wells.

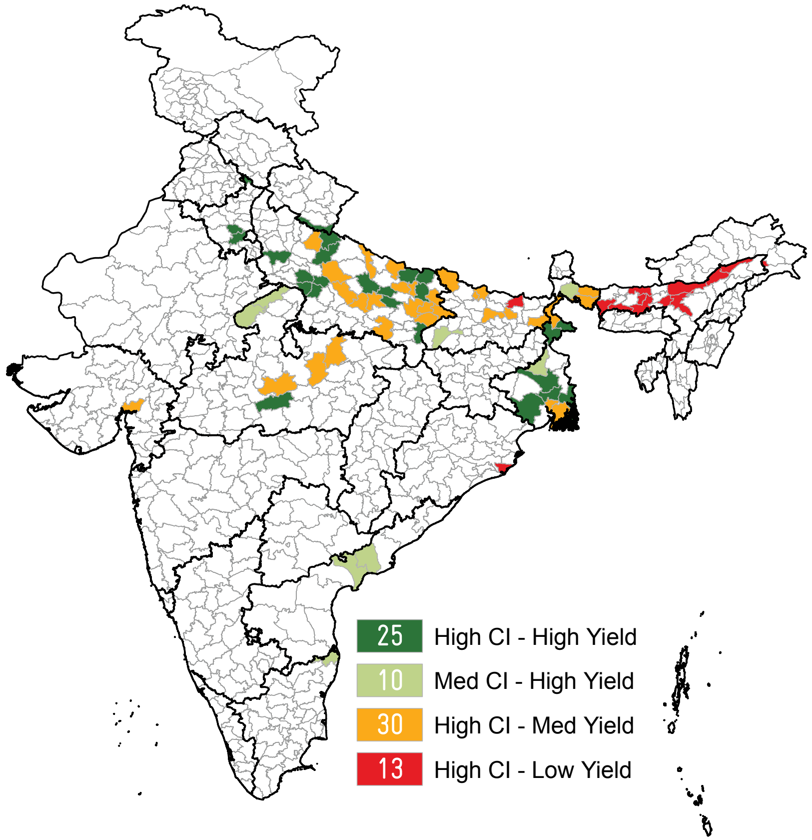
- **Hard rock aquifers:** These are the fissured rock systems (consolidated formations) with negligible primary porosity and cover two-third of country area. They are mainly of four types: Igneous and metamorphic rocks excluding volcanic and carbonate rocks, volcanic rocks, consolidated sedimentary rocks and carbonate rocks. As compared to soft rocks, they are much less productive and storage is limited.

- **Hilly area:** Aquifers in these areas have unique characteristics and are usually more difficult to access. These have been classified based on the topography with districts under Western Himalayas, Eastern Himalayas and Western Ghats.

These broad types reflect the available storage of groundwater resources, ease of access and require unique set of interventions.

4. NATIONAL TYPOLOGIES

Figure 1: High value diversfication districts (Soft rock aquifers)



78
Number of districts

1253.2
Avg rainfall (mm/year)

14.1
% of country

57.5
% Irrigation coverage

63.5
Groundwater irrigated area (%)

36.5
Surfacewater irrigated area (%)

173.4
Cropping Intensity (%)

24.9
Yield gap (%)

44.8
Avg GW development (%)

High Value Diversification Districts

These are the districts where cropping intensity is high (medium to high). Among these, desired districts are those where both cropping intensity and yield are high. There are 103 districts under this typology and occupy 14.1% of country total gross cropped area. In these districts, high cropping intensity (173.4%) is being achieved while staying largely within sustainability limits and groundwater development is under safe category (44.8%). Data shows that in these districts overall groundwater irrigation covers two third of the total irrigated areas whereas one third is irrigated by surface water. These districts are divided into two group based on aquifer type: Soft rocks (Figure 1) and Hard rocks (Figure 2). These districts are predominantly (~ 80 %) underlain by Alluvial (soft) aquifers.

Districts with soft (alluvial) rock aquifers (Figure 1) are predominantly in the Ganges plains across states of Uttar Pradesh and West Bengal where groundwater resources are abundant. In these districts, irrigation coverage is higher and yield gaps are lower. Only 13 districts (out of 78 districts), have low yield.

Districts with hard rock aquifers (Figure 2) are predominantly in Madhya Pradesh with a good network of rivers and canal systems. Relatively, these districts have lower irrigation coverage (41.1%) and higher yield gaps (34.9%). In these districts, 9 out of 25 district have low yields.

High cropping intensity shows that these districts have high-intensity agricultural development Efforts in these districts should be on sustaining high cropping intensity and increasing yield but keeping groundwater use under sustainable limits.

Broad development priorities:

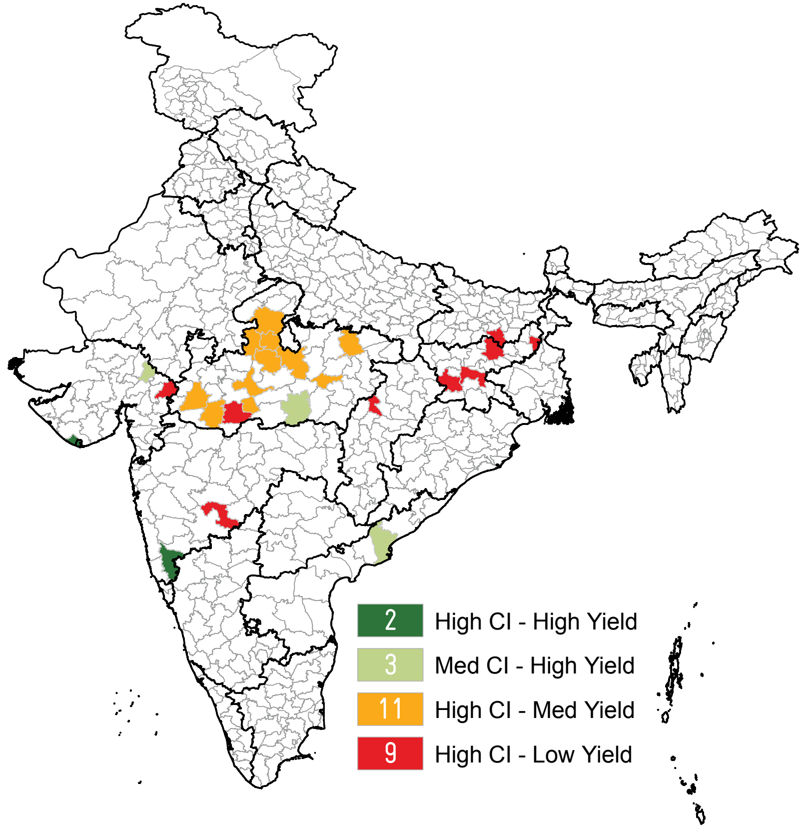
- **Increasing farmers' income through diversification and high value crops:** Effort in these districts should include increasing farmer's income through diversification of crops to high-value crops taking advantage of fertile lands and good water resource availability. Specifically, effort should be on reducing cropped area under rice and wheat. Preferably, under rice which is cultivated during hot summer season with high evapotranspiration demand.

- **Irrigation and agronomy measures to increase yields:** In these districts, cropping intensity is high but there is a scope of closing yield gaps. Thus, in districts with low to medium yield gaps, interventions should focus expanding irrigation and on agronomy measures including providing high yielding varieties, soil fertility improvement, value addition and mechanization.

- **Sustainable groundwater development:** Efforts to increase irrigation and yields should be in conjunction with interventions to support judicious and sustainable use of groundwater. This includes interventions on recharge and smart and and Water Management Practices for irrigation eater and energy savings, and improved productivity (e.g., land leveling, conservation agriculture etc.)

- **Efficient use of the available and created water resources:** It is prudent to increase yield and irrigation, efforts should be matched with interventions focusing on efficient use of water. This includes supplementary or deficit irrigation in the rainfed areas; adoption of simple and low-cost drip and micro-sprinkler irrigation methods. Promotion and popularization of efficient practices - moisture conservation, conservation agriculture practices, mulching of dryland crops; raising bunds height around the rice fields to retain the rain water, etc.

Figure 2: High value diversfication districts (Hard rock aquifers)



25	1064.2	6.8	41.1
Number of districts	Avg rainfall (mm/year)	% of country	% Irrigation coverage

63.0	37.0	177.3	34.1	46.9
Groundwater irrigated area (%)	Surfacewater irrigated area (%)	Cropping Intensity (%)	Yield gap (%)	Avg GW development (%)

Demand Management Districts

These are the districts with high agriculture production having high average cropping intensity and low yield gaps. There are 108 districts under this typology and occupy 21.6% of country's total gross cropped area. However, this is achieved at the expense of unsustainable groundwater development reflected in the high stage of groundwater development. Data shows that in these districts irrigation is dominated by groundwater contributing ~ 75% of the total irrigated area. These districts are divided into two groups based on aquifer type: Soft rocks (Figure 3) and Hard rocks (Figure 4). These districts are predominantly (~ 80%) underlain by Alluvial (soft) aquifers.

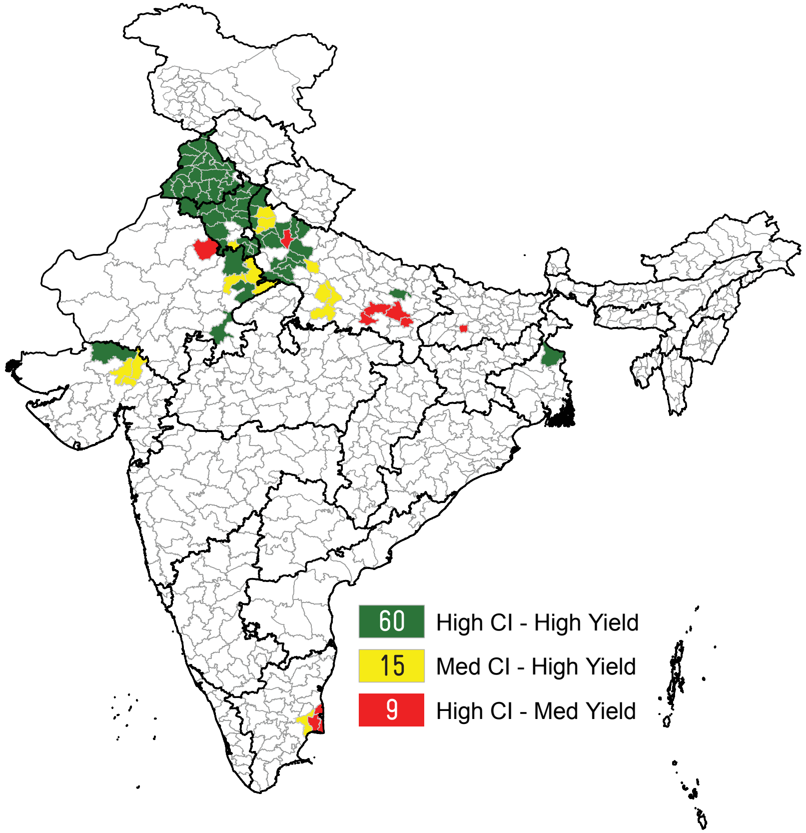
Districts with soft (alluvial) rock aquifers (Figure 3) are predominantly concentrated in the northwestern part of India covering states of Punjab, Haryana, and Western Uttar Pradesh. In these districts, irrigation coverage is very high (85.5%) and yield gaps very low (9.8%). Groundwater is overexploited with stage of development at 126.7%.

Districts with hard rock aquifers (Figure 4) are predominantly in Western Madhya Pradesh bordering Rajasthan. In these districts, irrigation coverage is comparatively lower (50.1%). This is reflected in comparatively higher yield gaps (26%). However, groundwater remains overexploited with stage of development at 94.7%.

Broad development priorities:

- **Demand management through technological and policy interventions:** Interventions should focus on managing water demand in these districts through both technological and policy solutions.
- **Efficient use of the available water resources:** Technological solutions include expanding efficient irrigation practices including micro-irrigation and efficient agronomy practices (Direct Seeded Rice (DSR), Alternate Wetting and Drying (AWD), Conservation Agriculture (CA).
- Management and policy interventions should encourage changes in the cropping pattern,

Figure 3: Demand management districts (Soft rock aquifers)



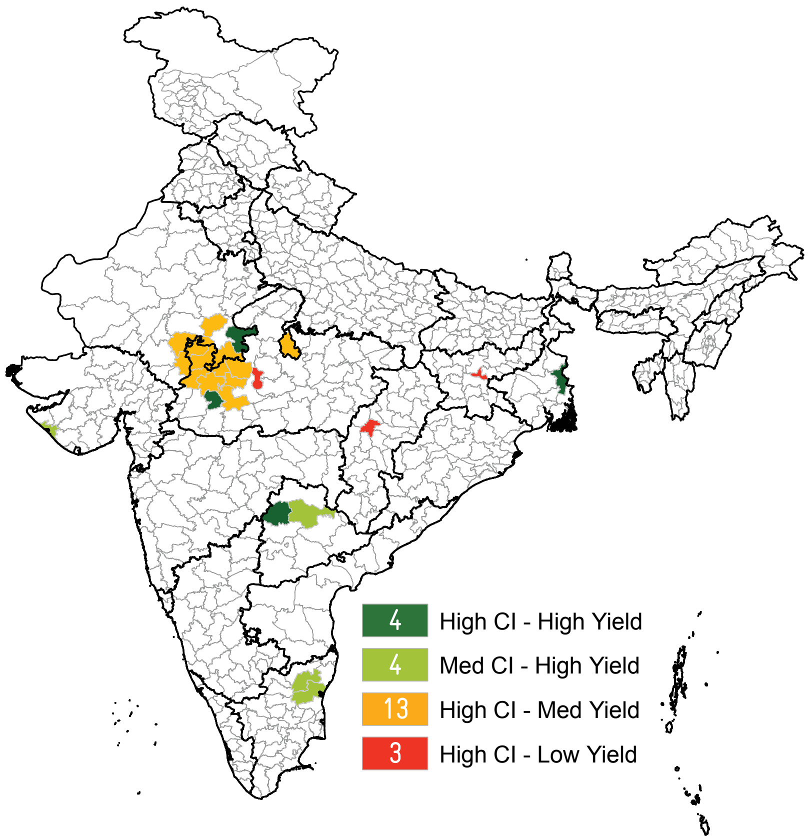
Number of districts	Avg rainfall (mm/year)	% of country	% Irrigation coverage	
84	721.9	15.6	85.5	
Groundwater irrigated area (%)	**Surfacewater irrigated area (%)**	**Cropping Intensity (%)**	**Yield gap (%)**	**Avg GW development (%)**
74.8	25.2	176.6	9.8	126.7

crop diversification and other measures to manage water demand. This includes, especially in northwest India, reduction in the area under rice and wheat and rice which is cultivated during hot summer season with high ET demand.

- **Increase yields through agronomy measures:** In hard rock districts, cropping intensity is high but there is scope of closing yield gaps. Thus, in districts with low to medium yield gaps, interventions shouldfocus on increasing irrigation and on agronomicmeasures including providing high yielding varieties, soil fertility improvement,value addition and farm mechanization.

- **Augmenting the available surface and ground water resources:** Availability of limited surface water resources and over-exploitation of groundwater resources require that development of additional water resources through rejuvenation of the existing water infrastructure and tapping the additional water resources through utilization of rain and/or canal water and the non-conventional water resources like the saline and alkali water, wastewater from the municipalities and villages, underground taming of surface water for recharge and rejuvenation of the village farm ponds etc.

Figure 4: Demand management districts (Hard rock aquifers)



24	938.3	6.0	50.1	
Number of districts	Avg rainfall (mm/year)	% of country	% Irrigation coverage	
74.4	25.6	175.4	26.0	94.7
Groundwater irrigated area (%)	Surfacewater irrigated area (%)	Cropping Intensity (%)	Yield gap (%)	Avg GW development (%)

Low Production Districts: Safe Groundwater

These districts have low cropping intensity and high yield gaps. These districts cover about one-third of the total districts (223) and occupy 30.9% of country's gross cropped area. These districts are concentrated in Eastern India, and Southern Peninsular. It is seen that there are low levels of agriculture as well as irrigation development in these districts. For planning and targeting interventions, these districts can be further segregated into three typologies based on underlying aquifer type and land use.

Groundwater Development Districts

These districts are underlain by soft rock aquifers and are predominantly concentrated in Eastern states of Bihar, Odisha, and Eastern Uttar Pradesh. In these districts, cropping intensity is low (130.6%) with high yield gaps (40.8%). Irrigation coverage in the districts is moderate (45.3%) with groundwater and surface contributing equally. Despite productive aquifers, stage of groundwater development is low (38.8%). In these districts, there is a good scope for developing irrigation as rainfall is high (1405.9 mm) and conjuctive water use with good network of canals and low groundwater development.

Broad development priorities:

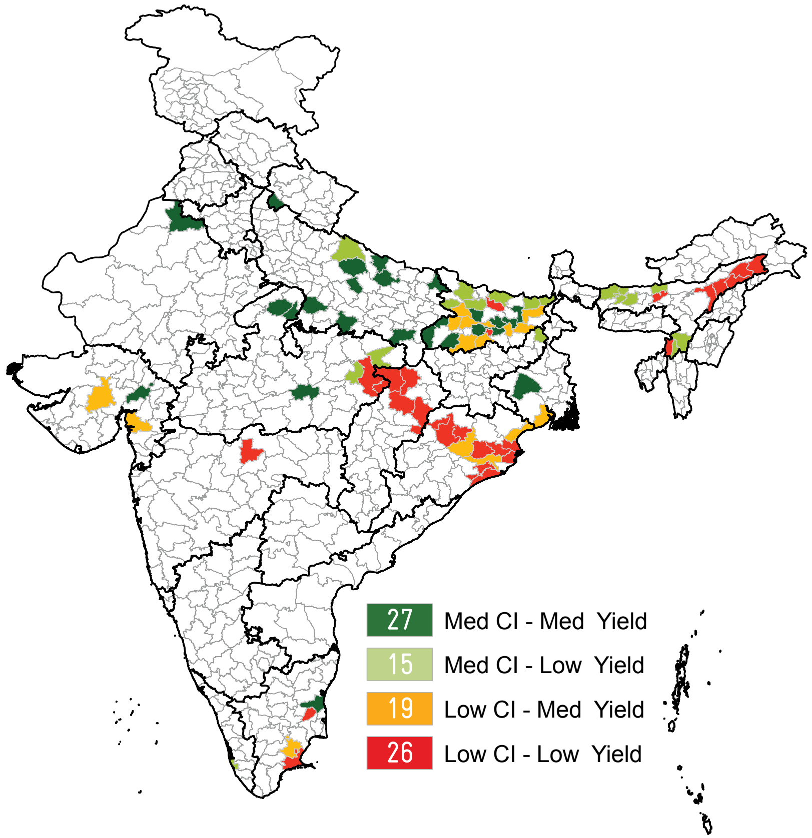
- **Rainwater management and Irrigation expansion:** Priority should be to develop water resources and expand irrigation coverage. In these districts, the constraint is not the physical water availability but rather the under development of rain, surface, and groundwater resources. Expansion of irrigation will help in expanding cropping intensity and closing the yield gap. This includes creation of new and completion of the ongoing surface-major, medium, and minor irrigation projects, development of groundwater and the water distribution network at the farm level coupled with on-farm water management.

- **Increase yields through agronomy measures:** Considering the high yield gap in these districts, equal focus should be on providing suitable crop cultivars, improved agronomic measures, soil fertility improvement, water management and farm mechanization.

- **Improving availability of affordable farm energy for groundwater lifting and other farm operations:** Effort should be on allocation of sufficient and affordable energy, replacing costly and polluting dieselfor the farm and irrigation sector and construction of an efficient distribution network for enhancing water access and coverage. Promotion of solar energy and installation of the solar irrigation pumps especially in the remote and tribal areas.

- **Development of Innovative Farming System Models:** High rainfall in the region and a rich biodiversity provide good opportunities for development and adoption of innovative farming systems based on local knowledge and the species which shall create higher economic value in a sustainable manner. Farmers may be encouraged to adopt: Integrated Farming Systems (IFS) with a pond and the surrounding farm area with integration of fisheries, livestock, crops, fruits and vegetables, and other plants of economic value.

Figure 5: Groundwater development districts



Number of districts	Avg rainfall (mm/year)	% of country	% Irrigation coverage
87	1405.9	10.2	45.3

Groundwater irrigated area (%)	Surfacewater irrigated area (%)	Cropping Intensity (%)	Yield gap (%)	Avg GW development (%)
49.9	50.1	130.6	40.8	38.8

Water Conservation Districts

These districts are underlain by hard rock aquifers and have intensive agriculture with more than 50% of the district area under agriculture. Districts underlain by hard rock aquifers are primarily in Deccan plateau in the states of Maharashtra, Karnataka and Southern Gujarat.

In these districts, cropping intensity is low (124.5%) with high yield gaps (43.1%). Irrigation coverage in the districts is low (33.6%) with groundwater and surface water contributing equally. Stage of groundwater development is also low (48.3%). Here scope for developing groundwater is low as it is constrained by the limited storage of the aquifers.

Broad development priorities:

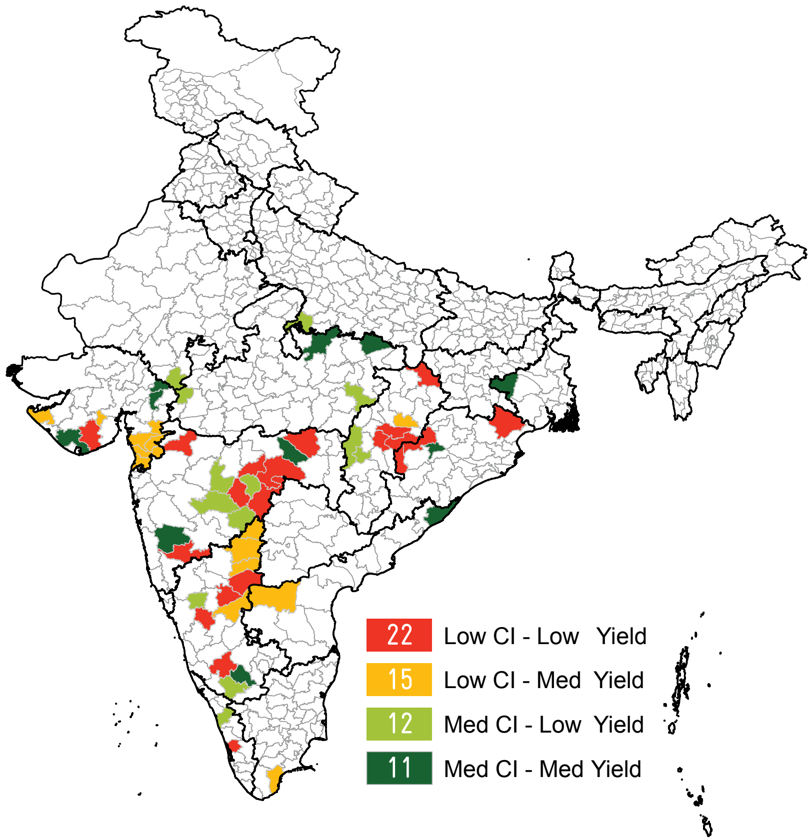
- **Rainwater management and Irrigation expansion:** Priority should be given to develop water resources and expand irrigation coverage. In these districts, the constraint is not the physical water availability but rather the under developed resources. Expansion of irrigation will help in expanding cropping intensity and closing the yield gaps.

- **Sustainable groundwater development:** Increase in irrigation expansion should not come at the cost of groundwater overexploitation and thus interventions to support judicious and sustainable use of groundwater,focusing on recharge should be planned

- **Increase yields through agronomy measures:** Considering the high yield gap in these districts, equal focus should be on providing suitable crop cultivars, improved agronomy measures, soil fertility improvement, water management and farm mechanization.

- **Efficient use of the available and created water resources:** Water scarcity, both physical and economical, necessitates those resources created should be efficiently used. Water efficient practices and interventions should be promoted. This includes supplementary or deficit irrigation in the rainfed areas; adoption of simple and low-cost drip and micro-sprinkler irrigation methods; promotion and popularization of efficient practices of soil moisture conservation, conservation agriculture, mulching of dryland crops; raising bunds height around the rice fields to retain the rain water, etc.

Figure 6: Water conservation districts



61	1097.9	12.5	33.6	
Number of districts	Avg rainfall (mm/year)	% of country	% Irrigation coverage	
52.1	47.9	124.5	43.1	48.3
Groundwater irrigated area (%)	Surfacewater irrigated area (%)	Cropping Intensity (%)	Yield gap (%)	Avg GW development (%)

Watershed Development Districts

Districts underlain by hard rock aquifers but are dominated by non-agriculture use (more than 50% of district area) including forest and fallow lands. These districts are predominantly in Central India covering states of Chhattisgarh, Jharkhand, and Odisha.

In these districts, cropping intensity is lowest (119.2%) and yield gaps are highest (46.7%). Irrigation coverage in the districts is very low (26.4%) with surface water covering most of the area (62%). Thus, stage of groundwater development is very low (35.5%). In these districts, with low agriculture development, forest areas and undulating topography, focus should be on watershed development and irrigation expansion.

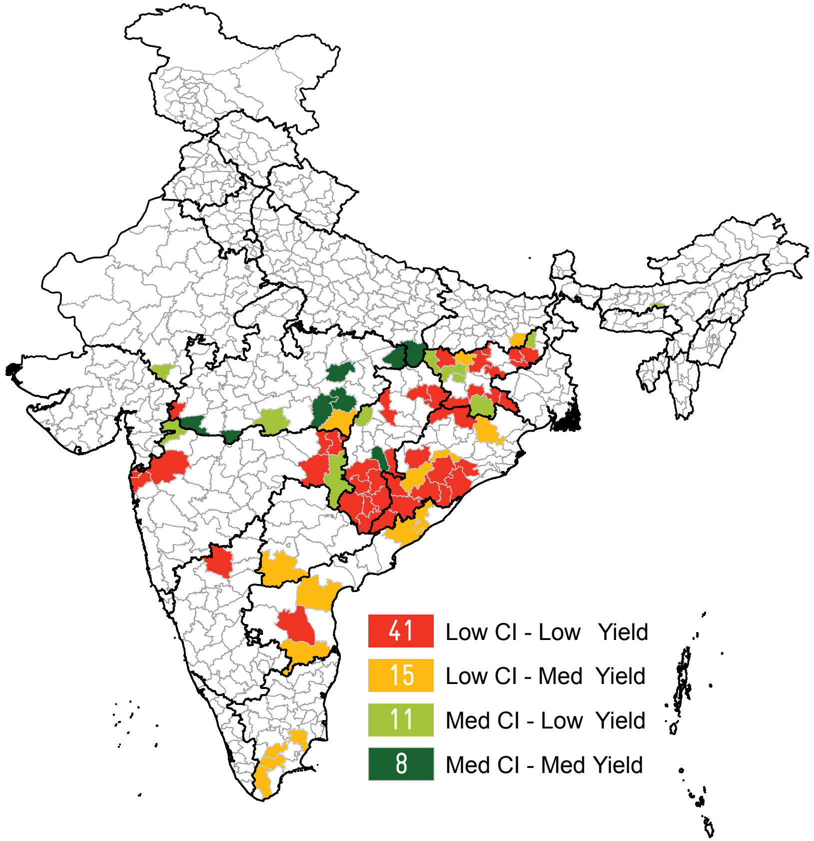
- **Watershed development:** A large part of the cropped area is rainfed and suffers from frequent droughts, long dry spells during rainy season and uncertain rainfall events. Water availability and its accessibility at the critical crop growth periods poses a major constraint. The prevailing situation can be mediated to a large extent through development and effective implementation of the participatory watershed management. This includes creation of the individual and community farm ponds of suitable size and at appropriate locations; construction of diversion channels and nala bunds in the hilly areas and construction of stop dams and check dams at suitable locations.

- **Rainwater management and Irrigation expansion:** Priority should be to develop water resources locally and expand irrigation coverage. In these districts, the constraint is not the physical water availability but rather the under development of rain, surface, and groundwater resources. Expansion of irrigation will help in expanding cropping intensity and closing the yield gap. This includes creation of minor irrigation projects, development of groundwater and the distribution network at the farm level.

- **Increase yields through agronomy measures:** Considering the high yield gap in these districts, focus should be on providing suitable crop cultivars, improved agronomy measures, soil fertility improvement, water management and farm mechanization.

- **Development of Innovative Farming System Models:** High rainfall in the region and a rich biodiversity provide good opportunities for development and adoption of innovative farming systems based on local knowledge and the species which shall create higher economic value in a sustainable manner. Farmers may be encouraged to adopt: Integrated Farming Systems (IFS) with a pond and the surrounding farm area with integration of fisheries, livestock, crops, fruits and vegetables, and other plants of economic value.

Figure 7: Watershed development districts



75	1237.1	8.2	26.4
Number of districts	Avg rainfall (mm/year)	% of country	% Irrigation coverage

37.9	62.1	119.2	46.7	35.5
Groundwater irrigated area (%)	Surfacewater irrigated area (%)	Cropping Intensity (%)	Yield gap (%)	Avg GW development (%)

Water Conservation Districts Overexploited Groundwater

These districts have low cropping intensity (127.4%) and high yield gaps (43.7%). Additionally, there is physical water scarcity highlighted by high groundwater development (113.4%) and low average rainfall (713.6mm). This limitst he scope for further development of water resources or expanding irrigation. There are 59 districts under this typology and occupy 17.5% ofcountry's total gross cropped area.

These districts can be classified under three categories:

1. Arid districts (aridity index (ration of precipitation to potential evaporation) of <0.2) with very low rainfall in the Western state of Rajasthan and Kachchh (6 districts).

2. Districts underlain by soft rock aquifers; they are also predominantly in the state of Rajasthan with low rainfall (15 districts).

3. Districts underlain by hard rock aquifers, they are predominantly in peninsular India in the states of Karnataka, Maharashtra and Tamil Nādu.

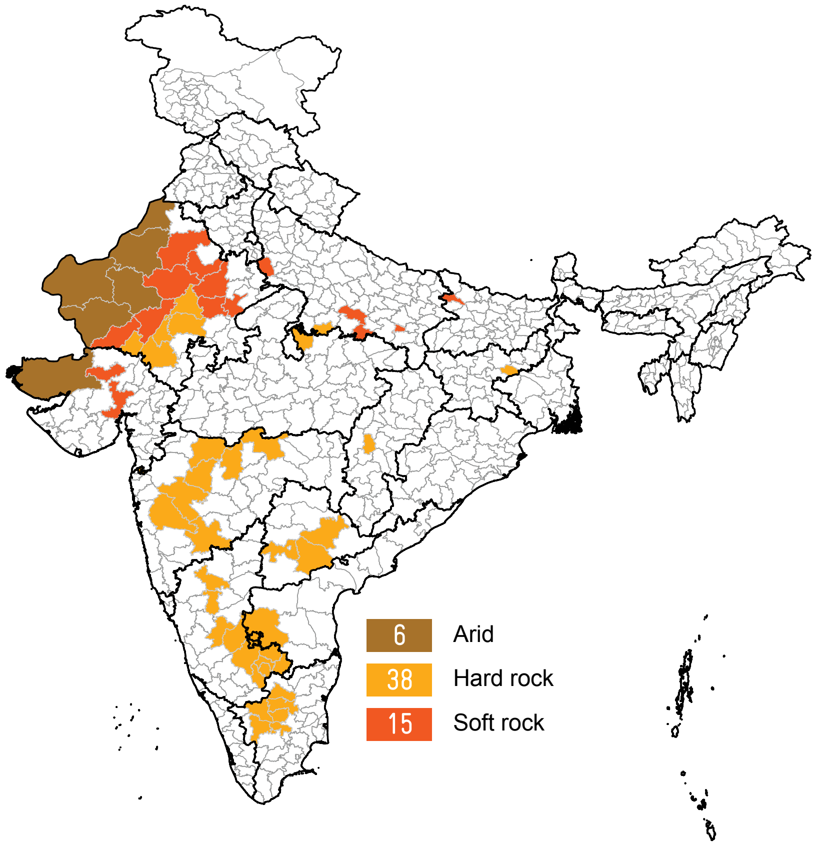
Broad development priorities:

- **Increasing water and economic productivity:** As there is limited scope to develop further irrigation, the focus should be on efficient and productive use of available water resources to increase water productivity through use of efficient irrigation practices and remunerative cropsto enhance economic water productivity. This includes supplementary or deficit irrigation in the rainfed areas; adoption of simple and low-cost drip and micro-sprinkler irrigation methods; promotion and popularization efficient practices of moisture conservation, conservation agriculture practices, mulching of dryland crops; raising bunds height around the rice fields to retain the rain water, etc.

- **Increase yields through agronomy measures:** Considering the high yield gap in these districts, more focus should be on providing better crop varieties (short duration and high yielding varieties), improved agronomy measures, soil fertility improvement, water management and farm mechanization.

- **Augmenting the available Surface and Ground Water Resources:** Availability of limited surface water resources and over-exploitation of groundwater resources requires development of additional water resources through rejuvenation of the existing water infrastructure and tapping the additional water resources through utilization of rain or canal water and the non-conventional water resources like the saline and alkali water, wastewater from the municipalities and villages, underground taming of surface water for recharge and rejuvenation of the village farm ponds etc.

Figure 8: Water conservation districts (overexploited groundwater)



59	713.6	17.5	40.4	
Number of districts	Avg rainfall (mm/year)	% of country	% Irrigation coverage	
74.8	25.2	127.4	43.7	113.4
Groundwater irrigated area (%)	Surfacewater irrigated area (%)	Cropping Intensity (%)	Yield gap (%)	Avg GW development (%)

Low Cropping Intensity High Yield Districts

These are the districts where cropping intensity is low (116.9%), but yields are high (low yield gap of 13.6%). These are the districts where either water availability is low or not developed thus cropping area in non-rainy season is limited. However, high yields suggest that during the main cropping season, water availability is high and inputs usage is high thus yields are high. There are in total 20 districts in this category covering 3.1% of country's gross cropped area.

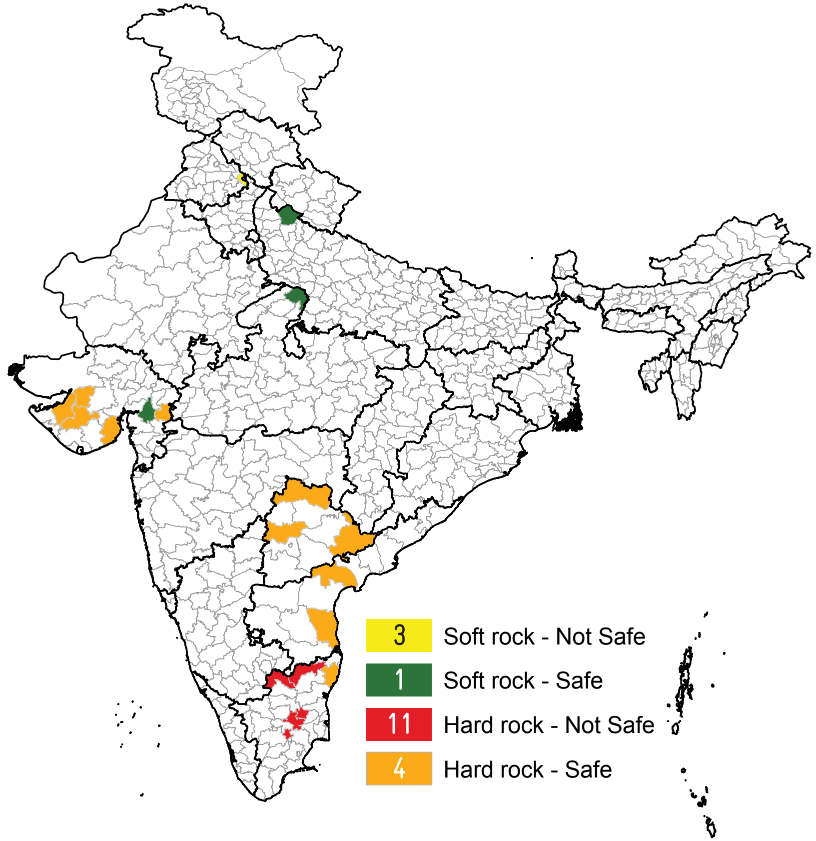
Most of these districts groundwater development is safe (15 out of 20) and are underlain by hard rock aquifers (15 out of 20). The map (figure 9) shows that thesedistricts are distributed across Western and Southern India in the states of Gujarat, Telangana, and Andhra Pradesh. Overall irrigation coverage in these districts is moderate (57%) with groundwater irrigation being the main source.

Broad development priorities:

- **Efficient use of the available and created water resources:** Water scarcity necessitates those resources created should be efficiently usedto maximize the benefits from available water resources, expand dry season crop acreage, and to keep the future development sustainable. Water efficient practices and interventions should be promoted. This includes adoption of simple and low-cost drip and micro-sprinkler irrigation methods; promotion and popularization efficient practices of moisture conservation, conservation agriculture practices, mulching of dryland crops; raising bunds height around the rice fields to retain the rainwater, etc.

- **Augmenting the available Surface and Ground Water Resources:** Availability of limited surface water resources and groundwater resources requires that development of additional water resources through rejuvenation of the existing water infrastructure and tapping the additional water resources through utilization of rain or canal water and the non-conventional water resources like the saline and alkali water, wastewater from the municipalities and villages, underground taming of surface water for recharge and rejuvenation of the village farm ponds etc.

Figure 9: Low Cropping intensity- High Yield districts



20	883.2	3.1	58.5	
Number of districts	Avg rainfall (mm/year)	% of country	% Irrigation coverage	
71.5	28.5	116.9	13.6	72.1
Groundwater irrigated area (%)	Surfacewater irrigated area (%)	Cropping Intensity (%)	Yield gap (%)	Avg GW development (%)

Hilly Districts

These districts are distributed across Himalayan ranges (Western and Eastern) and Western Ghats. In these hill districts, agro-climatic conditions are diverse, with steep slopes, shallow soil depths, high runoff and soil erosion. The topography isn't conducive for development of conventional irrigation and largely depend on small and minor irrigation/ micro level water resources development. These districts are also associated with high value plantation crops (coffee, tea, horticulture etc.).

These are segregated into three distinct regions: 1) Western Himalayas, 2) Eastern Himalayas and 3) Western Ghats

Western Himalayas

There are total 45 districts occupying only 1.4% of country's total gross cropped area in Western Himalayas. Predominantly these districts have low production with both CI and Yield either low or medium (26 of 45) or high cropping intensity with low yield (18 of 45). Both represent districts where irrigation development is low (30%). High cropping intensity with low yield could be attributed to low irrigation development though these districts are endowed with high rainfall and utilizable available water resources enough for double cropping but low inputs or rainfed farming leads to low yields.

Eastern Himalayas

There are in total 70 districts occupying only 1.3% of country total gross cropped area in Eastern Himalayas. Predominantly these districts have low production with both CI and Yield either low or medium (52 of 70). Both represent districts where irrigation development is low (18%). However, rainfall is very high in these districts (1935.5 mm) and surface water irrigation (92%) is the predominant source of irrigation.

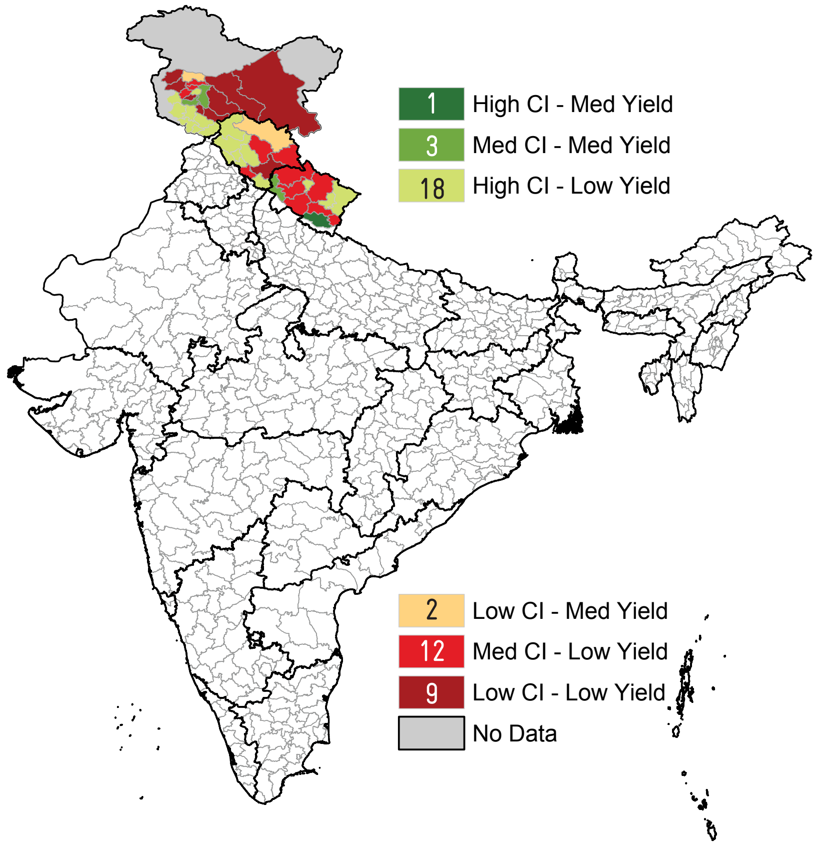
Western Ghats

There are in total 29 districts occupying only 1.9% of country's total gross cropped area in the Western Ghats. Predominantly these districts have low production with both CI and Yield either low or medium (26 of 29) with low irrigation development (22.5%). Like eastern Himalayas, rainfall is very high in these districts (2410.5 mm). Both groundwater and surface water irrigation contributes equally to irrigation.

Broad development priorities:

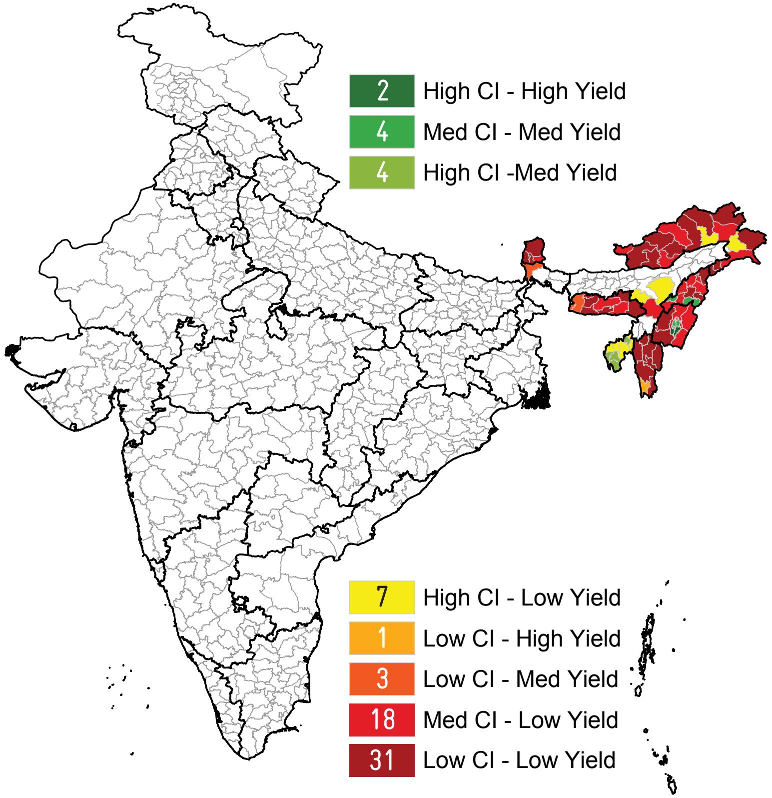
- **Improving livelihoods:** Restoration of fragile mountain ecosystem for improved agri-livelihoods
- **Springshed and watershed management:** In the hilly regions, most of the water usedcomes from springs. Decline in springs affect both household and agriculture water security. Thus, focus should be on technological (e.g., recharge interventions, efficient irrigation practices) and institutional (e.g., mapping, monitoring) solutions for managing springsheds.
- **Decentralized rainwater harvesting and minor irrigation development** through rainwater harvesting, sub-surface water harvesting, minor irrigation, springs revival through springshed management, soil water conservation and watershed management.
- **High value crops and value addition:** Promoting high value crops, supporting value addition and market linages, organic farming, improved agronomic practices, agri-horticulture, agro-forestry and alternate income generating activities.

Figure 10: Western Himalayas



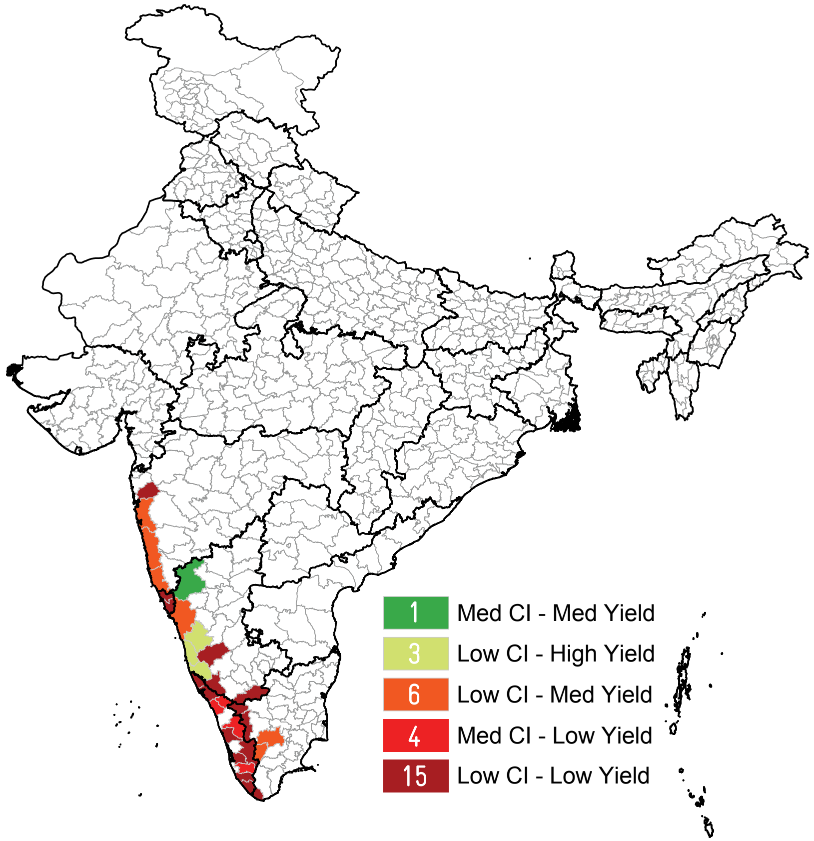
45	Number of districts
830.2	Avg rainfall (mm/year)
1.4	% of country
30.1	% Irrigation coverage
10.0	Groundwater irrigated area (%)
90.0	Surfacewater irrigated area (%)
151.8	Cropping Intensity (%)
52.2	Yield gap (%)
35.1	Avg GW development (%)

Figure 11: Eastern Himalayas



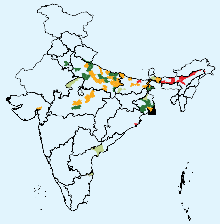
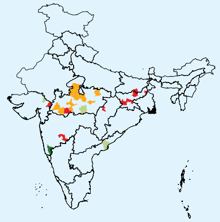
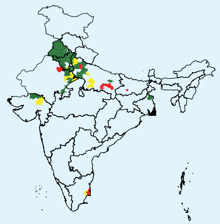
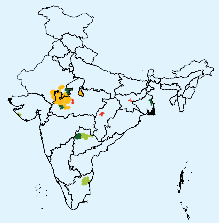
70	1935.5	1.3	18.8	
Number of districts	Avg rainfall (mm/year)	% of country	% Irrigation coverage	
7.9	92.1	135.9	47.6	2.7
Groundwater irrigated area (%)	Surfacewater irrigated area (%)	Cropping Intensity (%)	Yield gap (%)	Avg GW development (%)

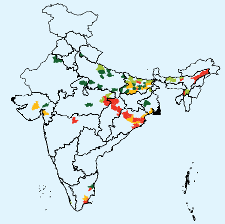
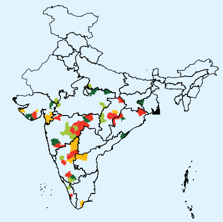
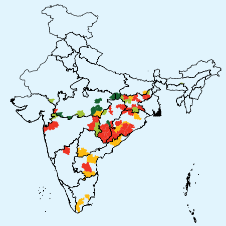
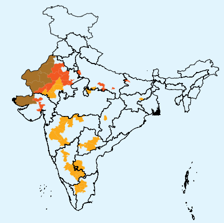
Figure 12: Western Ghats

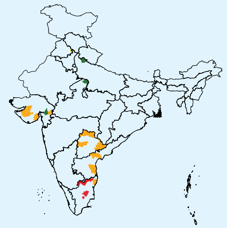
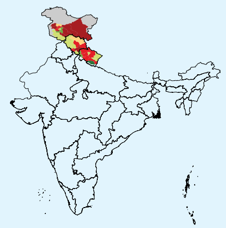
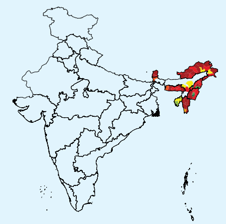
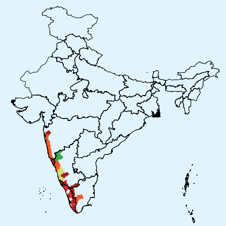


29	2446.4	3.2	25.2	
Number of districts	Avg rainfall (mm/year)	% of country	% Irrigation coverage	
49.2	50.8	116.9	41.7	48.6
Groundwater irrigated area (%)	Surfacewater irrigated area (%)	Cropping Intensity (%)	Yield gap (%)	Avg GW development (%)

Summary of Typologies

Typology	Stats	Broad development priorities	Map
High value diversification districts (Soft rock aquifers)	# 78 CI 173.4 Yield Gap 24.9 GW dev 44.8 Rainfall 1253.2	- Increasing farmers income through diversification and high value crops - Irrigation and agronomy measures to increase yields - Sustainable groundwater development - Efficient use of the available and created water resources	
High value diversification districts (Hard rock aquifers)	# 25 CI 177.3 Yield Gap 34.1 GW dev 46.9 Rainfall 1064.2		
Demand management districts (Soft rock aquifers)	# 84 CI 176.6 Yield Gap 9.8 GW dev 126.7 Rainfall 721.9	- Demand management through technological and policy interventions - Efficient use of the available water resources - Augmenting the available surface and ground Water Resources	
Demand management districts (Hard rock aquifers)	# 24 CI 175.4 Yield Gap 26.0 GW dev 94.7 Rainfall 938.3	- Demand management through technological and policy interventions - Efficient use of the available water resources - Augmenting the available surface and ground Water Resources - Increase yields through agronomy measure	

Typology	Stats	Broad development priorities	Map
Groundwater development districts	# 87 CI 130.6 Yield Gap 40.8 GW dev 38.8 Rainfall 1405.9	- Rainwater management and Irrigation expansion - Increase yields through agronomy measures - Improving availability of affordable farm energy for groundwater lifting and other farm operations - Development of Innovative Farming System Models	
Water conservation districts	# 61 CI 124.5 Yield Gap 43.1 GW dev 48.3 Rainfall 1097.9	- Rainwater management and Irrigation expansion - Increase yields through agronomy measures - Efficient use of the available and created water resources - Sustainable groundwater development	
Watershed development districts	# 75 CI 119.2 Yield Gap 46.7 GW dev 35.5 Rainfall 1237.1	- Development and effective implementation of the watershed management projects - Rainwater management and Irrigation expansion - Increase yields through agronomy measures - Development of Innovative Farming System Models	
Water conservation districts (overexploited groundwater)	# 59 CI 127.4 Yield Gap 43.7 GW dev 113.4 Rainfall 713.6	- Increasing water and economic productivity - Increase yields through agronomy measures - Augmenting the available Surface and Ground Water Resources	

Typology	Stats	Broad development priorities	Map
Low Cropping intensity- High Yield districts	# 20 CI 116.9 Yield Gap 13.6 GW dev 72.1 Rainfall 883.2	- Efficient use of the available and created water resources - Augmenting the available Surface and Ground Water Resources	
Hilly districts › Western Himalayas	# 45 CI 151.8 Yield Gap 52.2 GW dev 35.1 Rainfall 830.2		
Hilly districts › Eastern Himalayas	# 70 CI 135.9 Yield Gap 47.6 GW dev 2.7 Rainfall 1935.5	- Restoration of fragile mountain ecosystem for improved agri- livelihoods - Springshed management - Decentralized rainwater harvesting and minor irrigation development - High value crops and value addition	
Hilly districts › Western Ghats	# 29 CI 116.9 Yield Gap 41.7 GW dev 48.6 Rainfall 2446.4		

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