

Water Scarcity and Judicious Management for Agricultural Sustainability Under the Backdrop of a Shrinking Resource Base

Amruta Sawant, Chandani Lakhani, Sandeep Bodkhe

Water scarcity, climate change, uncontrolled resource exploitation, and governance challenges are the key drivers largely impacting agricultural sustainability. The chapter briefly reviews the water agriculture dependency with a focus on the key drivers, impacts, and strategies associated with water scarcity in agriculture. It also reviews the present declining water resource related issue and its effects on crop production, yield stability, soil degradation, salinity, and farmer livelihoods as possible emerging risks to food security and rural sustainability. Further, the chapter discusses water-smart agriculture practices, including the latest water-efficient irrigation technologies, advanced cropping patterns, and soil-water conservation measures as sustainable water management strategies. This section explains the role of traditional water management practices, policies, institutional measures, and emerging technologies in addressing challenges related to water scarcity in agriculture. It also explains how these efforts help to make efficient and judicious use of water in agriculture. Overall, the chapter has highlighted that efficient water management in agriculture is essential for achieving long-term water security and agricultural sustainability.

Keywords: *Water scarcity, Agricultural sustainability, Climate change, Water-smart agriculture, Sustainable water governance*

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Introduction

Water is a renewable resource essential for sustaining all life on earth and supporting agriculture and livelihood (Biswas et al., 2025). Water is heavily utilized by households, industries, and agricultural farms for a variety of everyday purposes such as food production, energy generation, and industrial production. Although water covers a major portion of the Earth's surface, only 3% of the total water in the world is

freshwater, and less than 1% is readily usable for humans. The balance between freshwater availability and demand is increasingly affected by climatic variations, population growth, rapid urbanization, industrial expansion, unsustainable patterns of resource use, and pollution (Biswas et al., 2025). Globally, the agriculture sector is the largest consumer of freshwater, and the rising water scarcity is a serious threat to the long-term sustainability of agricultural systems (Biswas et al., 2025; Deng et al., 2025; Paschaline & Kabari, 2024).

In many developing regions, agriculture remains the backbone of the rural economy and is highly dependent on monsoon rainfall and groundwater-based irrigation. Agriculture is known as a climate-sensitive sector, heavily dependent on water; hence, improving water management becomes important (Biswas et al., 2025). More than three-fourths of rice output in India is realized on 79 million hectares of irrigated lowland, and it is predicted that 17 out of 75 million hectares of Asia’s flood irrigated rice crop will experience physical water scarcity and 22 million hectares may experience economic water scarcity (Patel et al., 2010; Midya et al., 2025). The sustainability of rice production is threatened due to indiscriminate overlifting of groundwater in flooded rice culture in wet ecosystems leading to arsenic contamination in some parts of the Indo-Gangetic plain zone of India, sometimes referred to as the biggest arsenic calamity of the world (Midya et al., 2025). This chapter examines the interlinkage between water scarcity and agricultural sustainability. The chapter highlights key drivers of water scarcity and their impacts on agricultural systems and explores strategies of judicious management for promoting sustainable, water-smart agricultural practices.

Water scarcity and its relevance to agriculture

Globally, India ranks first with a total water footprint, estimated at nearly 1,047 billion cubic meters annually, reflecting severe and increasing pressure on freshwater resources driven by agricultural, industrial, and domestic demands (Mehla et al., 2023). Agriculture accounts for nearly 95% of total freshwater withdrawals in India, thus making the sector highly vulnerable to fluctuations in water availability (Biswas et al., 2025; Deng et al., 2025; Paschaline & Kabari, 2024). Water scarcity arises when surface and groundwater resources are insufficient to meet agricultural, domestic, and industrial water demands due to physical limitations, climatic variability, and socio-economic and institutional factors (Deng et al., 2025; Leijnse et al., 2024). The types of water scarcity, their primary constraints, and associated agricultural impacts are summarized in Table 1.

Table 1. Types of water scarcity, primary constraints, and agricultural impacts (Seckler et al., 2010)

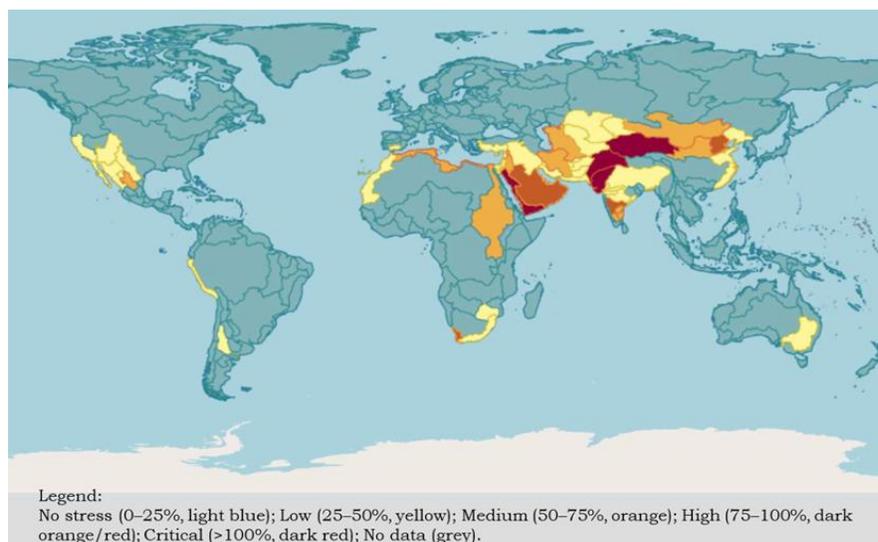
Type of water scarcity	Definition	Primary constraint	Agricultural impact
Physical water scarcity	Insufficient water to meet total demand	Hydrological limits, climate change	Reduced irrigation, yield loss
Green water scarcity	Inadequate rainfall for crops	Rainfall variability	Stress on rain-fed crops
Blue water scarcity	Insufficient renewable surface and groundwater	Overextraction	Irrigation restrictions
Economic water scarcity	Water available but inaccessible	Institutional and financial barriers	Inequitable water access
Total water scarcity	Combined physical and economic scarcity	Natural and governance failures	High agricultural vulnerability

As a result, water scarcity has emerged as a major limitation to agricultural sustainability, especially in climate-sensitive and monsoon-dependent countries such as India (Baraj et al., 2024; Biswas et al., 2025).

Even minor increases in average temperature significantly reduce crop yields, especially in rain-fed agriculture, which constitutes a major portion of Indian agriculture (Biswas et al., 2025). In addition, the rapid expansion of irrigated agriculture and cultivation of water-intensive crops have accelerated groundwater depletion, reducing irrigation reliability and increasing the cost of water access (Deng et al., 2025; He & Rosa, 2023; Paschaline & Kabari, 2024). Beyond crop production, water scarcity also constrains livestock productivity by limiting drinking water availability and food production, further threatening livelihoods (Deng et al., 2025). Addressing this multidimensional challenge is therefore central in achieving sustainable agriculture and requires integrated water resource management, climate-resilient farming practices, supportive institutional frameworks, and the adoption of smart agricultural technologies to enhance water-use efficiency and system resilience (Baraj et al., 2024; Biswas et al., 2025; Deng et al., 2025; Morchid et al., 2024; Verma et al., 2025).

Interlinkage between water scarcity and agricultural sustainability

Water scarcity results in non-renewable groundwater extraction and long-term depletion that largely affects agricultural sustainability (Leijnse et al., 2024). Long-term agricultural productivity depends on the availability of water resources, efficient water-use practices, soil conservation, and resilience to climatic variability. Water scarcity weakens these foundations by reducing crop yields, destabilizing production over time, degrading soil quality, and increasing livelihood vulnerability (He & Rosa, 2023). Agricultural sustainability is closely linked to climate-driven water stress, as changes in precipitation patterns, evapotranspiration rates, and frequency of extreme weather events alter crop–water relationships, soil moisture dynamics, and ecosystem functioning (Verma et al., 2025). Limited water availability accelerates soil degradation; threatens the long-term viability of water-dependent farming practices; increases the risk of crop failures, and leads to income loss (Biswas et al., 2025; Deng et al., 2025; He & Rosa, 2023). In countries such as India, rising agricultural water demand is increasingly met through unsustainable abstractions that prioritize short-term yield gains at the expense of long-term resource sustainability, leading to chronic and seasonal water scarcity (Biswas et al., 2025; Deng et al., 2025). Figure 1 shows the global water stress levels based on consumption. Figure 2 shows the global irrigation intensity distribution by percentage of area under irrigation.



**Figure 1. Global water stress levels based on consumption
(Food and Agriculture Organisation of the United Nations, 2024)**

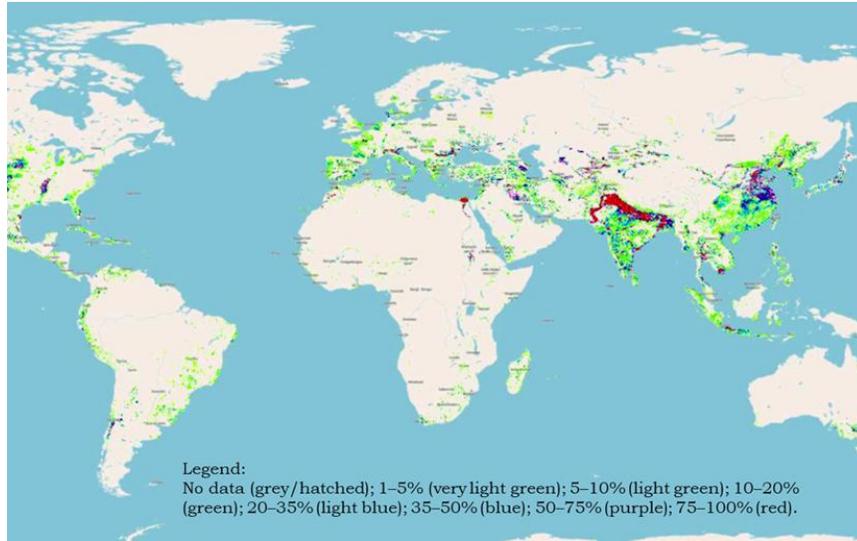


Figure 2. Global irrigation intensity distribution by percentage of area under irrigation (Food and Agriculture Organization of the United Nations, 2024)

Rain-fed agricultural systems, which sustain nearly 60% of global food production, are highly vulnerable to rainfall variations and temperature, further highlighting the sensitivity of agricultural systems to water stress (Baraj et al., 2024). Addressing this multidimensional challenge requires integrated water and land resource management, improved water use efficiency, climate-resilient farming practices, and supportive institutional frameworks (Baraj et al., 2024; Biswas et al., 2025; Deng et al., 2025; Morchid et al., 2024; Verma et al., 2025). The adoption of smart agricultural technologies, including IoT-enabled real-time monitoring of water, soil, and climatic parameters, enables data-driven decision-making that improves resource use efficiency, reduces environmental degradation, and strengthens the resilience of agricultural systems under increasing water scarcity (Biswas et al., 2025; Deng et al., 2025; Morchid et al., 2024). This spatial pattern represented in Figure 3 shows global agricultural water usage, highlighting the growing need for water-efficient irrigation and sustainable water management practices.

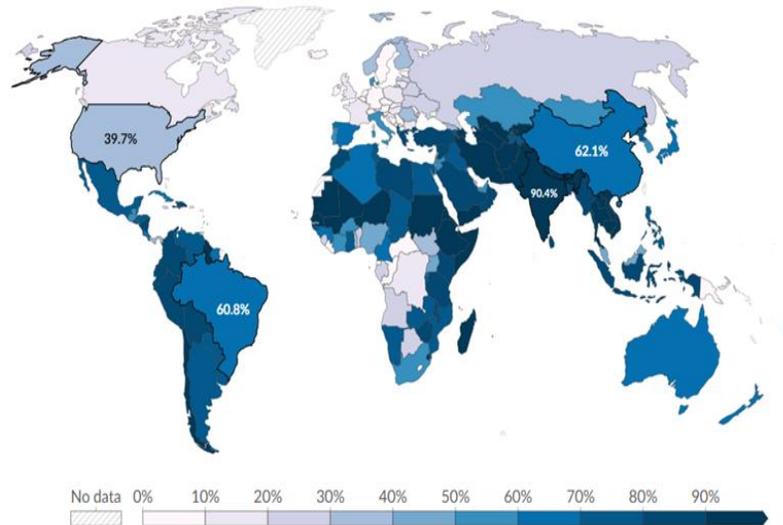


Figure 3. Global agricultural water usage (Food and Agriculture Organisation of the United Nations, 2024)

Key drivers of water scarcity and impacts on agricultural sustainability

Water scarcity is a profound issue faced globally, particularly by the agricultural sector, which is highly dependent on freshwater availability (Biswas et al., 2025; Tandle et al., 2025). The interaction of climatic, hydrological, socio-economic, institutional, and environmental drivers collectively reduces the availability, accessibility, and quality of freshwater resources. Globally, water scarcity is driven by climate change and droughts; rapid urbanization and industrialization; population growth; economic development; water pollution; and unsustainable agricultural practices (Biswas et al., 2025; Paschaline & Kabari, 2024; Tandle et al., 2025).

Climatic and natural influences

Climatic variability and long-term climate change are two of the most critical drivers of water scarcity affecting agriculture. In India, approximately 17% of the years between 1901 and 2010 were classified as drought years, and irrigation demand is projected to increase by nearly 56% by 2050, placing additional pressure on already stressed water resources (Tandle et al., 2025). Irregular monsoon rainfall, delayed onset, and uneven spatial distribution increase uncertainty in water supply, particularly for rain-fed agriculture, which constitutes a substantial share of Indian farming systems (Tandle et al., 2025). Rising temperatures further intensify water scarcity by increasing evapotranspiration losses, leading to higher crop water requirements and soil moisture depletion (Saikanth et al., 2023; Tandle et al., 2025). Hydro-climatic variability, characterized by alterations in precipitation patterns, temperature rise, and reduced snowpack, has been identified as a key driver of water scarcity across global hotspots (Leijnse et al., 2024). The fluctuations in ambient temperature, rainfall distribution, atmospheric CO₂ concentration, and the increasing frequency of extreme events significantly influence crop water stress and productivity across agro-ecosystems (Verma et al., 2025).

Agriculture water demand and resource overexploitation

Agricultural water demand is the most dominant driver of water scarcity, particularly in countries like India, where agriculture consumes nearly 80–90% of total freshwater withdrawals (Mehla et al., 2023; Tandle et al., 2025). Over 50% of India's irrigation requirements are met through groundwater; thus, excessive extraction has resulted in rapidly declining aquifer levels, especially in intensively cultivated regions such as Punjab and Rajasthan (Tandle et al., 2025). Water-intensive cropping patterns, expansion of irrigated agriculture, and inefficient irrigation practices have accelerated groundwater depletion beyond natural recharge rates (Biswas et al., 2025). Overexploitation of groundwater has led to declining water tables, increased pumping depths, higher energy consumption, and environmental degradation (Chouhan et al., 2023). Globally, agricultural water use is the dominant pressure in approximately 77% of identified water scarcity hotspots, where groundwater abstraction exceeds sustainable limits (Leijnse et al., 2024).

Socioeconomic, institutional, and policy factors

Socioeconomic, institutional, and policy factors significantly intensify water scarcity by shaping water access, allocation, and use efficiency. Rapid population growth, urbanization, and economic development increase competition for limited freshwater resources between agriculture, domestic, and industrial sectors (Paschaline & Kabari, 2024; Rastogi et al., 2024). In many regions, unregulated groundwater extraction and inequitable water rights systems restrict access to water for small and marginal farmers, increasing

agricultural vulnerability (Leijnse et al., 2024). Water pollution further reduces effective water availability. Pollution from agricultural runoff carrying fertilizers and pesticides, untreated domestic wastewater, and industrial effluents contaminates both surface and groundwater resources, rendering them unsuitable for irrigation (Biswas et al., 2025). Figure 4 shows the key drivers of water scarcity and its overall impacts.

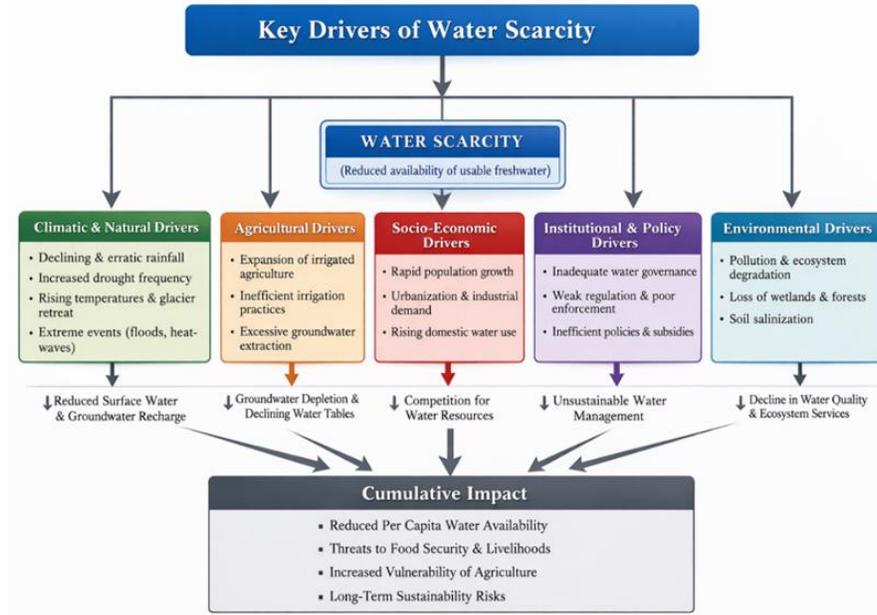


Figure 4. Key drivers of water scarcity and its overall impacts

Impacts of water scarcity on agricultural sustainability

Water scarcity largely impacts agricultural systems, with short-term production losses leading to long-term degradation of agro-ecosystem resilience, farmer livelihoods, and food security. Irrigated agriculture accounts for about 20% of global cultivated land, contributing nearly 40% of total food production, underscoring the critical dependence of global food systems on reliable water availability and efficient water management (Chouhan et al., 2023). This disturbs the balance by reducing crop productivity, degrading soil resources, increasing livelihood insecurity, and threatening the sustainability of food systems, mainly for water-stressed and climate-vulnerable regions.

Effects on crop productivity and yield stability

Water scarcity significantly affects crop productivity and yield stability by limiting water availability during critical stages of crop growth, including germination, flowering, and grain filling. Inadequate rainfall, frequent droughts, declining irrigation supplies, and increasing evapotranspiration losses reduce biomass accumulation, yield potential, and crop quality (Biswas et al., 2025). Under present climatic conditions, green water scarcity already affects food production for approximately 890 million people globally (He & Rosa, 2023). Under 1.5°C and 3°C warming scenarios, the population affected is projected to rise to 1.23 billion and 1.45 billion, respectively, indicating severe threats to crop productivity and global food security (He & Rosa, 2023). Water scarcity contributes directly to reduced agricultural production in many hotspots, where declining water availability limits irrigation reliability and increases crop vulnerability to climatic variability (Leijnse et al., 2024).

IoT-based monitoring systems provide real-time insights into soil moisture, temperature, and crop health, enabling timely interventions that mitigate yield losses under water-stressed conditions (Morchid et al., 2024). Climate variability explains a substantial proportion of global crop yield variability, with water stress and heat stress significantly reducing yields of major crops such as wheat, rice, maize, and soybean (Verma et al., 2025).

Soil degradation, salinity, and declining land quality

Water scarcity contributes directly to soil degradation, salinity, and long-term declining land quality, particularly in irrigated agricultural systems (Biswas et al., 2025). Excessive groundwater extraction, inefficient irrigation practices, and poor drainage result in waterlogging, soil salinization, nutrient leaching, and reduced soil fertility (Saikanth et al., 2023). Excessive irrigation and weak regulatory frameworks result in tailwater losses, groundwater depletion, soil erosion, and downstream water quality deterioration (Mehla et al., 2023). At the system level, groundwater depletion and surface water overuse frequently trigger secondary impacts such as land subsidence, soil salinity build-up, and deterioration of irrigation water quality (Leijnse et al., 2024). Climate extremes and prolonged water stress exacerbate soil degradation through erosion, nutrient imbalance, declining soil organic carbon, and reduced biological activity, thereby weakening soil resilience and water-holding capacity (Verma et al., 2025).

Implications for food security and farmer livelihoods

Water scarcity poses a significant threat to food security and farmer livelihoods by reducing agricultural output, increasing production uncertainty, and raising cultivation costs (Biswas et al., 2025). Smallholder and marginal farmers in developing countries, including India, are disproportionately affected due to their heavy reliance on rainfall and groundwater resources and limited adaptive capacity. Reduced water availability, combined with rising energy costs for irrigation and declining yields, contributes to income instability and heightened livelihood vulnerability. Green water scarcity already constrains rain-fed agricultural systems that support nearly 890 million people globally, and future warming is expected to further reduce calorie availability and increase food system vulnerability (He & Rosa, 2023). Water scarcity undermines food security by lowering agricultural production and increasing income instability, particularly among small and marginal farmers with limited access to technology and institutional support (Mehla et al., 2023; Tandle et al., 2025). In India, groundwater depletion, rainfall variability, rising input costs, and declining farm incomes collectively weaken long-term agricultural sustainability (Jatav & Naik, 2023). Beyond farm-level impacts, water scarcity has broader socio-economic consequences, including increased food prices, rural livelihood insecurity, health deterioration, conflict over water resources, and climate-induced migration in water-stressed regions (Leijnse et al., 2024; Verma et al., 2025). Smart agriculture, enabled by digital technologies such as IoT-based monitoring and precision water management, has emerged as a critical pathway for enhancing productivity while conserving water and strengthening the resilience of food systems (Morchid et al., 2024).

Sustainable water-smart agriculture strategies

Water-efficient irrigation and management practices

Water-efficient irrigation and management practices are key adaptation strategies to address agricultural water scarcity. Approaches aiming at using less water more effectively utilizing every drop of water for maximizing crop and water productivity, such as micro-irrigation, improved irrigation scheduling,

fertigation, conservation agriculture, and wastewater reuse, significantly enhance water-use efficiency and sustainability (Biswas et al., 2025). Climate resilient rice production technologies like aerobic Rice Culture, System of Rice Intensification, Direct Seeded Rice Technology (DSRT), Alternate Wetting and Drying (AWD) are emerging climate –Resilient rice technologies for improving crop and water productivity under shrinking resource base with additional benefits of reduced methane emission under global climate crisis and arsenic contamination in ecology and environment (Midya et al., 2021, Midya, 2025). Drip irrigation and sprinkler systems can conserve between 16% and 70% of water compared to conventional irrigation, while simultaneously improving crop yields by up to 57% (Chouhan et al., 2023).

Micro-irrigation technologies minimize conveyance and application losses by reducing evaporation, runoff, and deep percolation losses. Improved irrigation scheduling, including sensor and weather-based scheduling and water harvesting interventions, further optimizes water application and reduces unnecessary withdrawals (Jatav & Naik, 2023). The integration of IoT-enabled smart irrigation systems with combined soil moisture sensors, climatic data, and automated controls optimizes irrigation timing and volumes (Morchid et al., 2024). Climate-smart agricultural practices that integrate efficient irrigation, soil moisture conservation, and optimized water management improve crop resilience while reducing water consumption and greenhouse gas emissions (Verma et al., 2025).

Crop diversification, soil–water conservation, and climate-resilient agriculture

Crop diversification and soil–water conservation measures form the core of climate-resilient agriculture in water-stressed regions. Diversifying cropping systems through mixed cropping, crop rotation, and the adoption of drought-tolerant and short-duration varieties reduces reliance on water-intensive crops and enhances resilience to climatic variability and hydrological uncertainty (Sahoo et al., 2025; Verma et al., 2025). Aligning crop choices and sowing calendars with local rainfall patterns and water availability lowers irrigation demand and improves system-level water productivity, making diversification a critical adaptation strategy under increasing water scarcity (Leijnse et al., 2024).

Soil and water conservation practices complement crop diversification by enhancing in-situ moisture availability and improving green water retention. Nature-based interventions such as mulching, conservation tillage, no-till farming, cover crops, and contour farming reduce soil evaporation, increase rainfall infiltration, and improve soil structure (He & Rosa, 2023; Leijnse et al., 2024; Rastogi et al., 2024). These practices enhance soil organic matter content, which increases water-holding capacity, improves nutrient cycling, and buffers crops against droughts and extreme rainfall events (Verma et al., 2025). Sensor-based monitoring of soil moisture, nutrient status, and salinity enables precision application of water and inputs, reducing over-irrigation, nutrient leaching, and long-term soil degradation (Morchid et al., 2024).

Smart agriculture technologies further support adaptive crop management by enabling real-time responses to hydroclimatic variability, thereby strengthening the resilience of farming systems under changing climate conditions (Morchid et al., 2024; Sahoo et al., 2025). The combined adoption of crop diversification, soil moisture conservation, and climate-smart technologies reduces agricultural water demand, improves water-use efficiency, and enhances long-term soil health. These integrated approaches are essential for sustainable agricultural transformation in water-scarce regions (Leijnse et al., 2024; Verma et al., 2025).

Role of policy intervention, institutional support, and traditional practices

Policy and institutional support for water sustainability

National initiatives such as the National River Linking Project (NRLP), watershed development programs, and the National Water Policy provide an overarching water governance framework aimed at enhancing irrigation coverage, improving water accessibility, and strengthening agricultural resilience under water-scarce conditions (Tandle et al., 2025). Government-led interventions promoting watershed development, micro-irrigation, and integrated water resource management play a critical role in improving irrigation efficiency and groundwater sustainability; however, persistent governance, institutional capacity, and implementation challenges limit their effectiveness (Deng et al., 2025; Schreefel et al., 2024). The large-scale adoption of IoT-enabled smart agriculture further necessitates supportive policy incentives, investment in digital infrastructure, capacity building, and institutional arrangements to address challenges related to cost, standardization, interoperability, and data accessibility (Morchid et al., 2024). Overall, effective adaptation to climate-induced water scarcity depends on coherent water governance frameworks, coordinated institutional action across sectors, and the integration of scientific knowledge with on-the-ground agricultural practices (Verma et al., 2025). The ecological Intensification platform has already been designed as a futuristic advance crop management research in which the efficiency of water use and other inputs needs to be maximized to develop a highly productive multiple cropping system with climate and water-smart production technologies with sustainable ecological footprints (Midya et al., 2021).

Traditional practices, remote sensing, and digital decision support

Indigenous water management systems such as johads, baolis, tankas, ahar-pyne, kuhls, khadins, and eris have historically enabled rainwater harvesting, surface storage, and groundwater recharge, demonstrating sustainable, community-based water governance in India (Leijnse et al., 2024; Mehla et al., 2023; Rastogi et al., 2024). These traditional systems, along with indigenous cropping practices and soil–water conservation measures, have enhanced green water availability, improved soil moisture retention, and strengthened agricultural resilience under variable climatic conditions (Leijnse et al., 2024).

Integrating indigenous knowledge systems with modern climate-smart agricultural technologies, including remote sensing, GIS-based irrigation planning, soil moisture sensors, and IoT-enabled decision support systems, offers a powerful pathway for enhancing adaptive capacity in water-scarce agro-ecological settings (Morchid et al., 2024; Verma et al., 2025). Such hybrid approaches enable precision water management, reduce evapotranspiration losses, and support data-driven decision-making while retaining the ecological wisdom embedded in traditional practices. At broader scales, integrated water–agriculture nexus frameworks supported by geospatial data, climate and crop modelling, and digital technologies facilitate coordinated resource management, improve water-use efficiency, and enhance food security under climate change scenarios (Biswas et al., 2025; Leijnse et al., 2024; Sahoo et al., 2025).

Major irrigation projects in India and their role in sustainable water management

Irrigation projects such as dams, canal irrigation networks, and river interlinking schemes have played a major role in supporting agricultural development in India by increasing water availability for farming and reducing dependency on monsoon rainfall. According to the Central Water Commission, India currently has more than 1,700 major and medium irrigation projects, all together creating irrigation potential of approximately 47.6 million hectares by 2023 (Central Water Commission, Ministry of Jal Shakti, 2024). The

expansion of irrigation projects has also helped balance agricultural production in regions with irregular rainfall. As irrigation coverage has increased, farmers have been able to cultivate multiple crops per year and reduce the risks of drought. Irrigation now covers about 55% of the gross cropped area in India, compared with less than half of agricultural land a decade ago (Government of India, 2025). Irrigation systems have highly contributed to increasing agricultural productivity and rural livelihoods in irrigated states (Punjab, Haryana, and Uttar Pradesh). However, irrigation projects alone do not guarantee sustainable water management. A major challenge is the gap between irrigation potential created and its actual use. This gap often arises due to incomplete distribution networks, inefficient canal management, and limited access to water at the farm level (Central Water Commission, Ministry of Jal Shakti, 2024). Heavy metals are the most concerning contaminants in industrial wastewater. Elements such as Cd, Pb, Cr, Ni, Zn, and Cu are persistent in the environment and tend to accumulate in soils irrigated with contaminated water. Over time, these metals can disrupt soil microbial activity, alter nutrient availability, and degrade soil fertility. In addition, excessive salt concentrations in industrial effluents can increase soil salinity and negatively affect soil structure (Nasim et al., 2026). The accumulation of contaminants in soils also raises concerns about food safety and human health. Crops irrigated with highly polluted water can absorb heavy metals through their root systems, leading to the transfer of these toxic elements into edible plant tissues. Several studies have reported high concentrations of metals such as cadmium, lead, and zinc in vegetables grown in wastewater-irrigated areas. Continuous exposure to such contaminants may lead to bioaccumulation in the food chain, posing long-term health risks to consumers (Deshmukh et al., 2025). Despite these challenges, wastewater can also represent a valuable resource when properly treated and managed. Treated wastewater often contains nutrients such as nitrogen, phosphorus, and OM that can enhance soil fertility. In water-scarce regions, the safe reuse of treated wastewater can therefore contribute to sustainable irrigation practices (Niti Aayog, 2023).

Conclusion

Water scarcity poses a systemic threat to agricultural sustainability by undermining productivity, land quality, ecosystem services, and rural livelihoods. Addressing this challenge will require future-oriented, integrated, and climate-resilient strategies that enhance water-use efficiency, crop and water productivity, and adaptive capacity across agricultural systems. As a multidimensional challenge driven by hydroclimatic change, population growth, and intensive agricultural water use, water scarcity generates cascading risks for ecosystems, food security, and socio-economic stability. Emerging technologies such as IoT and sensor-enabled agricultural systems offer significant potential to strengthen resilience and food security through real-time monitoring, precision irrigation, automation, and data-driven farm management. Intervention of climate-smart-production technology will definitely optimize crop water productivity and water economy under the backdrop of a shrinking water resource base and climate crisis. India's transition toward sustainable and water-smart agriculture will depend on coherent policy frameworks, strengthened water governance institutions, and coordinated action across sectors, coupled with investments in digital infrastructure and farmer capacity building. Long-term resilience and food security further require the integration of climate-smart agricultural practices, technological innovation, and indigenous knowledge systems into region-specific water management strategies tailored to local scarcity dynamics. Together, these future strategies provide a pathway toward sustainable water governance and resilient agricultural systems under increasing climate uncertainty and shrinking natural resource base.

Conflict of Interest Statement

The authors declare no conflict of interest.

Acknowledgments

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